# DOP1000

## Model 1032

# User's manual

Software: 5,23.3
Revision: 1.2

SIGNAL PROCESSING S.A.
SWITZERLAND

# Table of contents

Important notice

The information contained in this manual is subject to change without prior notice.

The purpose of this manual is only to explain the use of the velocimeter. Signal Processing cannot be held responsible for any damage which could result from the improper use of the information contained herein.

Signal Processing cannot guarantee the reliability of the velocimeter, nor be held responsible for the consequences, when the velocimeter is being used in conjunction with equipment not supplied or approved by Signal Processing.

Medical application

This instrument should not be used on human body.



CE

This instrument complies to norms EN 50081-1/EN 50082-2. Nevertheless the immunity of the velocimeter to external perturbations conducted or radiated could not be guaranteed if their frequencies are in the range of the emitted ultrasonic frequencies and their harmonics.

Guarantee

Signal Processing guarantees that the velocimeter will function according to the specifications given in this manual under normal use. The guarantee is valid for one year after the date of delivery. All items not manufactured by Signal Processing are covered only by the warranties which their manufacturers supply.

Under this guarantee, Signal Processing will replace or repair (according to its best judgment) the defective part. This guarantee is automatically void if the damage is proven to be the result of improper use.

It is highly recommended that the buyer thoroughly inspect the apparatus immediately after delivery. Any malfunctions must be reported in writing to Signal Processing.

The costs of insurance and delivery for any defective parts are under the responsibility of the buyer. Signal Processing will return the parts postage paid to the address where the parts were originally sent, with the insurance remaining the responsibility of the buyer.

Assistance

All questions pertaining to the installation and use of the apparatus should be directed to:

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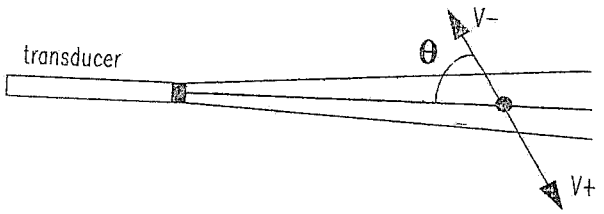
# 1 Doppler ultrasound velocimetry

## Doppler effect

The Doppler effect is the change in frequency of an acoustic or electromagnetic wave resulting from the movement of either the emitter or receptor.

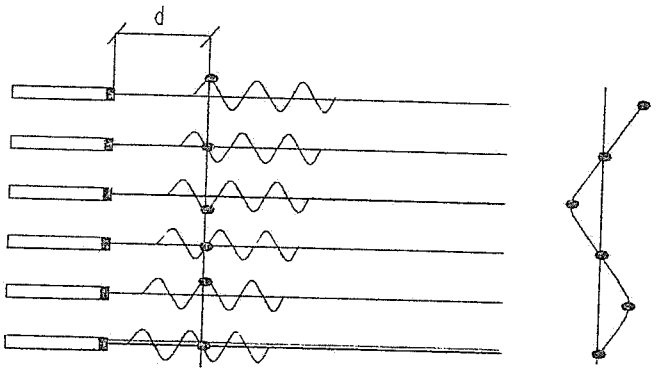
Consider an ultrasonic transducer which emits waves of frequency $f_e$ and remains fixed in a medium where the speed of sound is given by c. A receptor, or target, in the medium moves with a velocity v. By convention, v is considered negative when the target is moving toward the transducer. If the trajectory of the target forms an angle $\theta$ with respect to the propagation direction of the ultrasonic wave, the frequency of the waves perceived by the target will be:

$$f_g = f_e \pm \frac{f_e v \cos\theta}{c}$$



## 2 Functioning principles of pulsed Doppler ultrasound

By careful analysis of the target echoes, one may determine both the location and velocity of the target. Knowledge of the time delay between the emitted and received signals and of the wave speed c gives the distance between the transducer and the target.




$T_s$ = observation time

The principle for measuring the velocity of a target using a pulsed signal is illustrated above. If the target is moving toward the transducer, the time delay between the emitted and received signals $T_v=2d/c$ will diminish. If, instead of following the time delay, one examines the amplitude of the received signal after a fixed time delay $T_s$ after the emission of regularly timed pulses, ideally a sinusoidal signal will result. The sampling times are $t_n = n\,T_{prf} + T_s$, where n is an integer and $T_{prf}$ is the time between emitted pulses. This is only valid if the observation time $T_s$ is chosen in order to receive the proper echo.

If the acoustic impedance of the target is different from that of the surrounding medium, the waves will be partially reflected. In this way, the target acts as a moving source of ultrasonic signals. The frequency of the waves reflected by the target, as measured by a stationary transducer, is:

$$f_r = \frac{c}{c \mp v\cos\theta} f_g$$

By combining the two above equations, the frequency of the signal received by the transducer is:

$$f_r = \left\langle \frac{c \pm v\cos\theta}{c \mp v\cos\theta} \right\rangle f_e$$

This equation may be simplified by knowing that the velocity of the target is much smaller than the speed of sound ($v << c$). By expanding the denominator of the above equation into a geometric series, and neglecting the terms of order two and greater, one may obtain the difference between the frequencies of the emitted and received signals. This frequency shift, called the Doppler frequency, is given by:

$$f_d = \pm \frac{2 f_e v\cos\theta}{c}$$

The Doppler frequency that gives the velocity of the target is reconstructed from samples, which are separated in time by $T_{prf}$. According to the Nyquist theorem, the sampling rate cannot be less than twice the frequency of the signal being sampled. This minimum sampling rate is known as the Nyquist frequency. In addition to the sampling frequency limitation, there is a maximum depth at which a velocity may be measured. This limit is determined by the maximum time necessary for the ultrasonic signal to travel from the transducer to the target and back. This time is determined by the pulse repetition frequency (PRF) of the ultrasonic pulses, giving a maximum depth of:

$$P_{max} = \frac{T_{prf} \cdot c}{2}$$

Reducing the PRF (increasing $T_{prf}$) will increase the maximum measurable depth, but will also reduce the maximum Doppler frequency which can be measured. The maximum velocity and depth which may be measured are thus related according to the following equation:

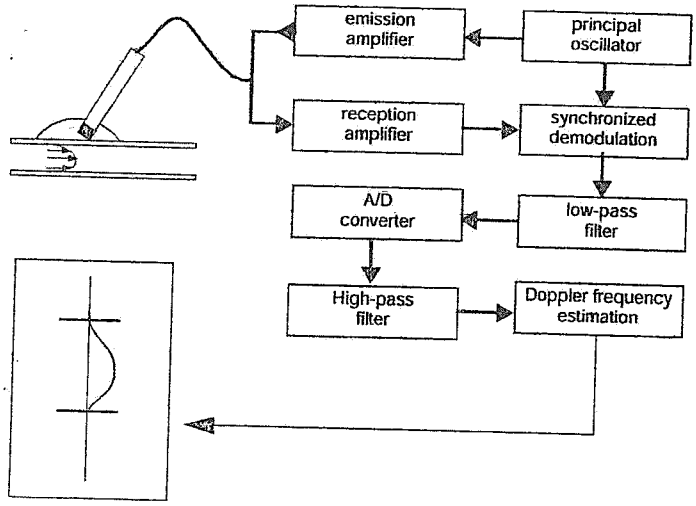
$$P_{max} V_{max} = \frac{c^2}{8 f_e \cos\theta}$$

At any given instant, an echo signal could come from many different depths, corresponding to echoes from previously emitted signals. The presence of several acoustic interfaces also causes several reflections which could cause a false determination of the

target depth. Nevertheless, if the PRF is sufficiently small (a few kHz), the attenuation of previously emitted pulses will render them indiscernible. The same goes for reflected signals. With a large increase in the PRF, pulsed Doppler ultrasound can approach the properties of continuous wave Doppler, with a loss of axial resolution but no maximum velocity limitation.

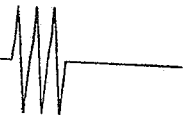
## 3 Internal architecture of the velocimeter

The working principle of the velocimeter is illustrated below. The same transducer is used to both transmit and receive the ultrasonic signals. The signal coming from the principal oscillator provides the trigger for the emitted signal at the PRF.




The amplification of the echo signal is increased according to the depth (Time Gain Control or TGC) in order to compensate for the attenuation of the waves. Following the amplification, the echo signal is demodulated, then filtered to isolate the Doppler information. A low pass filter suppresses artefactual frequencies in the spectrum generated by the demodulation.

The Doppler signal is then sampled and converted into digital form by a fast A/D converter. The time between acquisitions de-



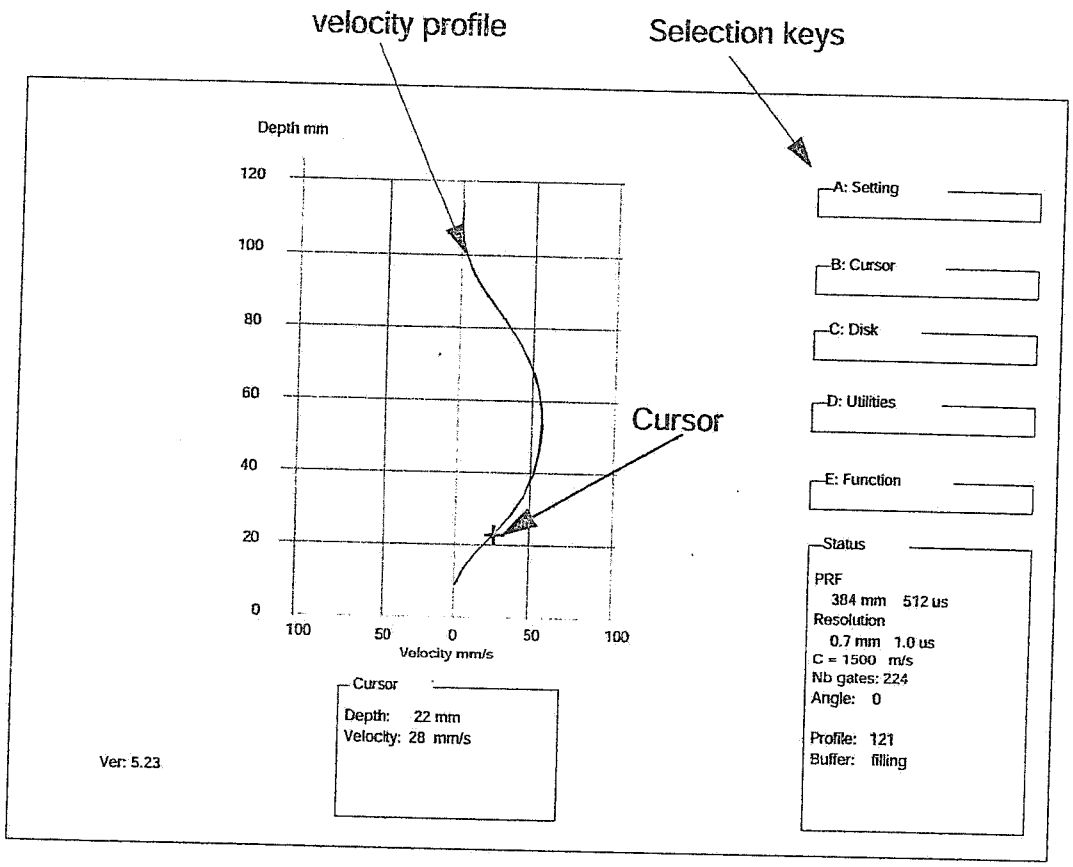
termines the axial spacing between sample volumes, while the delay between the emission and reception determines the distance to the sample volume. The signal coming from the converter is stored, then filtered by a high-pass filter which eliminates the steady and quasi-steady components. Finally, the frequency of the Doppler signal is estimated. The results may then be used to calculate the velocity.

The velocimeter is capable of producing many different PRF's, thus producing many different maximum depths of measurement. The number of analyzed channels is variable between 10 and 224.

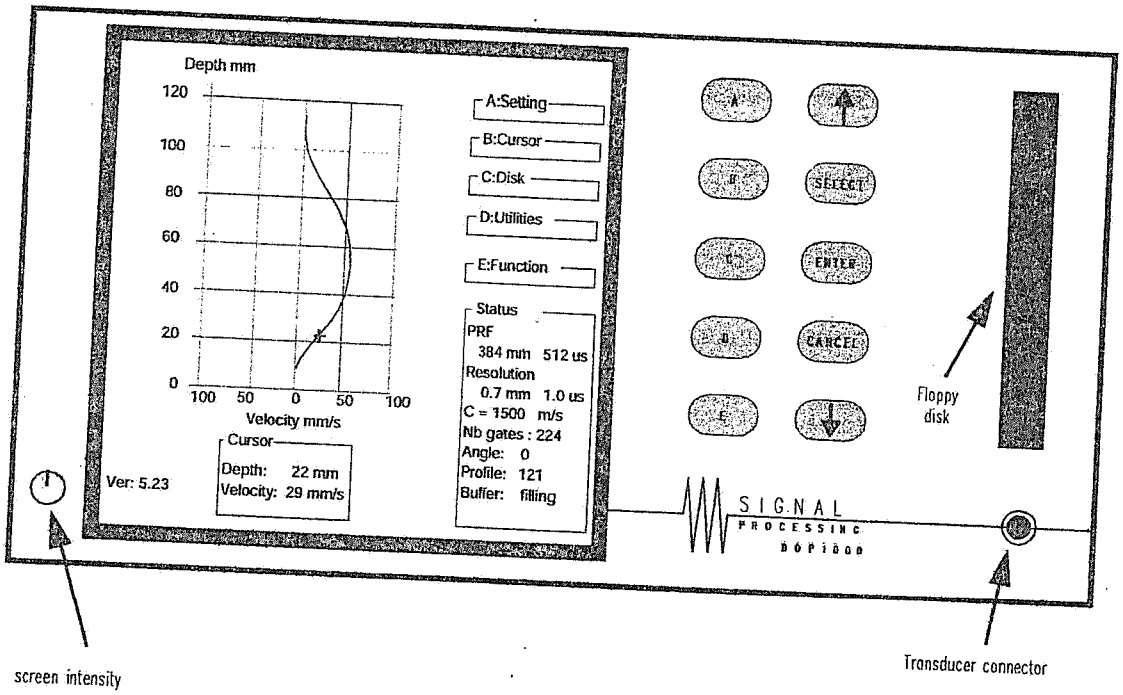
## 3.1 The status window

The status window displays the values of the most important parameters, and informs the user on the content of the memory state.

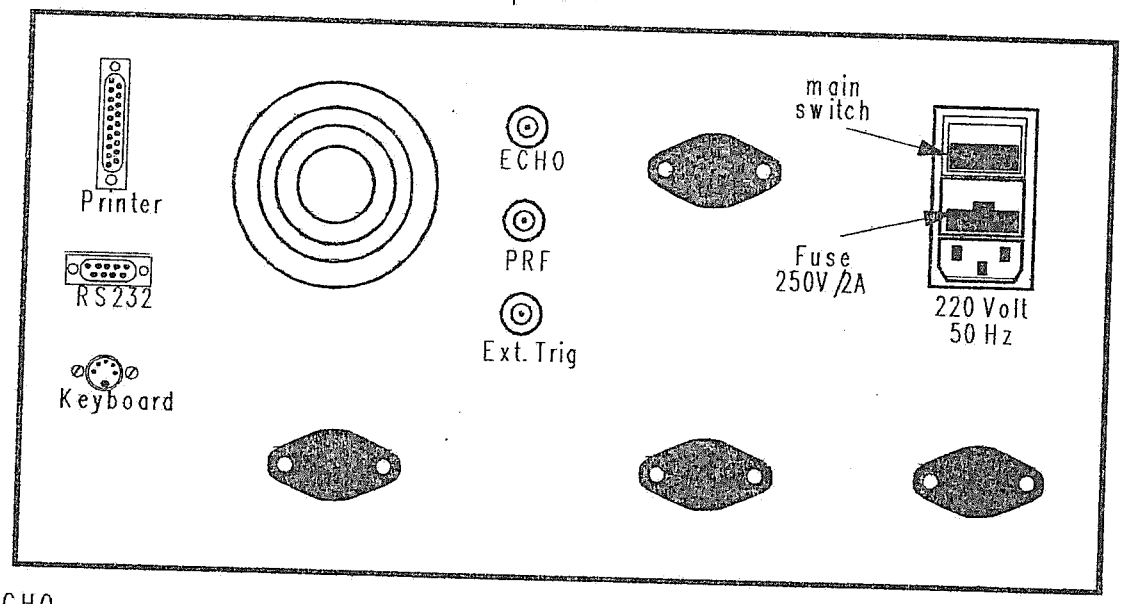
# Screen Layout



## Front panel


Depth mm
120
100
80
60
40
20
0
100 50 0 50 100
Velocity mm/s
A:Setting
B:Cursor
C:Disk
D:Utilities
E:Function
Status
PRF
384 mm 512 us
Resolution
0.7 mm 1.0 us
C = 1500 m/s
Nb gates : 224
Angle: 0
Profile: 121
Buffer: filling
Cursor
Depth: 22 mm
Velocity: 29 mm/s
Ver: 5.23
SELECT
ENTER
CANCEL
Floppy disk
SIGNAL PROCESSING
screen intensity
Transducer connector

Rear panel




ECHO

The amplified echo signal is output here.

SYNC

Synchronization signal
A TTL/CMOS compatible signal is present at the instant of each emission.
Impulse duration: 50 ns

Ext. Trig

External trigger input (default state 5 Volt by pull-up)
A change in the TTL/CMOS logic state will start a measurement in the Trigger mode. The trigger input is level sensitive, not edge sensitive.

The applied tension on this input must not exceed 5 volt or be negative.

# 4 Selection keys and keyboard

The velocimeter is controlled by the front panel selection keys or by an external PC compatible keyboard (option), connected at the rear panel.

Note: Both keyboard can not work together. The external keyboard, if connected, has the priority.
The external keyboard must be connected before power supply is applied.
The velocimeter recognizes which keyboard should be active.

The table below gives the correspondence between the names of the selection keys from the front panel and the external keyboard. The keys A through E have the same names on both keyboards.

| Front panel | External keyboard |
|---|---|
| UP | UP |
| SELECT | Space bar (Space) |
| ENTER | Carriage return (CR) |
| CANCEL | Escape (Esc) |
| DOWN | DOWN |

## 4.1 Introducing a parameter via the keyboard

If an external keyboard is attached to the velocimeter the value of some parameters can be defined directly by typing their value. In order to do this:

- select the parameter to be defined.
  (the key window must display the current value);
- press ENTER (carriage return) on the keyboard;
  a new window placed in the center of the screen appears;
- type the new value; the backspace key could be used to correct the last introduced character.
- validate the new value by pressing ENTER (carriage return) or cancel it by pressing the CANCEL (Esc) key.

Note: The AUTOEXEC.BAT file should contain the correct keyboard definition in order to guarantee the correspondence between the named keys of the front panel of the DOP1000 and the keyboard.

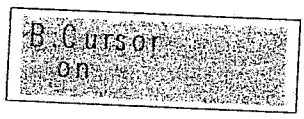
External keyboard function keys

When an external keyboard is attached to the velocimeter the F1 key allows a direct access to the cursor menu and the F2 key allows a direct access to the disk menu. These 2 function keys are not available in all menus.

## 5 Using the cursor

The Cursor menu, accessible from the main menu by pressing the B key or by pressing the F1 key if an external keyboard is attached to the velocimeter enables the measurement of a particular point on the velocity profile and allows statistical computations on the evolution of the velocities in a user defined area.

The Cursor menu also allows to place the anterior and posterior walls which define the area used for the flow computation.




The B key from the Cursor menu enables the suppression or the activation of the cursor.

Note: The acquisition time is longer when the cursor is in active mode.

When the cursor is in active mode, an information window is displayed under the velocity profile. Information relative to the cursor position is displayed in this window.

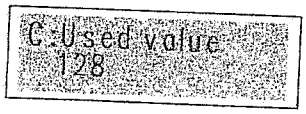
The cursor is moved by using the UP and DOWN keys or by typing directly a related value after pressing the ENTER key. The cursor can be moved only if the cursor is selected which is indicated by the B:Cursor key. The cursor always follows the measurement line (tracking mode).

## 5.1 Statistical Information

The Cursor menu enables the computation of statistical information on the evolution of the velocity in a portion of the velocity profile.


The E key from the Cursor menu enables or disables the statistical computations. When the statistical computations are enable, the mean and the standard deviation are displayed in the cursor window. The displayed depth corresponds to the mean depth of the selected area (cursor position). The size is displayed beside the word Size:


The B key from the Statistic menu select the position (Depth) of the analyzed area or it's size (Size). The UP and DOWN keys modify the current values which are displayed in the cursor window.




The number of profiles used to compute the statistical values is defined the key C from the Statistic menu. After pressing this key, this number could be changed by the UP and DOWN keys.

Note: The statistical information are updated after the acquisition of a profile (moving computation).


The E key from the Statistic menu enables the user to display the

velocity profile or the histogram of the velocity values.

The histogram is computed by dividing the velocity range (negative and positive values) in 32 classes. The scale is automatically computed.

To quit the statistical computation mode press CANCEL.

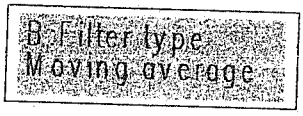
# 6 Filters

Two types of filters can be applied on the velocity profile in real--time.

- a moving average filter
- a mediane filter

## 6.1 The moving average filter ***

The moving average filter computes the mean value for all the displayed gates based on a define number of profile. An option allows to include or remove from the computation the zero values which may appear when low energy Doppler signal are analyzed. The mean value of each gate are computed independently, which means that zero values of one gate does not affect the computation of other gates.




To select the moving average filter, from the main menu:

- Press the A key,
- Press the B key,
- Press the B key,
- Use the UP and DOWN arrow keys to select the filter between:

  no filter (none),
  moving average,
  mediane.

C:Based on 16

The number of profiles used for computing the filtered profile is defined by the C key. In order to select it:

- Press the C key
- Use the UP and DOWN arrow keys to define the number of used profiles or if an external keyboard is attached type ENTER and input the desired values (between 2 and 1024).

D:Zero values rejected

The moving average filter has an option that allows to remove zero values from the computation. To select this option:

- Press the D key
- Use the UP and DOWN arrow keys to select the desired option, rejected or included.

After the selection of the filtering process, press CANCEL to quit the Filter menu.

## 6.2 The mediane filter

This filter rejects erroneous values by ordering a defined number of measured values by increasing order and output as a filtered value the value located in the middle of the ordered table.

B: Filter type
Median

To select the mediane filter, from the main menu:

- Press the A key,
- Press the B key,
- Press the B key,
- Use the UP and DOWN arrow keys to select the filter between:

  no filter (none),
  moving average,
  mediane.

- Press the C key, to define the number of used profile.
- Use the UP and DOWN arrow keys to define the number of used profiles or if an external keyboard is attached type ENTER and input the desired values (between 2 and 32).

Notes: The recorded velocity values are the non-filtered values.

The mediane filter slows down the acquisition process.

# 7 Computation and displayed curves

The velocimeter enables the display of:

- the velocity profile
- the echo modulus
- the Doppler energy profile
- the evolution of the velocity versus time of one gate
- the flow versus time
- the power spectrum of the Doppler signal of one gate
- the FFT of a time series of velocities
- the spatial intercorrelation between two channels

and also allows:

- the acquisition of the I and Q signals

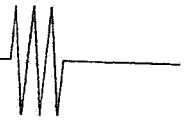
## 7.1 The velocity profile

A:Profile

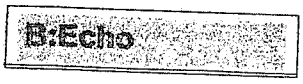
To select this display press from the main menu:

- A:Settings
- C:Computation
- and then A:Profile

To exit this menu press the key CANCEL.



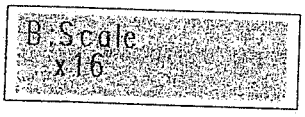
## 7.2 The echo modulus



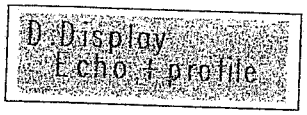

The modulus of the displayed echo corresponds to the echo envelope. This display informs the user on the presence of high reflective structures and on a possible saturation of the electronic induced by a wrong setting in the amplification level.

To select this display press from the main menu:

- A:Settings
- C:Computation
- and then B:Echo




The horizontal scale gives the intensity of the echo modulus (arbitrary unit). The UP and DOWN keys enable the modification of the scale. The current value of the scale is displayed inside the key B.




The velocimeter allows to acquire and display both the velocity profile and the modulus of the echo. In order to select this function simply press the D key to select both displays. The D key allows to switch between both displays mode.

When both, the velocity profile and the echo are displayed, the velocimeter memorize in its internal memory both information. When recorded, both values will be recorded.

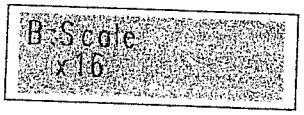
To exit this menu press the key CANCEL.

## 7.3 The Doppler energy

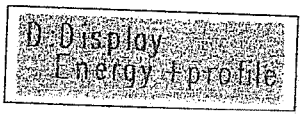

The displayed Doppler energy signal is the high-pass filtered echo signal. Only the echo modulus of moving structures will displayed. This signal enables the detection and visualization of high reflective moving structures.

To select this display press from the main menu:

- A:Settings
- C:Computation
- and then C:Energy




The horizontal scale gives the intensity of the Doppler energy. The UP and DOWN keys enable the modification of the scale. The current value of the scale is displayed inside the key B.




The velocimeter allows to acquire and display both the velocity profile and the Doppler energy. In order to select this function simply press the D key to select both displays. The D key allows to switch between both displays mode.

When both, the velocity profile and the Doppler energy are displayed, the velocimeter memorize in its internal memory both information. When recorded, both values will be recorded.

To exit this menu press the key CANCEL.

## 7.5 The spatial intercorrelation

A:Correlation

This mode computes and displays the result of the spatial intercorrelation of velocities measured in two gates. The position of the gates are defined by two cursors appearing on the velocity profile.

The computed intercorrelation value is given by:

$$C = \frac{\sum_{i=1}^{N} v(t_i, P_1) \bullet v(t_i, P_2)}{\sqrt{\frac{\sum_{i=1}^{N} v^2(t_i, P_1) \bullet v^2(t_i, P_2)}{N^2}}}$$

where:

- $V(t_i,P_1)$ is the measured velocity value at time $t_i$ at cursor $P_1$
- $V(t_i,P_2)$ is the measured velocity value at time $t_i$ at cursor $P_2$
- N is the intercorrelation length.

To select this display press from the main menu:

- A:Settings
- C:Computation
- E:Other

D:Flow

## 7.4 Evolution of the flow rate versus time

This display shows the evolution of the flow rate versus time. The section used to integrate the velocity profile should have been already defined in the Cursor menu.

To select this display press from the main menu:

- A:Settings
- C:Computation
- and then D:flow

The vertical scale shows the times at which the flows are measured. Depending on the values of the parameters a correct display of the time is not possible any more. In such a case a "?" replace the unity of the time measurement.

Note: The accuracy of the displayed time is in the order of 2%. The exact value is recorded within the binary data in the internal memory.

This display forces the selection of Flow axis for the parameter Unit.

The choice of this type of display does not affect the recorded values in the internal memory. The whole profile as defined in the Memory menu is always recorded.

To exit this menu press the key CANCEL.

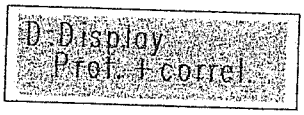
- and then A:correlation

To define the position of the gates:

- press B:Select cursor until the correct cursor is selected;
- use the UP and DOWN keys to place the cursor at the desired position on the velocity profile or if an external keyboard is attached use the ENTER key.

Select the number of measured velocities to compute the correlation:

- press C:Length
- use the UP and DOWN keys to define the number of used velocities or if an external keyboard is attached use the ENTER key.




The key D enables to switch between the display of the velocity profile, the display of the spatial intercorrelation or both displays.

The key E enables to select the Freeze mode and the key A enables a print screen (on a printer or a TIFF file). The type of printer must have been defined in the Printer menu from the Utilities menu.

To exit this menu press the key CANCEL.

Note: The choice of the display type does not affect the recorded values in the internal memory. The whole profile as defined in the Memory menu is always recorded.

## 7.6 Evolution of the velocity versus time

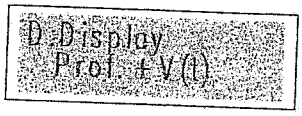

This display shows the evolution of the velocity versus time of one gate. The position of the gate is selected by the user by moving a cursor on the velocity profile. The vertical scale shows the times at which the profiles are measured. Depending on the values of the parameters a correct display of the time is not possible any more. In such a case a "?" replace the unity of the time measurement.

To select this display press from the main menu:

- A:Settings
- C:Computation
- E:Other
- and then B:V(t)

To define the position of the gate:

- press B:Cursor until the cursor is selected.
- use the UP and DOWN keys to place the cursor at the desired position on the velocity profile or if an external keyboard is attached use the ENTER key.




The key D enables to switch between the display of the velocity profile, the display of the velocity versus time or both displays. The display choice has no influences on the recorded values.

The key E enables to select the Freeze mode and the key A enables a print screen (on a printer or a TIFF file). The type of printer

must have been defined in the Printer menu from the Utilities menu.
To exit this menu press the key CANCEL.

Note: The accuracy of the displayed time is in the order of 2%.

It is not possible to exit this menu and keeping the display of the evolution of velocity versus time.

The choice of the display type does not affect the recorded values in the internal memory. The whole profile as defined in the Memory menu is always recorded.

## 7.7 The power spectrum of the Doppler signal

C:Channel FFT

The power spectrum of the Doppler signal shows the distribution of the Doppler energy among their different frequencies. This display allows to have a better interpretation of the result of the computed mean Doppler frequency value given by the velocimeter. It could inform the user on the presence of low frequency components of high energy coming from moving interfaces which may bias the measurement of the velocity of the flowing liquid.

The power spectrum is computed by means of the Fast Fourier Transform of the Doppler signal issue from one channel or one gate. The position of the gate is defined by a cursor appearing on the velocity profile. The amplitude of the power spectrum is dis-

played on a logarithmic scale.

To select this display press from the main menu:

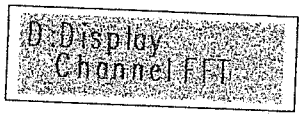
- A:Settings
- C:Computation
- E:Other
- and then C:Channel FFT

To define the position of the gate:

- press B:Cursor until the cursor is selected;
- use the UP and DOWN keys to place the cursor at the desired position on the velocity profile or if an external keyboard is attached use the ENTER key.

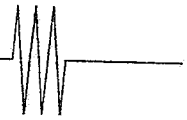
Select the power spectrum parameters:

- press E:FFT based on to select the desired number of emissions used to compute the power spectrum;
- press A:Window to define the desired FFT window;
- press C:FFT average to select the number of power spectrum used in the moving average filter. (1 means no filter)




The key D enables to switch between the display of the velocity profile and the display of the power spectrum.

Note: The unit of the Doppler frequency scale is converted in velocity.



The power spectrum use the high-pass filtered Doppler signal. For this reason the power spectrum value is zero at its origin.

The velocity offset value is taken into account.

To exit this menu press the key CANCEL. The selected display, power spectrum or velocity profile will be conserved. If the power spectrum is selected the recorded values will be power spectrum values.

## 7.8 The FFT of a time series of velocities

D:Time FFT

This mode computes and displays the result of the fast Fourier transform of a time series of velocities measured in a single gate. The position of the gate is defined by a cursor appearing on the velocity profile.

To select this display press from the main menu:

- A:Settings
- C:Computation
- E:Other
- and then D:Time FFT

To define the position of the gate:

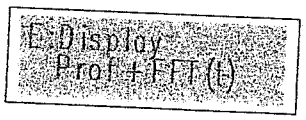
- press B:Cursor until the cursor is selected;
- use the UP and DOWN keys to place the cursor at

the desired position on the velocity profile or if an external keyboard is attached use the ENTER key.

Select the FFT parameters:

- press C:FFT length to select the desired number of emissions used to compute the FFT;

- press D:Sampling freq. to fixe the sampling frequency. The sampling frequency is defined by the number of velocity values which are skipped from the time series.



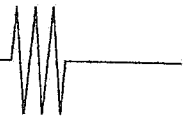

The key E enables to switch between the display of the velocity profile, the display of the FFT or both displays.

The key A enables a print screen (on a printer or a TIFF file). The type of printer must have been defined in the Printer menu from the Utilities menu.

Note: Normally the abscissa of the FFT graph is calibrated in Hz, but it may appear that the scale could not be calibrated. In such a case a ? is displayed instate of Hz unit.

The time series is not filtered before computing the FFT. This means that aliasing could be present in the output result.

To exit this menu press the key CANCEL. On exit the velocimeter will measure velocity profiles.



## 7.9 Acquisition of the I and Q signals

A: Get I and Q

This mode enables to record the I and Q Doppler signal for a defined number of gates. The position of the recorded gate are selected with a cursor placed on the velocity profile.

The I and Q signals are the signals which are normally processed by the velocimeter. They are the demodulated and low-pass filtered (cut off frequency of 220 kHz) echo signals.

The acquisition of these signals allows the user to extract off line other information from the Doppler signals based on their own algorithms.

To select this mode press from the main menu:

- A:Settings
- C:Computation
- E:Other
- E:Other
- and then A:Get I and Q

To define the position of the gates:

- press B:Cursor until the word Depth is selected;
- use the UP and DOWN keys to place the cursor at the desired position on the velocity profile or if an external keyboard is attached use the ENTER key.

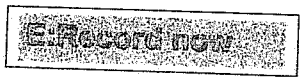
The cursor is placed in the middle of the acquisition depth. Its depth is displayed in the cursor window below the velocity profile.

To define the number of the gates:

- press B:Cursor until the word Size is selected;
- use the UP and DOWN keys to select the size of the recorded depth. The size value is displayed in the cursor window below the velocity profile. The selection of the size defines the number of gates which will be recorded.

Select the number of recorded emissions:

- press D:Nb emissions and then use the UP and DOWN keys to define the number of desired emissions or if an external keyboard is attached use the ENTER key.




The key E enables to start the record process. When the record process starts, the velocimeter stops to measure the velocity profile. It will only acquire the I and Q values for the selected area and transfer their values in its internal memory. This procedure will continue until the defined number of emissions are recorded. Then the velocimeter will automatically jump to the disk menu allowing the user to record the measured values on a file.

Note: The recorded I and Q values are the binary data output by the AD converter. They are in a signed word format (11 bits + sign). The structure of the record is defined in the chapter Storing and reading measures

The resolution could not be adapted.

If the cursor could not be moved to the desired position, you have to lower the size value and/or decrease the PRF value.

To exit this menu press the key CANCEL.

# 8 Definition of the amplification level (TGC)

Correct values of the amplification level are important. A to high level may induce saturation in the electronic which will give wrong measurement values.

The user can select a correct amplification level by two means.

The first one consist to define the amplification level at the minimum and at the maximum depth, depths displayed on the depth scale. The amplification will follow an exponential law between these 2 values (Slope mode).

The second one consist to define a constant value inside different cells for which the position and the size are defined by the user (Custom mode). By moving and sizing the cells, a particular amplification curve could be realized.

For both method the user can choose to display the modulus of the echo envelope or the amplification curve in state of the velocity profile. This helps the user to define a correct amplification curve.

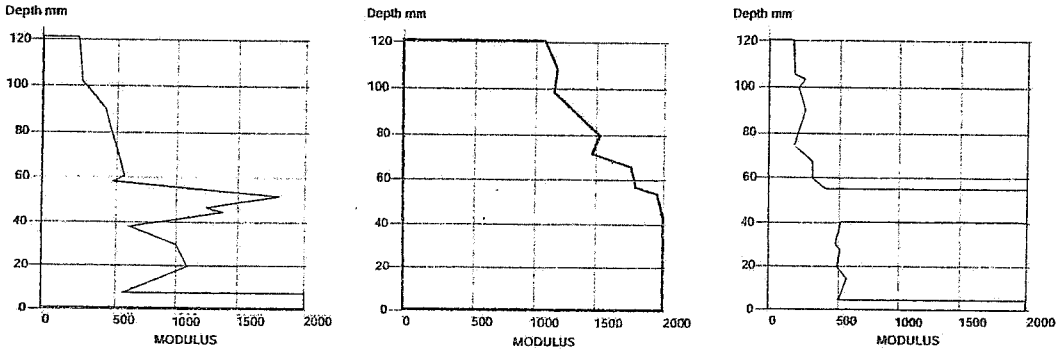
## 8.1 How to select a correct amplification

D:TGC

To define the amplification level press the key A from the main menu to go in the Settings menu. Then press the key D.

The velocimeter displays then the echo modulus of the Doppler signal and selects the current TGC mode.

The 3 figures below show 2 different situations that will need a modification of the current TGC amplification curve.

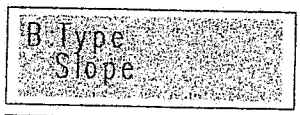



In A the amplification level is correct. The saturation appearing at the starting depths could not be removed and is normal. This saturation is induced by the ringing effect of the transducer appearing just after the emission.

In B, to much amplification has been selected. In one third of the measuring area the electronic is saturated. The TGC slope mode may be selected to decrease the amplification level at the starting depths. In some situation reducing the emitting power could also be necessary.

In C, the amplification level in correct in almost all the measuring area. The strong echo appearing in the middle of the profile could maybe come from a second reflection of the emitting burst. The saturation could be removed by using the TGC custom mode.

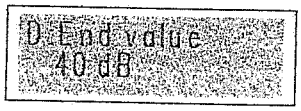
## 8.2 Setting the gain in the Slope mode




The text inside the key B indicates the current TGC mode. Press this key until the text Slope appears.


In order to define the amplification at the minimum depth:

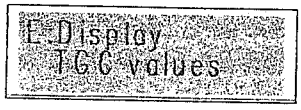
- press the key C,
- by means of the UP and DOWN keys, select the desired amplification level.




In order to define the amplification at the maximum depth:

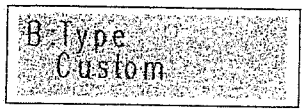
- press the key D,
- by means of the UP and DOWN keys, select the desired amplification level.

Note: The amplification level at the minimum depth can not be higher than the level at the maximum depth.



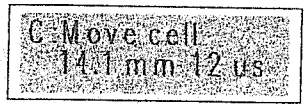

The key E enables to select one between three different display curve, the velocity profile, the echo modulus and the amplification curve.

## 8.3 Setting the gain in the custom mode



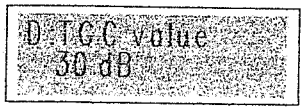

The text inside the B key indicates the current TGC mode. Press this key until the text Custom appears.

The TGC cell is represented in the right region of the velocity profile window by a rectangle.




The position and the size of the TGC cell is defined by using the key C. This key has three functions which enables the definition of the starting depth, the definition of the ending depth and the displacement of the cell.

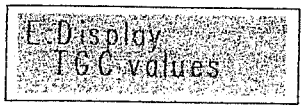
In order to define the TGC cell, select one of these functions by pressing the key C and then use the UP and DOWN keys to change the current value of the selected function.




In order to define the amplification level inside the cell, press the key D and use the UP and DOWN keys to change the current TGC value.

Note: The TGC values in Slope mode and in Custom mode are linked.

The TGC values in custom mode are not memorized when the parameters are saved.




The key E enables to select one between three different display curve, the velocity profile, the echo modulus and the amplification

curve.

# 9 The parameters

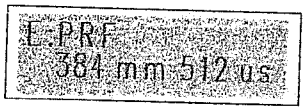
The velocimeter is controlled by a define number of parameters which are user's selectable for most of them. A correct setting of these parameters is of prime importance. In order to help the user to define a correct setup, the velocimeter contains a default setup which guarantee that the velocimeter will work correctly. It is recommended to always start from this setup.

Power up

At power up the velocimeter always use the parameters from configuration 1 and not the default values (factory setting).

The selection of the value of the different parameters is realized through different menus. These menus are described in details in the following section.

## 9.1 Pulse Repetition Frequency PRF




The PRF determines the maximum measurable depth as well as the maximum Doppler frequency which can be measured unambiguously. These two limitations are related by the expression:

$$P_{max} \cdot F_{max} = \frac{c}{4}$$

where $P_{max}$ is the maximum measurable depth, $F_{max}$ the maximum measurable Doppler frequency and c the speed of sound.

248 different values of PRF may be chosen. The velocimeter displays the value of the PRF in µs and the related maximum depth

in mm in the Status window

**Selecting the correct PRF value**

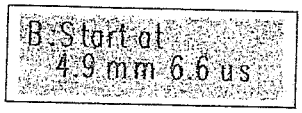
Whenever possible you should try to select the value which does not induce aliasing. The best way to select a correct value is to start with the maximum value (64µs) and to reduce its value until all the measuring range is used. The desired analyzed depth should be then adapted by changing the resolution and or the position of the first channel.

Note: The measuring range is displayed on the depth axis of the measuring profile. This measuring range could not be equal to the range corresponding to the PRF value (range displayed in the status window) and its maximum value is always a little bit lower.

The Offset function in the Velocity menu enables to increase the value of the maximum measurable velocity. This increase is done by allowing a bigger range to the positive or negative velocities.

To select a PRF value, from the main menu:

- press A:Settings
- then A:Parameters
- then A:Define
- then E:PRF
- then use the UP and DOWN keys to select the desired value or if an external keyboard is connected press ENTER and input the desired depth value.

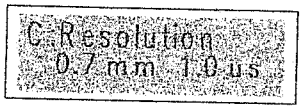



## 9.2 Position of the first channel

In order to measure a portion of the possible measuring range define by the PRF value, the position of the first channel to be analyzed may be shifted from the origin (surface of the transducer). The velocimeter allows to shift this position by step of 1 µs.

To select the position of the first channel, from the main menu:

- press A:Settings
- then A:Parameters
- then A:Define
- then B:Start at
- then use the UP and DOWN keys to select the desired value or if an external keyboard is connected press ENTER and input the desired depth value.




## 9.3 Resolution

The lateral sizes of the sampling volume (measured perpendicularly to the ultrasonic beam axis) are defined by the geometry of the ultrasonic beam. Its longitudinal size is defined by the burst length and the bandwidth of the electronic receiving unit.

The lateral dimensions of the sampling volume increase with the analyzed depth due to the divergence of the ultrasonic beam.

The longitudinal dimension of the sampling volume is defined by the emitting frequency and the length of the emitted burst. For example at 1 MHz with 16 cycles emitted the longitudinal resolution is 8µs or 6mm. The minimum value of the longitudinal resolution

could not be lower as of 1.2 µs or 0.9mm due to the limited bandwidth of the receiver.

The time laps between two displayed channels defines the display resolution. This resolution may vary between 32 µs and 0.5 µs. The display resolution also defines the total duration of the analyzed echo signal and the measuring range. The velocimeter displays the value of the resolution in µs and its value in millimeter in the status window.

Note: For some values of the selected resolution the measuring volumes may overlapped each other or unmeasured zones could appear between measuring channels. The chapter related to the measured sample volume explains in details how the sample volume is defined.

To select the resolution, from the main menu:

- press A:Settings
- then A:Parameters
- then A:Define
- then C:Resolution
- then use the UP and DOWN keys to select the desired value or if an external keyboard is connected press ENTER and input the desired depth value.

## 9.4 Sensitivity

D:Sensitivity
medium

The algorithm used to measure the Doppler frequency allows to nullify the result when the Doppler energy is below a defined level.

The sensitivity parameter is a very useful parameter to evaluate the influence of the noise level on the quality of the measurement. As both the Doppler signal and the noise are measured it is important to insure that the noise level does not influence the measured values. If the measurement are not affected by a modification of the sensitivity parameter, the noise level is situated well below the energy of the Doppler signal.

The velocimeter enables the selection of 5 levels of sensitivity.

To select the sensitivity, from the main menu:

- press A:Settings
- then A:Parameters
- then A:Define
- then D:Sensitivity
- then use the UP and DOWN keys to select the desired value.

## 9.5 Number of emissions by profile

E-Prf/profile 128

The measurement of the Doppler frequency needs many ultrasonic emissions. This number will affect the variance of the estimated frequency and the measuring time of a profile.

This number should be selected in accordance to the type of flow investigated. For steady flows a high number will decrease the variance and therefore should be selected. For unstationnary flows this number should be adapted to the degree of variation versus time of the velocities. The algorithm used to estimate the

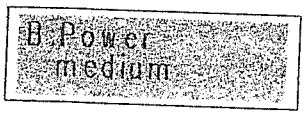
Doppler frequency is based on the assumption that the velocity of the particles contained in the sample volume remains constant during the measuring time. For such a flow a compromise is to be taken between the quality of the estimation (minimum variance) and the measuring time.

Note: The variance of the measurement could be improved by using one of the two available filters, moving average or median.

To select the number of emissions per profile, from the main menu:

- press A:Settings
- then A:Parameters
- then A:Define
- then A:Next
- then E:PRF/profile
- then use the UP and DOWN keys to select the desired value or if an external keyboard is connected press ENTER and input the desired depth value.

## 9.6 Emitting power




The ultrasonic power has to be selected in accordance to the degree of attenuation of the investigated liquid and the type and content of particles. The emitting power must be linked to the TGC amplification. It is advantageous to select the minimum emitting power that gives good results. The emitting power should be increase if not enough Doppler signal is received and decrease if the input stage of the receiving unit of the velocimeter saturates

even with a low amplification level.

Note: When using large transducers better results are obtained with low emitting power.

To select the emitting power, from the main menu:

- press A:Settings
- then A:Parameters
- then A:Define
- then A:Next
- then B:Power
- then use the UP and DOWN keys to select the desired value.

## 9.7 Emitting frequency

C.Frequency
8 MHz

The choice of the emitting frequency depends mostly on:

- the desired size of the sampling volume;
  the emitting frequency contributes to the definition of the longitudinal dimension of the sampling volume. A high frequency gives a better resolution.
- the attenuation of the ultrasonic signal;
  the attenuation of the ultrasonic waves depends on their frequencies. The low frequencies are less attenuated.
- the maximum measurable velocity;
  the maximum measurable velocity which does not produce aliasing is a function of the emitting frequency.
- the backscattered energy;
  the ultrasonic energy backscattered by the particles depends a lot on the

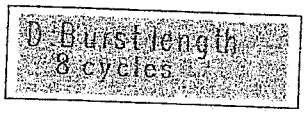
ultrasonic frequency (power of 4).

Note: It is absolutely necessary to select the emitting frequency corresponding to the attached transducer. Each transducer works only at one frequency.

To select the emitting frequency, from the main menu:

- press A:Settings
- then A:Parameters
- then A:Define
- then A:Next
- then C:Frequency
- then use the UP and DOWN keys to select the desired value.

## 9.8 Burst length




The ultrasonic emitted burst could contain 2, 4 or 8 cycles. The length of the emitted burst affects the resolution and/or the received Doppler energy.

The resolution is affected by a change in the burst length only if the duration of the emission is higher then the integration time associated to the bandwidth of the receiver unit which is 1.2 µs.

The received Doppler energy is affected by a change in the burst length only if the duration of the emission is lower then the integration time associated to the bandwidth of the receiver unit which is 1.2 µs.

Note: 32 cycles are emitted when measuring sound speed.

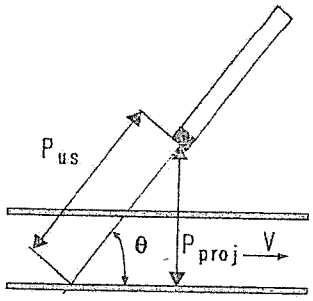
To select the burst length, from the main menu:

- press A:Settings
- then A:Parameters
- then A:Define
- then A:Next
- then D:Burst length
- then use the UP and DOWN keys to select the desired value.

Measurement unit

D Unity
US axis

The velocimeter measures only the velocity component in the direction of the ultrasonic beam. When the velocity component and the measured depth ($P_{us}$) should be computed in this direction choose the value «US axis» for the parameter Unit.



Definition of the computed depth

When the direction of the flow is known, it may be useful to compute the velocity component in the direction of the flow, which corresponds to the real velocity. The Doppler angle (θ) is used to link the direction of the ultrasonic beam and the direction of the flow. By selecting the value «Flow axis» for the parameter Unit, the computed velocity component is the projection of the measured velocity on the flow axis. For such a selection the computed depth ($P_{proj}$) are measured perpendicularly to the flow axis.

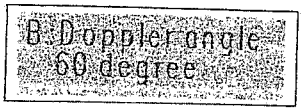
Note: The value of the parameter Unit as no effect on the

recorded binary data. The recorded data are always the velocity values measured in the direction of the ultrasonic beam, which are the only component that the velocimeter could measure.

To select the parameter Unit, from the main menu:

- press A:Settings
- then A:Parameters
- then A:Define
- then A:Next
- then D:Unit
- then use the UP and DOWN keys to select the desired value.

## 9.9 Doppler angle




The value of the Doppler angle is used to link the direction of the ultrasonic beam and the direction of the flow when the parameter Unit as been selected on Flow axis. It has no effect on the recorded data and is only used for computation purposes.

To select the value of the Doppler angle, from the main menu:

- press A:Settings
- then A:Parameters
- then A:Define
- then A:Next
- then A:Next
- then B:Doppler angle
- then use the UP and DOWN keys to select the de-

sired value or if an external keyboard is connected press ENTER and input the desired depth value.

## 9.10 Speed of sound

C:Sound speed

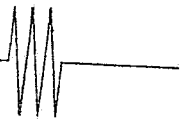
The knowledge of the speed of sound in the medium is necessary to compute a velocity in mm/s and a depth in millimeter. This parameter has no effect on the recorded data and is used only for computation purposes.

A good knowledge of the sound velocity in the medium is necessary to obtain good quantitative measurement values, as all errors on this parameter is directly reported on the velocity values.

In many cases the sound speed value in the medium may be found in tables. If no such tables are available the sound speed may be measured directly with the velocimeter by the use of the measuring sound speed unit (accessory of the velocimeter).

To introduce the sound speed, from the main menu:

- press A:Settings
- then A:Parameters
- then A:Define
- then A:Next
- then A:Next
- then C:Sound speed
- then C:Set value
- use the UP and DOWN keys to select the desired value or if an external keyboard is connected press ENTER and input the desired depth value.



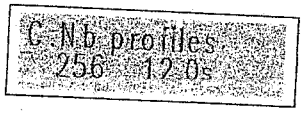
### Measuring the sound speed

The velocimeter could not measure directly this value with precision without the use of the measuring sound speed unit. Nevertheless an approximate value could be obtained by using the display of the echo modulus and placing in front of a transducer a flat target at a known distance. By changing the value of the sound speed until the distance at which appears the rising edge of the echo generated by the target much the known distance, the user could estimate the value of the sound speed in the medium.

By using the sound speed measuring unit the velocimeter could measure the sound speed value with a precision of about 1%. Please refer to Appendix A for an explanation on how to use this unit.

## 9.11 Internal memory

All data profiles measured by the velocimeter are memorized in the internal memory of the velocimeter. The internal memory is designed in such a way that when the internal memory is full the oldest measured data profile will be overwritten by the newest. The size of the internal memory is defined in number of profiles and it could be selected by the user between 16 and 32'768 (depending on the amount of memory installed in the velocimeter). The time needed to fill the whole memory is displayed inside the key D. This value is an approximate value.



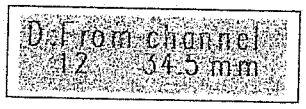

A change in an acquisition parameter induces the erase of the whole memory. This insure that all the data profiles contained in

the memory have been measured with the same configuration parameters.

The Status window displays the state of the content of the internal memory by indicating «Buffer:filling» when all the memory is not full and by indicating «Buffer:full» when it is completely filled.

To select the size of the internal memory, from the main menu:

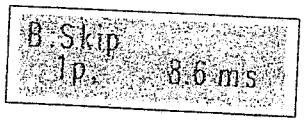
- press A:Settings
- then A:Parameters
- then A:Define
- then A:Next
- then A:Next
- then D:Memory
- then C:Nb profiles
- then use the UP and DOWN keys to select the desired value or if an external keyboard is connected press ENTER and input the desired depth value.




In order to optimize the use of the internal memory the user could memorize only a portion of the whole measured data profiles. This capability is achieved by defining the first and the last channel number of the region of interest that has to be memorized. The two keys D:From channel and E:To channel are used for this purpose. The values of the data profiles outside the memorized profile are set to zero.

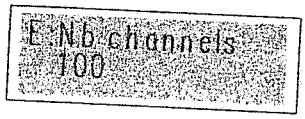
Note: A zero (0) value for these two parameters means that the velocimeter will use automatically the first available channel for the parameter From channel and the

last available channel for the parameter E:To channel.




The velocimeter allows also to slow down the acquisition rate of the data profiles by skipping a certain number of profiles between each measured profile. This number is defined by the key B:Skip.

## 9.12 Number of channels




The velocimeter could measured up to 224 channels or gates. The number of channels that could be measured depends on the selected PRF, the position of the first channel and the selected resolution.

The user has the possibility to select the number of channels. The minimum number is 10. Reducing the amount of measured channels increases the amount of profiles that could be memorized and also enlarges the display (more pixels display per channel). A value of zero (0) for this parameter means that the velocimeter will select automatically the maximum number of channels that could be measured.

To select the number of channel, from the main menu:

- press A:Settings
- then A:Parameters
- then A:Define
- then A:Next
- then A:Next
- then E:Max. gates

- then use the UP and DOWN keys to select the desired value or if an external keyboard is connected press ENTER and input the desired depth value.

## 9.13 Definition of the main parameters

B: Define all

The definition of the main parameters may be done through a single menu. In this menu the velocimeter disables the acquisition process and displays the main parameter window.

A cursor (arrow shape) appears on the left side of the value of a parameter. In order to select a parameter and modify its value:

- place the cursor in front of the parameter to be modified by using the UP and DOWN keys;
- select the parameter by pressing SELECT. The value of the parameter is than surrounded by a rectangle;
- modify the value by using the UP and DOWN keys or press ENTER if an external keyboard is connected;
- accept the modification and enable the selection of an other parameter by pressing SELECT or quit the menu by pressing CANCEL.

## 9.14 Memorization of the parameters

C: Save

The velocimeter can store up to 5 different configurations of the parameters. For each configuration a legend, of up to 32 characters, can be attached.

In order to memorize a configuration, from the main menu:

- press A:Settings
- then A:Parameters
- then C:Save
- select a configuration by moving the arrow by using the UP and DOWN keys.
- select this configuration by pressing ENTER
- Input the comment which describes the configuration
- validate the introduced comment by pressing ENTER.
- press B:Save to store the parameters

Note: The TGC values in Custom mode are not memorized. Only the start and end value of the TGC amplification level are memorized.

## 9.15 Recall the parameters


A recorded configuration can be recalled any time.

In order to recall a configuration, from the main menu:

- press A:Settings
- then A:Parameters
- then D:Recall
- select a configuration by moving the arrow by using the UP and DOWN keys.
- press D:Recall to recall the configuration parameters

Note: The TGC values for Custom mode are initialized to the same values as the slope mode.

E: Default

## 9.16 The default parameters

This configuration can be recalled any time. The default parameters can not be changed. This configuration insures a coherence between all the parameters. It is recommended to always start with this configuration for new measurements.

In order to select the default configuration, from the main menu:

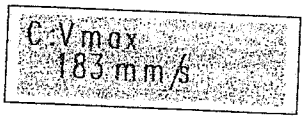
- press A:Settings
- then A:Parameters
- then E:Default

Note: The selection of the Default parameters does not imply the memorization of this configuration.

## 9.17 Maximum velocity

The velocimeter has three velocity scales for each PRF value. The maximum velocity range corresponds to the maximum measurable velocity defined by the PRF value. A decrease in the velocity scale enables an increase in the velocity resolution for the same acquisition time. Decreasing the velocity range will also decrease the aliasing limit.

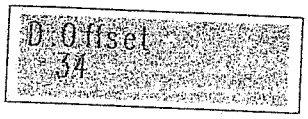
Note: It is recommended whenever possible to reduce the PRF value instead of reducing the velocity scale.




In order to select the velocity scale, from the main menu:

- press A:Settings
- then E:Velocity
- use the UP and DOWN keys to select the desired value.

Normally the velocimeter allocates the same range to positive and negative velocity. In some cases it could be useful to reserve a bigger range to one of the signed portion. This method allows to measure higher velocities without loosing the capability of measuring bi-directional flows. The key D:Offset defines the range of both the positive and negative velocity range.




To select the velocity offset, from the main menu:

- press A:Settings
- then E:Velocity
- then D:Offset
- use the UP and DOWN keys to select the desired value.

tory after power up.

**To select the current directory, from the main menu:**

- press C:Disk
- then B:Directory
  After pressing this key, the velocimeter displays a window in which the first line gives the complete name of the current directory and the following lines display all the available directories.
- use the UP and DOWN keys to select an available directory, or select the position labeled "." to visualize the content of the parent directory, or select the position labeled "NEW" to introduce a new directory. (see creating a new directory)
- validate your choice by pressing ENTER. The velocimeter jumps to the new selected directory and selects it as the current directory.

**Creating a new directory:**

- place the cursor on the line labeled "NEW:" by using the UP and DOWN keys,
- then press ENTER. The size of the cursor increases and a default name "1" appears.
- introduce the new directory name:

  If an external PC keyboard is connected:

  enter the name of the new directory. The backspace key erases the last character introduced.

# 10 Storing and reading measures

C:Disk

The content of the internal memory, which contains the data profiles, can be recorded with the parameters on the floppy disk or on the hard disk. The recorded data profiles could be:

- the velocity profiles, included the flow rate
- the echo modulus profile, included the flow rate
- the Doppler energy profile, included the flow rate
- the velocity profile with the echo modulus
- the velocity profile with the Doppler energy
- the power spectrum of a channel
- the I and Q Doppler signals.

The resulting record is compatible with DOS.

An ASCII bloc and all the configuration parameters are attached to the recorded data profiles.

IMPORTANT NOTE

The recorded data profiles are raw data. Any applied filters are not taken into account. This allows a better and sure way to post-process the measurements.

## 10.1 Working with directories

B:Directory

The current directory is the directory where data profiles could be recorded and read. The velocimeter contains a menu which allows to browse all the available directories in all the available drives. It is also possible to create and remove directories and to save the current selection in order to select it as the current direc-

if no external PC keyboard is connected:

the key SELECT can be used to fixe the position of a character to introduce. This position is indicated by an underscore "_". The UP and DOWN keys are used to select the character.

- validate the name by pressing the ENTER or cancel the creation of the new directory by pressing the key CANCEL. The new created directory will be selected as the current directory


**To select an other drive, from the main menu:**

- press C:Disk
- then B:Directory
- then each time the key B:Change drive is pressed the next available drive will be selected.


**To remove a directory:**

- place the cursor on the line which contains the name of the directory to be removed by using the UP and DOWN keys,
- press the key A. The velocimeter removes the directory. If the directory to be removed contains files a message appears in the directory window and the velocimeter jumps to this directory.

C:Save

**To memorize the current directory**

The name of the current directory can be saved by pressing the key C follow by ENTER. Saving this name ensures that, at next power up, the velocimeter will select this name as the current directory.

**To quit the directory menu**

To quit the Directory menu and accept the current selection press the key CANCEL.

## 10.2 Working with files

A:File

The velocimeter can save, read or delete files contained in the current directory. Saving a file means recording the content of the internal memory (its filled part), an ASCII bloc and the configuration parameters. Reading a file means transferring the data profiles contained in the file into the internal memory and getting the configuration parameters from the file (see Reading DOP files).

To access a file, from the main menu:

- press C:Disk
- then A:File

After pressing this key, the velocimeter displays a window in which the first line gives the complete name of the current directory and the following lines

display all the available files. If the number of existing files contained in the current directory is bigger than the number of displayed files, the label "MORE..." appears at the bottom right of the window. Selecting this label by means of the UP and DOWN keys and pressing ENTER allows to display the other files.

## 10.3 Deleting a file

C:Delete

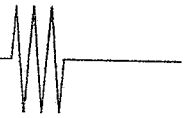
To delete a file contained in the current directory, from the main menu:

- select the file to be deleted by using the UP and DOWN keys,
- press C:Delete
- confirm by pressing ENTER or cancel by pressing CANCEL.

## 10.4 How to record data profiles

The velocimeter offers two ways to record data profiles. The first way consists to use directly the Disk menu and the other one involve the use of the Trigger menu.

When using directly the Disk menu, the data profiles which will be recorded are the data contained in the internal memory just before entering in the Disk menu. This means that the user will record the profiles which have been measured and displayed (record past measurements).



On the other hand, when using the Trigger menu the data profiles which will be recorded are the data contained in the internal memory issue from the first trigger signal up to the last trigger sequence. This means that the user will record the profiles which will be measured and displayed (record future measurements). The Trigger menu describes in details this method to record data profiles.

Note: The velocimeter rearrange the internal memory in order to always place the latest measured data profile at the end of the file.

If the user memorize measurements before having fill up the whole memory, only the measured data profile will be recorded in the file.

A:Store

When using the Disk menu the user must follows the procedure below:

- be sure that all the parameters have the desired values;
- go to the main menu by pressing as many times as necessary the CANCEL key;
- wait until all the internal memory is full, which is indicated in status windows by "Buffer:full";
- then press C:Disk;
- then A:file
- place the cursor on the desired file name by using the UP and DOWN keys, or select a new file name

(see below Defining a file name):

A:Writing

- press A:Store to record the measure. In case of an existing file name a message appears inside the key A which asks the user to confirm the overwriting process. Press ENTER to confirm or CANCEL in order to select an other file name.

  If an external keyboard is connected:

  A new window appears in which the user can introduce a description of the file content. Terminate the introduction of the description and store the file by pressing the key CANCEL. The backspace key could be used to erase characters.

  if no external keyboard is connected, the velocimeters starts to record the file.

  A message inside the key A indicates the status of the velocimeter.

Note: The Disk menu is directly accessible by pressing the F2 key in many menus.

Defining a file name

NEW: 1

The following procedure should be used to introduce a new file name:

- place the cursor on the line labeled "NEW:" by using the UP and DOWN keys, and press ENTER. The size

of the cursor increases and the default file name «1» appears.

If an external keyboard is connected,

introduce the new file name. The name must be compatible with DOS (8 characters follow by a point and 3 characters for the extension). Then press ENTER to validate the new name or CANCEL to quit.

If no external keyboard is connected,

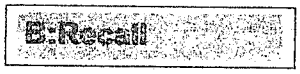
select the position of the character to be introduce by the key SELECT which is indicated by the underscore «_». Use the UP and DOWN keys to define the character. Repeat the two steps above until the whole name is introduced. Then press ENTER to validate the new name or CANCEL to quit.

## 10.5 Reading DOP files and cine mode

The velocimeter allows to read and replay a measure from the floppy disk or the hard disk. This replay mode, called the cine mode, enables to visualize the evolution of the data profiles slowly or step-by-step.

As all the configuration parameters are also read from the file, the user can also visualize these parameters. Any applied filters during the measurement will be activated in cine mode. The user could change some settings (filters, sound speed, and others) to see their influences on the measurements. Of course, all parameters related to the acquisition process (resolution, PRF, and oth-

ers) could or should not be changed.



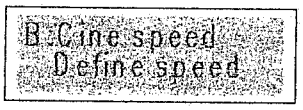

To access the cine mode, the first step is to read a DOP1000 binary data file. To do it, from the main menu:

- press C:Disk
- then A:File
- select the file to be read by using the UP and DOWN keys,
- press then B:Recall.
  The velocimeter jumps afterwards in the cine mode.- The cine mode and file name being in used are indicated on the bottom left of the display.

In cine mode the velocimeter runs the same way that during the acquisition mode.

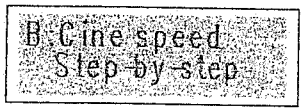
**Selecting the display mode**

In cine mode the velocimeter can display the data profiles continuously or step-by-step. The update rate of the data profiles is user's selectable in the continuous mode.




**To select the update rate, from the main menu:**

- press D:Utilities
- then B:Cine speed as many times it is necessary to see inside the B key the text Define speed.
- select the update rate by using the UP and DOWN keys,
- press the key CANCEL to return to the main menu




**To select the step-by-step mode, from the main menu:**

- press D:Utilities
- then B:Cine speed as many times it is necessary to see inside the B key the text Step-by-step.
- select the next profile to be displayed by using the UP and DOWN keys. The status window indicates the profile number.
- press the key CANCEL to return to the main menu


**Quit the cine mode**

To return to the normal acquisition mode, from the main menu:

- press D:Utilities
- then A:Cine mode

The velocimeter will recall the parameters that where in use before entering in the cine mode.

# 11 Structure of a binary DOP file

The velocimeter records data profiles in a format compatible with DOS. A dop file contains three blocs:

- an ASCII bloc which contains the principal parameters values of the measurement and a description of the file content introduced by the user;
- a binary bloc which contains all the parameters used during the measurement process
- a data bloc which contains the binary values of the measured data.

## 11.1 The ASCII bloc

This bloc is the first bloc and has a length of 1536 bytes. It allows a direct visualization of the values of the principal parameters and the description of the file content introduced by the user. The DOS command TYPE from DOS or any text editor can display the content of this ASCII bloc.

Note: The description of the file content is only present if the file was recorded by means of an external keyboard.

**The structure of the ASCII bloc**

Signal Processing SA: DOP1000 Ver:5.23

---

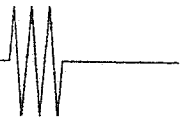
Recorded data type: velocity profile

Pulse repetition frequency .....: 156mm208us
First channel at.....: 0.0 mm.0 us
Resolution.....: .0.375mm 0.5us
Sensitivity .....: medium
Number of emission / profile .....: 128,32 ms
Emission power .....: medium
frequency .....: 8 MHz
burst length .....: 8 cycles
Unit .....: US axis
Sound speed.....: 1500 m/s
Doppler angle .....: 60 degrees
Memory size .....: 256,8.3ms
From channel .....: 0,auto
To channel.....: 0,auto
Skip .....: 0p,0 ms
Maximum velocity.....: 225 mm/s
Velocity offset.....: 0 mm/s

Measurement Description:

---

Up to 10 lines of 43 characters each could describe the measurement.



## Definitions of the binary parameters

| offset | description |
|---|---|
| 0 | software version number |
| 2 | emitting power<br>0: high 2:medium 3:low |
| 4 | coded pulse rep. frequency |
| 6 | coded emitting frequency<br>0:8 MHz 3:1 MHz |
| 8 | position of the first channel in µsx10 |
| 10 | TGC coded value at minimum depth |
| 12 | TGC coded value at maximum depth |
| 14 | Doppler scale factor (2,4 or 8) |
| 16 | coded resolution |
| 18 | memory size (in profile) |
| 20 | sensitivity<br>0:very high -> 5:very low |
| 22 | IIR filter coefficient x 100 |
| 24 | Doppler angle in degrees |
| 26 | Echo modulus scale factor |
| 28 | Nb of emissions/profile |
| 30 | Nb of emissions for stabilization IIR |
| 32 | internal variable |
| 34 | sound velocity m/s |
| 36 | unit:= 0 US axis =1 Flow axis |
| 38 | main oscillator, frequency kHz |
| 40 | main oscillator, period nsx100 |
| 42 | internal variable |
| 44 | number of channels |
| 46 | power spectrum window<br>0:none 1:Hamming |
| 48 | nb of profiles for statistics |
| 50 | nb of channels for statistics |
| 52 | burst length (0=>2, 1=>4, 2=>8) |
| 54 | internal variable |
| 56 | TGC mode: 0=slope 1=custom |
| 58 | TGC custom, beginning depth |

| offset | description |
|---|---|
| 60 | TGC custom, end depth |
| 62 | TGC custom, cell value |
| 64 | applied filter flag |
| 66 | nb of profiles for moving average |
| 68 | internal variable |
| 70 | internal variable |
| 72 | internal variable |
| 74 | channel duration in µsx10 |
| 76 | channel number of the anterior wall |
| 78 | channel number of the posterior wall |
| 80 | internal variable |
| 82 | coded offset velocity value |
| 84 | internal variable |
| 86 | internal variable |
| 88 | internal variable |
| 90 | internal variable |
| 92 | first recorded channel |
| 94 | last recorded channel |
| 96 | nb profiles used for median |
| 98 | nb points for FFT |
| 100 | multiplex mode flag |
| 102 | internal variable |
| 104 | nb bytes by profile (NB_PRO) |
| 106 | nb profiles skip between recorded profile |
| 108 | Trigger flags |
| 110 | Trigger delay (in profile) |
| 112 | nb profiles by Trigger event |
| 114 | nb Trigger sequence |
| 116 - 155 | table of nb of profiles in multiplex |
| 156 | nb of averaged power spectrum |
| 158 | FFT channel |
| 160 | multiplexer flag |
| 162 | internal variable |
| 164 | nb points for time FFT |

## 11.2 The binary parameters bloc

This second bloc has a length of 256 bytes and contains the binary words linked to the parameters.

The following table gives the position and the meaning of these words. The position are given relative to the beginning of this bloc which starts at offset 1'536 bytes from the beginning of the file.

## 11.3 The measured data bloc

This third bloc starts at the offset 1'792 bytes from the beginning of the file and contains the binary data.

Each profile is formed by NB_PRO bytes. The value of NB_PRO depends on the number of channels used in the measurement and is found at the offset 104 from the beginning of the binary parameters bloc.

These NB_PRO bytes contain the coded measured data for each channel. The channel located at the minimum depth is in the first position. The last bytes inside a profile give information relative to the multiplex mode, the flow rate value and the recording time of the profile in microseconds.

When the recorded values contain both the echo modulus or the Doppler energy and the velocity profile, the first K bytes give the echo or Doppler energy (low depth first), where:

$$K = \frac{NBPRO - 10}{2}$$

Structure of one velocity profile

| offset | description |
|---|---|
| 0 | The following bytes give the coded Doppler data, low depth first. If 2 types of profiles, K bytes for the modulus or Doppler energy, then K bytes for the velocity profiles, where:: $K = \frac{NBPRO - 10}{2}$ |
| NB_PRO - 10 | word reserved for the multiplex mode. |
| NB_PRO - 8 | 4 bytes that give the flow rate value in the selected flow rate unit (ml/min or l/min).<br>low byte first |
| NB_PRO - 4 | 4 bytes that give the measuring time of the profile |

## 11.4 Conversion of a coded Doppler frequency

The recorded Doppler frequency values are coded and are in a byte format.

In order to convert these coded values in a Doppler frequency $F_{dop}$ in Hz, you should applied the following relation:

$$F_{Dop}[Hz] = \frac{Val \cdot 10^{11}}{Par[14] \cdot Par[4] \cdot Par[40] \cdot 32768}$$

where:

| | |
|---|---|
| Val | is the coded value extracted from the file. It has a value between -128 et +127 |
| Par[40] | is the binary value (format word) located at offset 40 from the beginning of the binary parameters bloc. (main period of the oscillator in nsx100) |
| Par[14] | is the binary value (format word) located at offset 14 from the beginning of the binary parameters bloc (Doppler scale factor). |
| Par[4] | is the binary value (format word) located at offset 4 from the beginning of the binary parameters bloc (coded value for PRF). |

The relation above is valid only if the velocity offset value is 0. If the velocity offset is not 0 the recorded coded binary values have to be corrected by the following algorithm befor using the above formula.

```
Val = Val + Par(42)
ICOR = 0
IF Val > 127 then ICOR = -256
IF Val < -128) then ICOR = 256
Val = Val + ICOR
```

Val = Val - Par(42)

This Doppler frequency in Hz can be converted in a velocity by the relation below. This velocity is the component in the direction of the ultrasonic beam.

$$V\,[m/s] = \frac{F_{Dop} \cdot Par\,[34] \cdot 2^{[1+Par\,[6]]}}{Par\,[38] \cdot 10^{3}}$$

where:

| | |
|---|---|
| $F_{Dop}$ | is the Doppler frequency in Hz (computed by the preceding relation) |
| Par[6] | is the binary value (format word) located at offset 6 from the beginning of the binary parameters bloc (coded emitting frequency). |
| Par[34] | is the binary value (format word) located at offset 34 from the beginning of the binary parameters bloc (sound speed). |
| Par[38] | is the binary value (format word) located at offset 38 from the beginning of the binary parameters bloc (main oscillator frequency in kHz). |

## 11.5 Extraction of other data values

DOP files could also contain other data types as coded Doppler frequencies. This is the case when the files contained modulus of the echo, Doppler energy or power spectrum values. In these cases the data values contained in a profile as no unit and therefore can be directly used. No conversations are needed.

Note: The data are also in a byte format, but without signed bit except for I and Q signals

## 11.6 Extraction of the depth of a channel

The depth of a channel is given by its position in a profile. The channel located is the lowest depth is placed at the beginning of a profile. The following equation can be used to extract the depth

$$P_{mm}[mm] = \frac{Par[34] \circ [Par[8] + Par[74] \circ (i-1)]}{2 \circ 10^4}$$

where:

Par[8] is the binary value (format word) located at offset 8 from the beginning of the binary parameters bloc

Par[74] is the binary value (format word) located at offset 74 from the beginning of the binary parameters bloc

Par[34] is the binary value (format word) located at offset 34 from the beginning of the binary parameters bloc (sound speed).

i the channel number (starting from 1). The channel number is associated with data value located at the offset (i-1) inside a profile (composed of NB_PRO bytes).

## 11.7 Extraction of I and Q signals

When recorded data are I and Q Doppler signals a special format is used. The first two blocs are the same but the last bloc, the bloc that contains the binary recorded values is different. The length of this bloc is defined by (NxSx4) where N is the number of emissions (binary parameter at offset 178) and S the number of recorded gates. The structure of the record is:

- I value from gate 1 (lower depth), emission1
- Q value from gate 1 (lower depth), emission 1
- I value from gate 2, emission1
- Q value from gate 2, emission 1
- ....
- I value from gate S (last gate), emission1
- Q value from gate S (last gate), emission 1

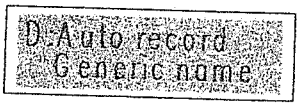
- I value from gate 1 (lower depth), emission 2
- Q value from gate 1 (lower depth), emission 2
- I value from gate 2, emission 2
- Q value from gate 2, emission 2
- ....
- I value from gate S (last gate), emission 2
- Q value from gate S (last gate), emission 2
- and so on...until last emission

Each recorded value, I and Q, are in a signed word format.

Note: The ASCII conversion program could also convert these data in ASCII format.

generic file name associated to a value of a recording counter. The recording counter is initialized to 1 when entering in the Trigger menu via the main menu and is incremented after each recording process.

The automatic recording mode is selected if the function Auto record is enabled and if the user has defined a generic file name.




to enable the function Auto record, from the main menu

- press C:Disk
- then A:File
- then D:Auto record
- then use the UP and DOWN keys to select "Generic name"
- then press ENTER. A new window is opened.
- introduce the generic name (maximum 8 characters) without extension.
- validate by ENTER
- press CANCEL go back to the main menu

After these steps the automatic record mode is enable. The extension counter is set to 1, which means that the extension of the first recorded file will be ".1"

Note: If the first character of the generic name starts with the character "!" the Ext. Trig. connector will be enable when the velocimeter will jump again to the Trigger menu. In all other cases, the Ext. Trig. connector will be disable.

# 12 The Trigger mode

The acquisition process can be triggered by an external event. This event can be a change in the logic state at the Ext. Trig. connector located at the rear panel or can be an action on the key A.

In Trigger mode the velocimeter executes one or many acquisitions sequences and jumps directly to the File menu from the Disk menu and the end of the last sequence of acquisition in order to record all the measurements realized. This recording process can execute automatically.

## 12.1 The trigger menu

The Trigger menu allows to define the parameters relative to the acquisition procedure in trigger mode. A record in trigger mode is characterized 4 points:

- the trigger event
- the delay after the trigger event
- the acquisition of the data profiles
- the number of sequences


To enter in the Trigger menu, from the main menu:

- press D:Utilities
- then E:Trigger

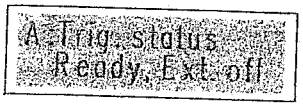
You should then define the parameters of the trigger sequences.

## 1. The Trigger event

IMPORTANT NOTE

The applied tension on the Ext. Trig. connector should not exceed 5 Volt or be negative!

The trigger event can be a change in the logic state appearing at the Ext. Trig connector or an action on the key A from the Trigger menu.




When entering in the Trigger menu, the Ext. Trig connector is disable. This allows the definition of the parameters defining the trigger sequence. The Ext. Trig connector could enable "Ext. on" or disable "Ext. off" by pressing the SELECT key.

In trigger mode the velocimeter can:

- continuously acquire data profiles and display these profile without storing it in its internal memory (mode With display).
- stop the acquisition process and wait for a trigger event (mode Waiting for)

When the mode Waiting for is selected the velocimeter stops the acquisition process and waits until a trigger event appears. This mode allows a more stable and much shorter time laps between the trigger event and the beginning of the acquisition procedure. In this mode the minimum trigger impulsion is 30µs and does not depend on the settings of the velocimeter.

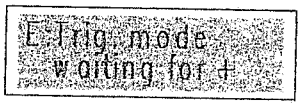
When the mode With display is selected the velocimeter continues to acquire and display the data profiles but will not store them

in its internal memory until the trigger appears. In this mode the minimum duration of the trigger impulsion should about 4 to 5 ms and could depends on the setting of the parameters. For this reason a long trigger impulsion is recommended.

Note: After receiving and accepting the trigger event the velocimeter does not check for an other event until the end of the sequence.

The velocimeter informs the user that a trigger event has been accepted by placing inside the key A the label "Trigger run"

For both mode, the trigger event could be a high logic level (+5 Volt) appearing on the Ext. Trig. connector which is indicated by the label "+", or a low logic level (0 Volt) which is indicated by the label "-".

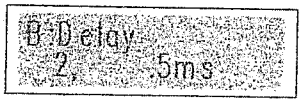



To select the trigger mode, from the Trigger menu:

- press E:Trig. mode
- then use the UP and DOWN keys to select the desired mode

2. The delay

After the acceptation of the trigger event the velocimeter could skip a certain number of profiles before it starts to transfer them in its internal memory. This number of skipped profile are define by the key B.



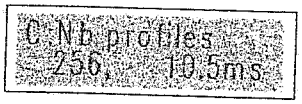

To select the delay, from the Trigger menu:

- press B:Delay
- then use the UP and DOWN keys to select the desired value (in number of skipped profiles) or if an external keyboard is connected use the ENTER key.

3. The acquisition of the profiles

At the end of the delay the velocimeter starts to transfer a user's defined number of profiles in its internal memory. At the end of the acquisition of the last profile the velocimeter stops the acquisition process. If other trigger sequences have to be performed it returns to step 1 and wait for an other trigger event. If the last trigger sequence has be achieved, it jumps to the Disk menu in order to record all the measured sequences.

During the acquisition of the data profiles of a sequence, the status window displays the profile number and the number of the trigger sequence in progress.




To select the number of profiles in a trigger sequence, from the Trigger menu:

- press C:Nb profiles
- then use the UP and DOWN keys to select the desired value or if an external keyboard is connected use the ENTER key.

4. The number of sequences

A trigger sequence is formed by a unique trigger event followed

by an optional delay and followed by the acquisition of a defined number of data profiles. The velocimeter allows to repeat many sequences before recording the measurements. This means that a file could contain many sequences, one after each other.


To select the number of sequences, from the Trigger menu:

- press D:Repeat
- then use the UP and DOWN keys to select the desired value or if an external keyboard is connected use the ENTER key.

Note: Take care that the memory size could contain the addition of all profiles of each sequence.

## 12.2 Recording trigger sequences

The velocimeter offers to way to record trigger sequences. A manual one and an automatic one.

In the manual mode, at the end of the last sequence, the velocimeter jumps directly to the Disk menu. The user is then asked to introduce a file name and proceed the same way as when recording a non-trigger measurement.

In the automatic mode, at the end of the last sequences the velocimeter records automatically the data profiles contained in its internal memory in a file having a user's defined name and an extension number given by a counter.

Selecting the manual recording mode

The manual recording mode is selected if the function Auto record is disabled.

to disable the function Auto record, from the main menu

- press C:Disk
- then A:File
- then D:Auto record
- then use the UP and DOWN keys to select disable
- then press CANCEL to return to the main menu

In the manual mode the recording procedure follows exactly the same steps as for non-trigger measurements. The user as the possibility to associate to the file comments if an external keyboard is connected. If the user decides to not record the measurements he should press the CANCEL key just after entering in the Disk menu.

Note: After the file has been recorded, the velocimeter return to the trigger menu. The Ext. Trig connector is disable after each recording process.

Selecting the automatic recording mode

In the automatic mode, at the end of the last trigger sequences the velocimeter records automatically all the sequences without going through the Disk menu in a file name which is formed by a

## 12.3 Some Important notes in trigger mode

The few comments below should be taken into account when selection the trigger mode:

- When entering in the Trigger menu the Ext. Trig. connector is always disable except when the automatic record procedure has been selected and the generic file name starts with the character "!".
- The internal memory is initialized when the velocimeter enters in the Trigger menu.
- The first profile on a trigger record is always the first profile from the first sequence.
- The parameter Skip from the Memory menu is also taken into account. It affects the trigger delay value.
- The value of the first time stamp on a trigger record gives the delay between the first trigger event and the first recorded profile. The time stamp is not initialize by the start of an other sequence.
- The user can interrupt at any time a trigger measurement by pressing the key CANCEL.
- In trigger mode the median filter is disabled. The moving average filter consider only profiles inside a sequence.
- In trigger mode the moving average filter consider only profiles inside a sequence.
- In trigger mode, the multiplexer is reset and the first transducer is selected at the beginning of each sequence.

# 13 Using the velocimeter

This chapter is intended to point out some of the basic aspects of the use of the ultrasonic Doppler velocimeter.

## 13.1 Installation of the ultrasonic probe

IMPORTANT NOTE

Ultrasonic probes are fragile. They must be handle with care and they must not receive any shocks. The probe support must not induce mechanical stress. Although the probes are waterproof they should not be in contact with the liquid for a longer time (many hours).

Whenever possible it is always better to put the probe directly in contact with the liquid. Crossing interfaces or walls induces reflections which reduce the amount of ultrasonic power injected in the liquid and may disturb the ultrasonic field (see below «Influences of interfaces»).

The probe should be mounted in a rigid support which should have some degrees of freedom in order to select an appropriate position. When positioning the probe the points below should be taken into account:

- a good position is a position with the minimum stationary echoes;
- when crossing interfaces, the angle between the probe axis and the surface of the interface must take into account the maximum refraction angle. This angle is defined by the characteristic impedance of the different medium in presence.
- vibrations of the probe support should be avoided.

When the ultrasonic probe is directly in contact with the liquid it is not necessary to use any coupling medium. Be sure that the front face of the probe is always in contact with the liquid and no gas are present.

If the ultrasonic waves have to cross a solid interface it is absolutely necessary to use a coupling medium. It is not necessary to put the probe in contact with the interface. The coupling medium, which could be any ultrasonic gel or liquids, will guarantee a path for the ultrasonic waves. The coupling medium should be put in enough quantity.

Note: It may be useful to start by handling the probe by hand in order to find a good position.

Small gas bubbles may appears after a certain time on the surface of the probe especially when the liquid contains a lot of gas dissolved in it. These bubbles should be removed.

## 13.2 Choosing correct values of the configuration parameters

The quality of the measurements depends on the choice of the parameters values. It is not possible to give a rule which guarantee the best choice in any cases. Nevertheless the following advises will help the user to find appropriate settings. We recommend to follow the procedure described below:

1 always start with the default values

2 select the emitting frequency that corresponds to the ultrasonic probe.

3 select the TGC menu in order to examine the amplitude of the echoes. If necessary reduce the gain and/or the emitting power in order to remove any saturation.

4 If no velocity profile appears:
try to increase the sensitivity and/or the emitting power. It is recommended to check the amplitude of the echoes through the TGC menu;

5 be sure that the probe angle has not exceed the critical angle.

6 be sure that no frequency aliasing appears. This can be checked by changing the probe angle and/or modifying the pulse repetition frequency. Be careful when using the moving average filter. This filter masks the aliasing effect.

7 adapt if necessary the velocity offset

8 select the desired resolution

9 select the desired maximum depth by changing if necessary the PRF. When doing this take care of the aliasing.

10 adapt if necessary the number of emission per profiles.

11 apply a filter (moving average or mediane) if possible to reduce the variance of the measurement.

12 define the memory characteristic.

13 define the number of channel to display

14 before recording a measurement be sure that the internal memory is full (Buffer:full)

## 13.3 Influences of Interfaces

The interfaces reflect and modify the acoustic field. The intensity of the acoustic field received in a point depends on the material, on the shape and on the number of interfaces crossed by the ultrasonic waves. This means that it is often very difficult to have a good knowledge of the ultrasonic intensity. This lack of knowledge does not allow a precise determination of the size of the measuring volume.

The interfaces may generate, in certain situations, artifacts and induce modifications in the velocity profiles as presented in the figures 2 and 3 below.

Figure 2

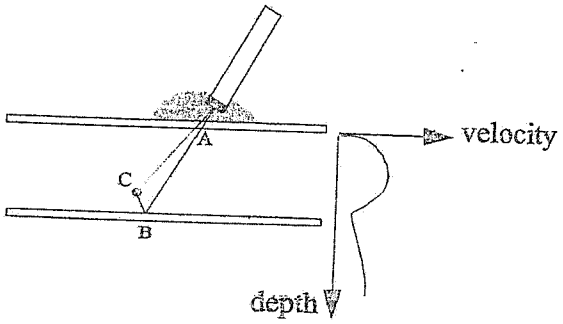
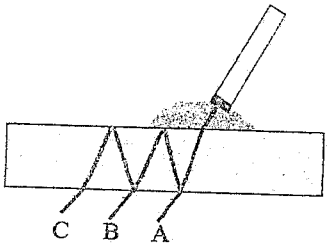



Figure 3




The ultrasonic beam BC reflected by the far interface of the figure 2 transforms this interface in a transmitter. The same particles contained in the liquid will backscatter a second time energy in the direction to the transducer. The depth associated to the path ABC is located outside the flowing liquid. Imaginary velocity components are added to the real velocity profile. The measurement

of velocities near the far interface is affected by this phenomenon. The size of the ultrasonic beam determines mainly the level of this artifact.

The figure 3 displays another situation often founded. The reflected ultrasonic waves inside a wall enlarge the ultrasonic beam inside the liquid and modify its shape. These reflections disturb the determination of the size and the shape of the measuring volume. The thickness, the acoustical impedance and the attenuation coefficient of the interface determine the level of this phenomenon.

### Moving interfaces

Interfaces often give strong reflections. Despite of the many reflections which are necessary to reach the transducer, the energy reflected by these interfaces is often stronger than the energy coming from the particles flowing with the liquid. When some interfaces are in movement the correct estimation of all the velocity field is more difficult. The echoes generated by such interfaces may affect the velocity profile in some places due to the combination of many reflections. The Doppler frequency induced by these movable interfaces can not be removed if their values have the same values as the flowing particles.

# 14 Utilities

The velocimeter has additional functions which control the acquisition process of the instrument.

## 14.1 The Freeze/Run mode

The Freeze/Run mode enables the user to interrupt the acquisition process by pressing a key. This mode is controlled by the key E from the main menu.

In Freeze mode, which is indicated by the text «Freeze» inside the key E, the velocimeter stops the acquisition process and keeps the display of the last measured profile. If the key E is pressed again, the velocimeter go back in the Run mode.

In Run mode, which is indicated by the text «Run» inside the key E, the velocimeter acquires and displays the profiles continuously. This mode could be interrupted by the key E.

## 14.2 Print screen

The Printer menu gives access to a menu that allows the copy of the displayed screen to a printer or to a file (format TIFF).


To realize a print screen copy, from the main menu:

- press D:Utilities
- then C:Printer
- then B:Printer type

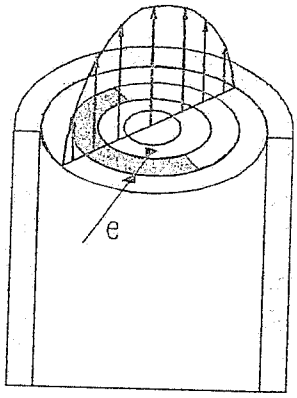
- select the type of printer or the copy to a file by u sing UP and DOWN keys.
- execute the copy by pressing the key A.

If you have selected to copy to a TIFF file, a new window will be open. Introduce the file name an terminate the introduction by pressing ENTER. The file will be recorded in the current directory.

Note: If no printer are connected an error message will be displayed.

If an external keyboard is connected, the Prt Scr key, or print screen key, could be used any time to create a hard copy of the displayed screen on a file or on a printer depending the type of printer selected.

# 15 Flow rate measurement



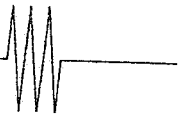

The velocimeter can compute and display in real-time the flow rate by integrating the velocity profile on a user's defined area.

The flow rate is computed by spatially integrating the velocity profile. The integration is carried out by summing the flow rates through several small regions (indicated by the shaded region in the figure), each of them corresponding to one measured channel. The velocity is assumed to be uniform throughout each region. The cross-section of the conduit is always assumed to be circular, with a diameter equal to the spacing between the anterior and posterior wall indicators.

The flow rate is given by:

$$Q = \frac{\pi e^2 \sin^2\theta}{2}\left[ V_{\frac{N}{2}} + V_{\frac{N}{2}+1} + \sum_{i=1}^{\frac{N}{2}-1} (V_i + V_{N-1+1})\,(N-2i+1) \right]$$

if the pseudo-diameter D/sinθ corresponds to an even number of channels,



and by:

$$Q = \frac{\pi e^2 \sin^2\theta}{2}\left[\frac{1}{2}V_{\frac{N+1}{2}} + \sum_{i=1}^{\frac{N-1}{2}} (V_i + V_{N-1+1})\,(N-2i+1)\right]$$

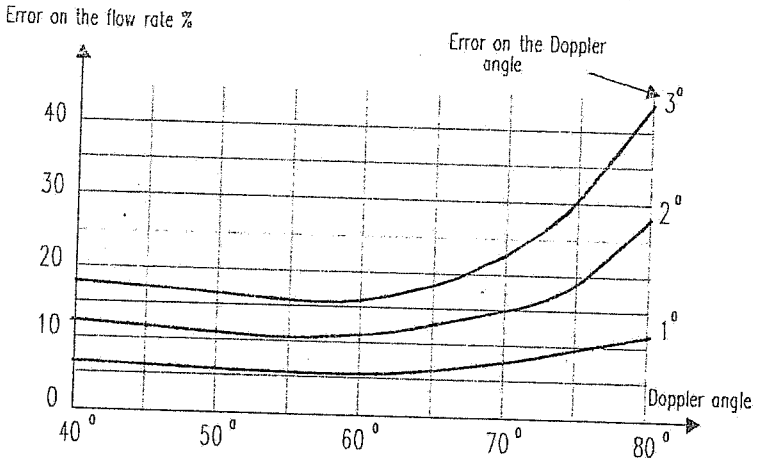
for an odd number of channels.

e is the thickness of the semi-annular region and v the velocity component perpendicular to the cross section.

Note that these two relationships do not explicitly contain the diameter. The diameter is only used to determine the number of channels contain in the conduit.

A precise evaluation of the flow rate is possible only if the axes of the pipe and of the ultrasonic field lie in the same plane, and if the flow field is axially symmetric. The size of the ultrasonic beam must also be much smaller than the diameter of the pipe.

Knowledge of the Doppler angle $\theta$ is necessary for the computation of the flow rate. The flow rate is based on the computation of velocities in the flow axis. It is therefore necessary to compute these velocities from the only velocity components measured by the velocimeter which are the velocities in the direction of the ultrasonic beam. The graph below illustrates the error introduced in the flow rate computation as a function of the Doppler angle, for a few errors in the input value of the Doppler angle.




## 15.1 Placing the wall indicators

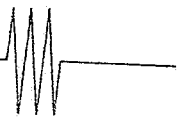
The diameter of the conduit is defined in an interactive manner, by placing on the velocity profile two indicators, one defining the position of the anterior wall, the other the position of the posterior wall. The Cursor menu allows to move these indicators.

A:Move both walls

In order to place the wall indicators, from the main menu:

- press B:Cursor
- then A:Flow section
- then A:Move

  pressing many times A:Move allows to choose the object to be moved between the anterior wall, the posterior wall, both walls or to change the diameter value.

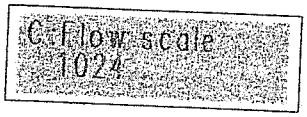


- move the selected object by using the UP and DOWN arrow keys, or if an external keyboard is connected, press ENTER and introduce the desired value.

Note: the channel located at the position of the wall indicator belongs to the flow rate section.

## 15.2 Flow scale and unit

The velocimeter allows to display the flow rate in milliliter per minute (ml/min) or liter per minute (l/min). By adapting the flow scale flow rates could be measured between 1 ml/min and 16384 l/min (maximum scale).




To select the flow scale, from the flow menu:

- press C:Flow scale
- select the desired value by using the UP and DOWN arrow keys.


To select the flow unit, from the flow menu:

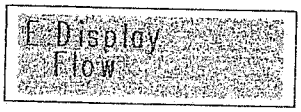
- press D:Unit
- select the desired value by using the UP and DOWN arrow keys.

## 15.3 Selecting the flow rate display

The key E:Display enables to choose between two different displays, the display of the velocity profile and the display of the flow rate versus time.

At each new velocity profile corresponds a new calculation of the flow rate. The ordinate of the displayed flow rate curve gives an approximate value of the time between the different flow values. If the time estimation is to far from it's real value, the time unit, normally ms, is replaced by a «?».

The cursor window, located below the abscissa, displays the flow rate value in the chosen unit, ml/min or l/min. A «?» indicates an overflow value.




In order to select one of the two displays, from the main menu:

- press B:Cursor
- then pressing the key E:Display will switch between the two available displays.

Note: The Display menu also enables the selection of the flow rate versus time display.

No filters could be applied directly on the flow rate curve. Filters applied on the velocity profiles will average the flow rate curve.

## 16 Measurement sample volume

In order to precisely locate the depth of the measurement, the shortest possible signal emission should be used. Unfortunately, increasing the spatial resolution decreases the accuracy of the estimation of the Doppler frequency. The relationship between these two parameters is presented in detail in this section.

Consider a pulse which has been received by a transducer, given by:

$$R(t) = A(t-t_v)\sin[2\pi f_e(t-t_v)]$$

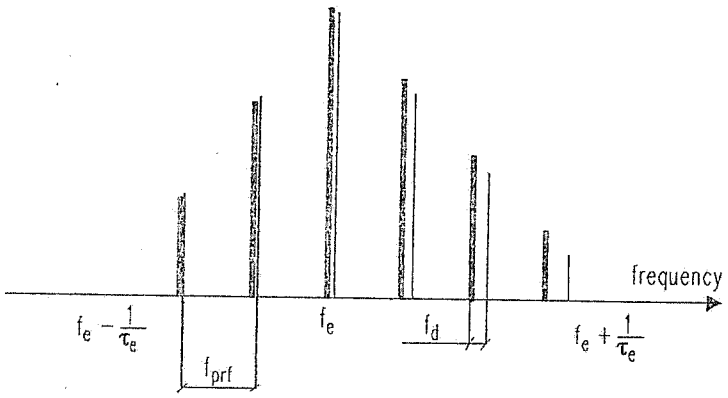
where $A(t-t_v)$ is the envelope of the received impulse and $t_v$ is the time required for the signal to travel from the transducer to the target and back. For a periodic emitted pulse of period $T_{prf}$, the echo signal will be given by the convolution (denoted as x) of a train of Dirac delta functions with the received impulse.

$$R(t) = \sum_{n=-\infty}^{\infty} \delta(t-nT_{prf}) \otimes A(t-t_v)\sin[2\pi f_e(t-t_v)]$$

The Fourier transform of the above expression is:

$$R(t) = \text{cste} \sum_{n=-\infty}^{\infty} [F_A(f_{prf}-f_e) - F_A(f_{prf}+f_e)]\,\delta(f-nf_{prf})$$

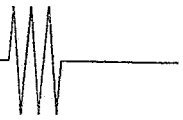
Reducing the length of the emitted pulse will reduce the signal to noise ratio (SNR) of the Doppler signal if it is not possible to increase the amplitude.




The duration of the impulse determines the depth resolution by determining the longitudinal size of the sample volume. The other dimensions are determined by the beam pattern of the transducer.

Consider an impulse of duration $\tau_e$ as illustrated in the figure on the following page. In this figure, the right portion of the horizontal axis represents time, while the left portion represents the energy of the received impulse. The top vertical axis gives the amplitude of the emitted pulse, and the bottom the depth. The impulse propagates in time along a straight slanted line, with the slope being the speed of sound.

Consider a measurement time $T_m$ on the time axis. By drawing a straight line which is perpendicular to the propagation line and



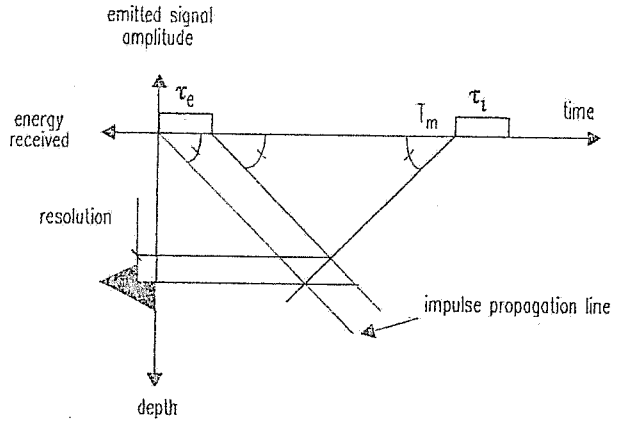
where cste is a constant and $F_a$ is the Fourier transform of the impulse envelope. The frequency spectrum of the above equation generated by a non-moving target is given on the following page by the heavy line, assuming an impulse envelope of the form $\text{sinc}^2(t/\tau_e)$, $\tau_e$ = the length of the emitted pulse.

The movement of the target alters this spectrum in a complex manner. Each spectral component gets shifted according to the Doppler effect by an amount proportional to its frequency. The spectrum becomes, in the case of moving targets:

$$R(t) = \text{cste} \sum_{n=-\infty}^{\infty} [F_A(f_{prf} - f_e) - F_A(f_{prf} + f_e)]\,\delta\left(f - n\left(1 - \frac{2v\cos\theta}{c} f_{prf}\right)\right)$$

This new spectrum is given by the thin lines. A target which is moving at a constant uniform velocity will generate a series of Doppler frequencies. An accurate estimation of the target velocity requires a narrow spectrum, and thus a long emitted pulse. Such an emission will decrease the depth resolution. A compromise between the length of the emitted pulse and the depth resolution is difficult to attain, since the duration of the emitted pulse determines the energy available in the signal. For a given value of emitted pulse energy, decreasing the duration of the pulse means that the amplitude must increase. Unfortunately, it is impossible to increase the amplitude of the emitted pulse beyond a certain threshold without risking the appearance of unwanted phenomena such as cavitation.

which passes through $T_m$, the depth resolution may be determined by the projection of the intersection of these two lines on the depth axis.




The resolution is therefore:

$$Res = \frac{c\tau_e}{2}$$

and corresponds to the maximum attainable resolution for this type of emission. The integration of the demodulated signal over a time period $\tau_i$ reduces the depth resolution, as shown in the figure by the broken line. In the case where $\tau_i = \tau_e$, the energy distribution will be given by a triangle whose base measures $\tau_e c$.

The demodulated Doppler signals must be filtered in order to eliminate the frequency generated by the demodulation process,

## 17 Spectral content of the Doppler echo

The sample volume in which the velocity is measured is of a finite dimension. Each particle which traverses the ultrasonic beam backscatter the acoustic waves for a short time. The duration of the backscattering time depends on the angle of incidence as well as on the particle velocity, and is referred to as the transit time. If the fluid contains small particles possessing different acoustic properties than the fluid, the echo signal amplitude will evolve over time depending on the passage of a group of particles through the sample volume. This results in a modulation of the echo signal which serves to broaden its frequency spectrum. The signal is further modulated by the non-homogeneity of the fluid-particle medium. This spectral broadening depends on the velocity at which the particles traverse the ultrasonic beam. The higher the velocity, the faster the signal will be modulated and its spectrum broadened. Since the Doppler signal is related to the velocity, it is possible to evaluate the effect of the transit time as a function of the Doppler frequency. One of several researchers who studied this effect was Newhouse [2], who estimated the spectral broadening $\delta f_d$ as:

$$\frac{\delta f_d}{f_d} = \frac{k\lambda}{D}\tan\theta$$

where k is a constant between 2 and 3, depending on the ratio of the intensity of the acoustic wave at its center to its intensity near the periphery, $\lambda$ is the wavelength and D is the diameter of the ultrasonic beam. For example, with an emission frequency of 3 MHz ($\lambda$ = 0.5 mm), a transducer diameter of 10 mm and a Doppler an-

which is equal to twice the emitted frequency. The low pass filter cut-off frequency should be as low as possible in order to reduce the noise, but not so low as to degrade the resolution.

Real Doppler signals always contain a certain amount of noise. The cut-off frequency will naturally affect the SNR. There is an optimum value of the product of the bandwidth and the impulse duration which will give the maximum SNR, provided the frequency and temporal characteristics of the noise are known [1]. This value also depends on the characteristics of the filter and the signal to be filtered.

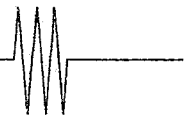
## 18 Theoretical basis of the Doppler frequency estimation

The amplitudes of the echoes reflected by the particles within the flowing fluid are somewhat random in nature, corresponding to the random distribution of the particles in the fluid medium. Thus, the Doppler signals may be treated as random processes, and characterized by different moments. In order to be able to determine the probability of occurrence of this process, one must have access to a great number of actual occurrences of the process. In practice, it is difficult to obtain measurements of the exact same process under the exact same conditions at several different times. Therefore, a temporal average is preferable to an ensemble average. The temporal average and the ensemble average will not be the same unless the process is stationary and the analysis time is very long (tending to infinity). Considering the Doppler process as stationary, the average frequency may be expressed as the normalized first moment, or:

$$\mu_1 = \bar{f} = \frac{\int_{-\infty}^{\infty} fS(f)\,df}{\int_{-\infty}^{\infty} S(f)\,df}$$

where S(f) is the spectral density or probability density of the Doppler signal.

The Doppler frequency calculation algorithm is based on the fact that the inverse Fourier transform of the probability density of a



gle of 45 degrees, the spectral broadening is on the order of 10%.

The spectral broadening created by the modulation of the echo signal amplitude may also be explained based on geometric considerations. The finite dimension of the sample volume implies that each particle contained within it is viewed from a slightly different Doppler angle. This results in a spread of Doppler frequencies corresponding to this small angle change.

As the ultrasonic waves propagate, they encounter different echogenic structures which may create echoes stronger than the echoes from the particles within the fluid. Furthermore, these structures may themselves be moving. Therefore, the echo signal may contain a certain number of stationary and quasi-stationary echoes of low frequency and large amplitude, as well as the echoes from the particles within the fluid at higher frequencies but of smaller amplitudes. The difference between the amplitudes of these two types of signals may be 20 to 60 dB. For the case of moving flow boundaries, the velocity of the wall creates a Doppler effect which must be filtered out. These low frequency components may be eliminated by the wall motion filter. Unfortunately, this hi-pass filter also diminishes the amplitudes of the already weak Doppler signals coming from the particles within the fluid.

# 19 Ultrasonic field

The generation of ultrasonic waves as well as their transformation into an electrical signal is of obvious importance to the quality of the information which may be obtained concerning the flow field.

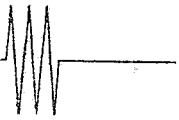
In Doppler echography, the object is not to make use of a plane longitudinal wave, but rather an ultrasonic beam that is as thin as possible throughout the measurement depth. The geometry of the acoustic field generated by the ultrasonic wave determines the lateral resolution. The characteristics of the acoustic field depend on the size and shape of the piezoelectric element for a single element transducer, and on the combination of the individual emissions in the case of a multi-element transducer.

Using Huygen's principle, one may theoretically predict the geometry of the acoustic field. In this approach, the transducer is modeled as a combination of several adjacent point sources, each generating a spherical wave.

For a circular transducer of radius a operating in a piston-like manner, the intensity of the acoustic field along the axis is given by:

$$\frac{I_z}{I_o} = \sin^2\left[\frac{\pi}{\lambda}\left(\sqrt{a^2 + z^2} - z\right)\right]$$

where $I_o$ is the maximum intensity, z is the distance from the transducer and $\lambda$ is the wavelength.



stationary process is equal to the auto-correlation function [3]. The first moment $\mu_1$ may be expressed in terms of the time derivatives of the auto-correlation function at the origin:

$$\bar{f} = \frac{1}{j2\pi} \frac{\frac{d}{dt}R(0)}{R(0)}$$

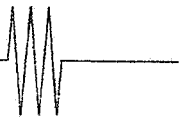
The auto-correlation function is estimated using the complex envelope of the echo signal.

$$D_r(\gamma) = \frac{2J_1(k a \sin\gamma)}{k a \sin\gamma}$$

where $J_1$ is the first order Bessel function of the first kind, and $k = 2\pi/\lambda$ the wave number. This function has roots at $(ka \sin\lambda) = 3.83$, 7.02, 10.17, etc. and defines lobes. The angle of divergence of the main lobe $\gamma$ is given by:

$$\gamma_0 = \sin^{-1}\left(\frac{0.61\lambda}{a}\right)$$

and is approximately 5 degrees. for the above example. The acoustic energy contained in the secondary lobes is always much smaller than that contained in the main lobe. For a circular transducer, the acoustic energy contained in the secondary lobe is 18 dB less than in the main lobe.



The acoustic field generated by a transducer possesses two characteristic regions, separated by the distance of the furthermost maximum of the above function. This distance is given by:

$$Z_0 = \frac{4a^2 - \lambda^2}{4\lambda}$$

If $a^2 >> \lambda^2$, $z_0$ becomes:

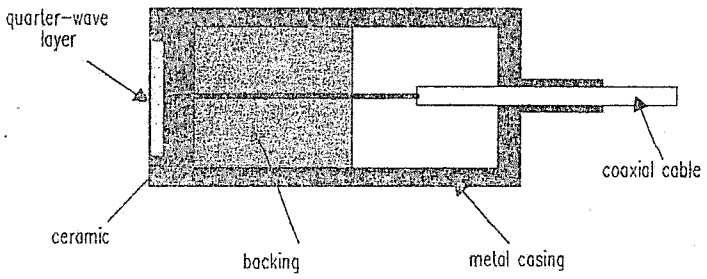
$$Z_0 = \frac{a^2}{\lambda}$$

The zone between the transducer and $z_0$ is called the Fresnel zone, or the near field. In the near field, the intensity oscillates along the axis of the transducer, and the acoustic field is basically cylindrical with the same diameter as the transducer. The zone lying beyond $z_0$ is called the Frauenhofer zone or the far field. In the far field, the intensity of the acoustic field varies as the inverse of the square of the distance from the transducer z, and oscillates in the plane perpendicular to the axis of propagation. For a 5 mm transducer functioning at 4 MHz, the far field begins at a distance of approximately 1.6 cm.

In the far field, the acoustic field may possess intensity lobes as one moves away from the axis of the transducer. The relationship between the acoustic field intensity and the angle off the transducer axis depends on the directivity function:

## 20 Ultrasonic transducers

The material most often used in the construction of ultrasonic transducers is a piezoelectric ceramic. Another material which may be used is the polymer polyvinylidene fluoride (PVDF) which possesses good piezoelectric properties, and has the additional advantages of being more flexible and having a smaller acoustic impedance than ceramic materials. PVDF is, on the other hand, less efficient. With the advent of composite materials [6], ultrasonic transducers have been produced which are as efficient as ceramic materials and which have a small acoustic impedance. They offer the advantage of a better acoustic coupling between the transducer and the medium, as well as the ability to produce a shorter ultrasonic impulse, due to their relatively high coefficient of absorption. A typical design is illustrated below.




The electrodes are positioned so that the ceramic operates in a piston-like mode.

The transfer of energy from the ceramic (medium 1) to the surroundings (medium 3) is determined by the characteristic imped-

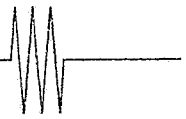


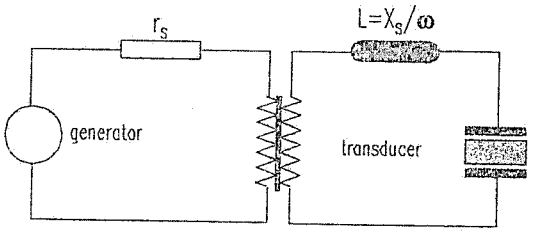
**Table 1: Near field value in mm**
**(c=1500 m/s)**

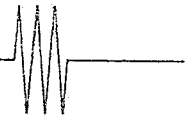
| Frequency Mhz | Transducer diameter in mm | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | 8 | 10 | 12 | 16 |
| 1 | 0.6 | 1.5 | 2.6 | 4.1 | 10.6 | 16.6 | 24.0 | 42.7 |
| 2 | 1.3 | 3.0 | 5.3 | 8.3 | 21.3 | 33.3 | 48.0 | 85.3 |
| 4 | 2.7 | 6.0 | 10.7 | 16.7 | 42.7 | 66.7 | 96.0 | 170.7 |
| 5 | 3.3 | 7.5 | 13.3 | 20.8 | 53.3 | 83.3 | 120.0 | 213.3 |
| 8 | 5.3 | 12.0 | 21.3 | 33.3 | 85.3 | 133.3 | 192.0 | 341.3 |
| 10 | 6.7 | 15.0 | 26.7 | 41.7 | 106.7 | 166.7 | 240.0 | 426.7 |

**Table 2: Directivity in degrees (half-angle)**
**(c=1500 m/s)**

| Frequency Mhz | Transducer diameter in mm | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 2 | 3 | 4 | 5 | 8 | 10 | 12 | 16 |
| 1 | 66.2 | 37.5 | 27.2 | 21.5 | 13.2 | 10.5 | 8.8 | 6.6 |
| 2 | 27.2 | 17.6 | 13.2 | 10.5 | 6.6 | 5.2 | 4.4 | 3.3 |
| 4 | 13.2 | 8.8 | 6.6 | 5.2 | 3.3 | 2.6 | 2.2 | 1.6 |
| 5 | 10.5 | 7.0 | 2.6 | 5.2 | 2.6 | 2.1 | 1.7 | 1.3 |
| 8 | 6.6 | 4.4 | 3.3 | 2.6 | 1.6 | 1.3 | 1.1 | 0.8 |
| 10 | 5.2 | 3.5 | 2.6 | 2.1 | 1.3 | 1.0 | 0.9 | 0.7 |

The electric energy transferred from the generator to the probe depends on their respective electric impedances. Adapting the electric impedance of the transducer to that of the generator using passive elements can optimize the transfer of energy. The reactive component ($x_s$) of the probe impedance ($z_s = r_s + jx_s$) may be eliminated with an inductance of $L = x_s/\omega$. An impedance transformer assures the compatibility of the generator impedance with the corrected probe impedance.





ances z of the two media, defined as:

$$z = \rho c$$

where ρ is the density of the medium and c is the speed of sound.

By placing an additional layer between these two media, the energy transfer may be optimized. The acoustic impedance of this middle layer should be:

$$z_2 = \sqrt{z_1 z_3}$$

and its thickness:

$$e_2 = (2n-1)\frac{\lambda_2}{4}$$

where n is an integer and $\lambda_2$ is the wavelength in the middle layer. This additional layer, called the quarter-wave layer, is used in the construction of most ultrasonic transducers.

The rear part of the transducer (called the absorber or backing) behaves like a shock absorber whose efficiency depends on its acoustic properties. The choice of the material for the backing determines the type of acoustic impulses which may be emitted by the transducer. For a highly absorbent material, most of the energy is absorbed, tending to produce a short emission. For a weakly absorbing material, the energy at the rear of the transducer is returned to the front face, thereby increasing the energy transmitted out into the medium.

# 21 Application software

The application software SIMUL allows the user:

- to simulate the DOP1000 software on a PC
- to visualize all the parameters associated to a binary DOP file
- to convert data values from a binary DOP file in ASCII format

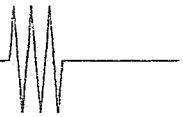
Note: The application software could not be executed on the velocimeter.

## 21.1 Installation of the application software

To install the application software:

- insert the original floppy disk in our PC
- create on your PC a new directory
- copy both files SIMUL.EXE and PEROM.522 located in A:\UTI in the new created directory in your PC

To execute the application software, go to the new created directory in strike SIMUL.



## 21.2 Selecting files

In order to create ASCII files or to visualize the parameters the user must select the files he would like to work with. The menu F1:Get files allows the selection of the files. After pressing this key, two small windows appear. The left window contains the files found in the current selected directory, which name is given under Selected directory. The right windows indicates the user's selected files. The first step in selecting files is to select the directory.

To select the directory, in the Get files menu:

- press F1: Directory
- use the UP and DOWN arrow keys to place the chosen directory inside the selection rectangle located at the top of the displayed window and press ENTER to select it, or
- press F2: Parent directory to go to the parent directory, or
- press F1:Change drive to select an other drive
- press F5:Return when the current selected directory, is displayed in the line above the window.

After selecting the directory, the user can then select the files he would like to work with.

To select the files, in the Get files menu:

- press F2:Switch until the selection rectangle appears in the source files window.

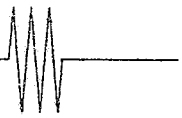
- use the UP and DOWN arrow keys to place a chosen file to the selection rectangle displayed at the top of the source window.
  If the selected file is a binary DOP file the comment found in that file (if any) is displayed in the bottom window.
- press F3:Select to select it
- repeat the selection procedure for all the files that have to be selected.
- return to the previous menu by F5:Exit

To remove a selected file, in the Get files menu:

- press F2:Switch until the selection rectangle appears in the selected files window.
- use the UP and DOWN arrow keys to place a chosen selected file to the selection rectangle displayed at the top of the source window.
- press F4:Remove to remove it
- repeat the procedure for all the files that have to be removed.

## 21.3 Making ASCII files

The velocimeter record data values in a binary format. This format ensures a minimum space requirement. The application software SIMUL, could convert these data in an ASCII format, which may help the user in the analysis of the measured data profiles and other values.



This software extracts the values for a portion of the data profiles and for a given number of profiles. The extracted values may be converted in different units (Hz, mm/s or without unit) and are stored in a new file in ASCII format. The application software also allows to compute the mean profile, the standard deviation and the maximum and minimum values.

The chosen portion is defined by selecting the numbers of a first and a last channel. For each profile corresponds a line of ASCII numbers in a floating point format (xx.x) which are separated by a user's defined character. The extraction procedure is realized for all the profiles inside the user's defined limit.

The converted data are recorded in a new file. This new file has the same name as the source file and have a user's defined extension. Generally this new file, in ASCII format, has a number a columns equal to the number of channels inside the chosen portion of the profile plus a last column which gives the acquisition time of the profile in milliseconds. The number of lines is equal to the number of converted profiles plus a first line which gives the depth of the selected channels in mm. This first line does not appear when the extracted values are flow rate values.

The figure below displays the content of an ASCII file generated by the program SIMUL.

**To create ASCII files**

- start the program by typing SIMUL
- press F2: Analyze data

should be contained in the internal memory during the acquisition, the software indicates the number the last founded profile.

The conversion settings are memorized in a file SIMUL.CFG.

**The conversion parameters**

extension for destination

The converted file name has the same name as the input file name but has a different extension. The extension could be formed of up to 3 characters. These three characters are defined in this field.

extract ...

introduce 0 if you want to extract a data profile (velocity, echo or Doppler energy;

introduce 1 to extract only the flow rate values. The resulting file will give 2 columns, the first giving the flow rate values in the unit contains in the file and the second column the time in ms;

introduce 2 to extract the echo or Doppler energy from a binary DOP files which contains both velocity profile and echo or Doppler energy profile.

In trigger mode an additional column gives the number of the trigger sequence.

floating point character

this parameter defines the character used to separate the integer from the fractional part of the numbers.

character to separate columns

The user can choose between 3 ASCII characters to separate the columns. The choice are:
0 for tabulation

| | | | | | | |
|---|---|---|---|---|---|---|
| 13.1 | 13.5 | 13.8 | 14.2 | 14.6 | 15.0 | 0.0 |
| 74.0 | 88.0 | 97.0 | 97.0 | 94.0 | 2.0 | 1.0 |
| 94.0 | 97.0 | 94.0 | 91.0 | 88.0 | 7.0 | 1.0 |
| 91.0 | 97.0 | 97.0 | 94.0 | 91.0 | 12.0 | 1.0 |
| 94.0 | 97.0 | 97.0 | 91.0 | 88.0 | 17.0 | 1.0 |
| 85.0 | 85.0 | 88.0 | 88.0 | 85.0 | 80.0 | 2.0 |
| 77.0 | 80.0 | 80.0 | 82.0 | 85.0 | 85.0 | 2.0 |
| 62.0 | 80.0 | 91.0 | 88.0 | 85.0 | 90.0 | 2.0 |
| 62.0 | 68.0 | 68.0 | 77.0 | 91.0 | 95.0 | 2.0 |
| 88.0 | 88.0 | 88.0 | 88.0 | 85.0 | 155.0 | 3.0 |
| 77.0 | 82.0 | 82.0 | 82.0 | 80.0 | 160.0 | 3.0 |
| 85.0 | 91.0 | 97.0 | 100.0 | 102.0 | 165.0 | 3.0 |

This line gives the depth of the selected channels in mm. The sound speed value contained in the parameters is used to compute theses values

This column gives the number of the Trigger sequence. This column only exists in trigger mode.

This column gives the time stamp or the time at which the profile was acquired.

- press F1: Get files
- select the desired files to be converted (see Selecting files)
- then press F3: Make ASCII files
- fill or modify the conversion parameters (see below for their definition);
  to select a parameter use the UP and DOWN arrow keys and type the desired value for the parameter; the backspace key will erase a character.
- press F1: Execute to convert the selected files

During the conversion process the software informs the user of the result of the conversion.

Note: If the number of profiles contained in the binary file does not corresponds to the number of profiles that

| | |
|---|---|
| | 1 for space<br>2 for comma |
| character to separate lines | The user can choose between 4 ASCII characters to separate the lines or profiles. The choice are:<br>0 for tabulation<br>1 for space<br>2 for line feed<br>3 for carriage return followed by a line feed |
| Unit | The converted ASCII values can have different unit. If the user selects:<br><br>0: the converted ASCII values will be frequencies in Hz;<br>1: the converted ASCII values will be the velocities component in the direction of the ultrasonic beam in mm/s; the depths are measured in the direction of the ultrasonic beam.<br>2: the converted ASCII values will be the velocities components in the direction of the flow defined by the Doppler angle in mm/s; the depths are measured perpendicularly to the flow axis.<br>3: the converted ASCII values will be the binary values. The offset value on the velocity is taken into account. |
| apply filter | The recorded binary values contained in the source files does not take into account the moving average or median filter. The value of this parameter enables to apply (value=1) or not to apply (value=0) the filter chosen when the measurement was realized. |
| zero values | If the moving average were chosen during the measurement, zero values could be included or rejected. Introducing a value of 0 will include zero values in the computation, and introducing 1 will reject the zero values. |
| first channel | Select the number of the channel from where should begin the conversion. The introduction of the character * will always take the first channel available from the DOP binary file. |

last channel

Select the number of the channel from where should end the conversion. The introduction of the character * will always take the last channel available from the DOP binary file.

first profile

Select the number of the first profile to be converted.The introduction of the character * will always take the first profile of the DOP binary file.

last profile

Select the number of the last profile to be converted. The introduction of the character * will always take the last profile of the binary DOP file.

Compute mean values

If a value of 1 is selected, the ASCII output file will contain only the depth line, the mean data values of all the profiles between «first profile» and «last profile», the standard deviation and the maximum and minimum values of the converted values, and the mean time between profiles.

with legendIf a value of 1 is selected, the ASCII output file will contain the ASCII part of the binary source file plus additional legends.

## 21.4 Extracting I and Q Doppler signals

If the binary DOP file contains I and Q signal, the following parameters are ignored

- extract, automatically select to 0
- Unit, automatically select to 3
- filter, automatically select to 0
- compute mean, automatically select to 0
- with legend, automatically select to 0

The first line of the ASCII output file will contain the depth of the

channel in the direction of the US beam. Odd columns will contain I values and even columns the Q values. The last column will contain the acquisition time of the I and Q signals.

## 21.5 Display of the parameters of a DOP file

The application software could display all the parameters used during the acquisition. These parameters are extracted from the binary DOP file.

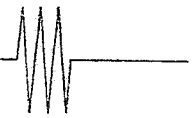
**To display the parameters**

- start the program by typing SIMUL
- press F2: Analyze data
- press F1: Get files
- select the desired files to be converted (see Selecting files)
- then press F2: View parameters
  the UP and DOWN arrow keys could be used to scroll up and down.

The function key F1:Next file allows to display the parameters from the next selected files and the function key F2:Previous from the previous selected files.

Pressing F3:Other files allows to select other files and F5:Exit return to the selection menu

The function key F4:Save allows to create an ASCII file containing the values of all the parameters.



## 21.6 Simulating the velocimeter

The simulation software enables the user to run the software of the velocimeter on a PC computer. This software simulates the DOP1000 and enables the user to visualize measurements in replay mode (cine mode). The simulation software is controlled the same way as the velocimeter.

Note: As no real data are measured, the simulation software displays a fictive profile which has no meaning.

# 22 DOP1000 software installation and update procedure

A internal PC compatible computer controls the velocimeter. This computer works the same way as a normal PC. The operating system of the velocimeter is DR-DOS version 7.0

Normally the software has already been installed and the only thing you should do is to keep the original floppy disk in a safe place!

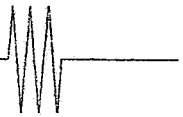
If you need to re-installed the software of the velocimeter, due to a new update for instance, follow the simple procedure below:

- exit the DOP1000 software by pressing Control C (CTRL C)
- place the floppy disk in the velocimeter
- type A:\UPDATE. The update procedure will:
  copy the files HDOP.EXE and PEROM.522 in directory C:\DOP.
  update the analog board if necessary
- check the file AUTOXEC.BAT. The last line should be HDOP

## 22.1 Improving the velocimeter

### Using additional memory

If the velocimeter contains more than 1 Mbytes of memory it is possible to use the extended memory and increase by this mean



the maximum number of profiles that could be recorded.

In order to use the extended memory the velocimeter should create a virtual disk before starting the software HDOP. The DR-DOS operating system contains a software that creates such a virtual disk. To use it, you should add to the CONFIG.SYS file the following line:

DEVICE=C:\NWDOS\VDISK.SYS xxx/E

where xxx is amount of memory used in kbytes.

The software of the velocimeter will recognize the virtual disk and will use it if necessary.

Note: The performances of the velocimeter could be increased by adding the following command to the AUTOEXEC.BAT file.

MODE CON: RATE=32 DELAY=1

This command increase the reaction time of the keyboard.

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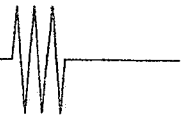
Advances in turbulence VI, Kluwer academic publishers



29 1st International Symposium on Ultrasonic Doppler Methods
for Fluid Mechanics and Fluid Engineering
September 9-11, 1996
Paul Scherrer Institut, 5232 Villigen PSI, Switzerland

# 24 Ultrasonic data

Data from Alan R. Selfridge , IEEE Transac. on Sonic and Ultrasonics, Vol SU-32, No3, May 1985

$V_l$=longitudinal sound velocity [m/s], ρ= density, $Z_l$= acoustic impedance [MRayls=(kg/(sxm$^2$)x10$^6$]

## Solides and Epoxys

| Material | $V_l$ | ρ | $Z_l$ |
|---|---|---|---|
| Aluminium rolled | 6420 | 2.70 | 17.33 |
| Araldite 502/956 20 phe | 2600 | 1.39 | 3.52 |
| Araldite 502/956 50 phe | 2130 | 1.95 | 4.14 |
| Araldite 502/956 90 phe | 1520 | 8.40 | 12.81 |
| Beryllium | 1289 | 1.87 | 24.10 |
| Bismuth | 2200 | 9.8 | 21.5 |
| Brass 70cu 30 Zn | 4700 | 8.64 | 40.6 |
| Brick | 4300 | 1.7 | 7.4 |
| Cadmium | 2600 | 8.6 | 24 |
| Carbon vitreous | 4260 | 1.47 | 6.26 |
| Copper rolled | 5010 | 2.6 | 8.0 |
| Duraluminium 17S | 6320 | 2.79 | 17.63 |
| Epotek 301 | 2640 | 1.08 | 2.85 |
| Fused silica | 5960 | 2.20 | 13.1 |
| Germanium | 5410 | 5.47 | 29.6 |
| Glass pyrex | 5640 | 2.24 | 13.1 |
| Glass quartz | 5500 | 2.2 | 12 |
| Glass silica | 5900 | 2.2 | 13.0 |
| Glucose | 3200 | 1.56 | 5.0 |
| Gold | 3240 | 19.7 | 63.8 |
| Granite | 6500 | 4.1 | 26.8 |
| Indium | 2560 | 7.3 | 18.7 |
| Iron | 5900 | 7.69 | 46.4 |
| Iron cast | 4600 | 7.22 | 33.2 |
| Lead | 2200 | 11.2 | 24.6 |
| Lithium | 7080 | 4.7 | 33.8 |
| Magnesium | 5800 | 1.73 | 10.0 |
| Marble | 3800 | 2.8 | 10.5 |
| Molybdenum | 6300 | 10.0 | 63.1 |
| Nickel | 5600 | 8.84 | 49.5 |

| Material | $V_l$ | ρ | $Z_l$ |
|---|---|---|---|
| Paraffin | 3260 | 21.4 | 69.8 |
| Polyester casting resin | 2290 | 1.07 | 2.86 |
| Porcelain | 5900 | 2.3 | 13.5 |
| PVF2 | 2380 | 1.79 | 4.2 |
| Quartz x cut | 5750 | 2.65 | 15.3 |
| Rubidium | 1260 | 1.53 | 1.93 |
| Salt crystalline x direction | 4.78 | 2.17 | 10.37 |
| Sapphire, aluminium oxide | 11.15 | 3.98 | 44.46 |
| Scotch tape 2.5 mils thick | 1900 | 1.16 | 2.08 |
| Silicon very anisotropic approx | 8430 | 2.34 | 19.7 |
| Silicon carbide | 6660 | 13.8 | 91.8 |
| Silicon nitride | 11.0 | 3.27 | 36 |
| Silver | 3600 | 10.6 | 38.0 |
| Silver epoxy | 1900 | 2.71 | 5.14 |
| Steel mild | 5900 | 7.8 | 46.0 |
| Steel stainless | 5790 | 7.89 | 45.7 |
| Stycast | 2220 | 1.19 | 2.64 |
| Tantalum | 4100 | 16.0 | 54.8 |
| Teflon | 1390 | 2.14 | 2.97 |
| Tin | 3300 | 4.48 | 27.3 |
| Titanium | 6100 | 4.48 | 27.3 |
| Tracon | 2970 | 1.62 | 4.82 |
| Tungsten | 5200 | 19.4 | 101.0 |
| Uranium | 3400 | 18.5 | 63.0 |
| Vanadium | 6000 | 6.03 | 36.2 |
| Wood cork | 500 | 0.24 | 0.12 |
| Wood pine | 3500 | 0.45 | 1.57 |
| Zinc | 4200 | 7.0 | 29.6 |
| Zinc oxyde | 6400 | 5.68 | 36.4 |

## Plastics

| Material | $V_l$ | ρ | $Z_l$ |
|---|---|---|---|
| ABS | 2230 | 1.03 | 2.31 |
| Acrylic plexiglas | 2750 | 1.19 | 3.26 |
| Acrylic plexiglas M1-7 | 2610 | 1.18 | 3.03 |
| Adiprene | 1680 | 1.16 | 1-94 |
| Bakelite | 1590 | 1.40 | 3.63 |
| Cellulose Butyrate | 2140 | 1.19 | 2.56 |
| Delrin | 2430 | 1.42 | 3.45 |
| Ethyl vinyl acetate | 1800 | 0.94 | 1.69 |
| Neoprene | 1600 | 1.31 | 2.1 |
| Mylar | 2540 | 1.18 | 3.00 |

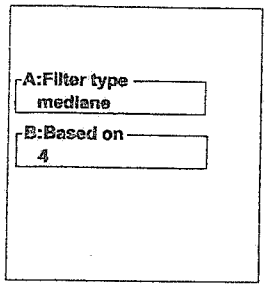
| Material | $V_l$ | ρ | $Z_l$ |
|---|---|---|---|
| Nylon 6/6 | 2900 | 1.7 | 4.93 |
| Polycarbonate | 2270 | 1.22 | 2.77 |
| Polyethylene | 1950 | 0.90 | 1.76 |
| Polyethylene high density | 2430 | 0.96 | 2.33 |
| Polyethylene low density | 1950 | 0.92 | 1.79 |
| Polypropylene | 2740 | 0.88 | 2.40 |
| Polystyrene | 2320 | 1.04 | 2.42 |
| Polyurethane | 1700 | 1.10 | 1.8 |
| PVC | 2380 | 1.38 | 3.27 |
| Vinyl rigid | 2230 | 1.33 | 2.96 |

## Liquides

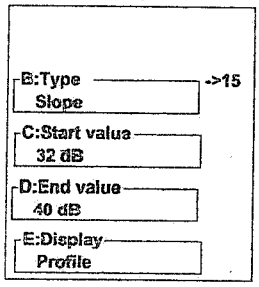
| Material | $V_l$ | ρ | $Z_l$ |
|---|---|---|---|
| Acetate | 1270 | 0.871 | 1.02 |
| Acetone | 1180 | 0.891 | 1.05 |
| Alcohol ethanol | 1207 | 0.79 | 0.95 |
| Benzene | 1295 | 0.87 | 1.12 |
| Benzol | 1330 | 0.878 | 1.16 |
| Carbipol | 1460 | 0.988 | 1.431 |
| Chloroform | 987 | 1.49 | 1.47 |
| Ethanol amide | 1724 | 1.018 | 1.755 |
| Ethyl ether | 985 | 0.713 | 0.703 |
| Freon | 716 | 1.57 | 1.12 |
| Gallium at 30 degrees | 2870 | 6.09 | 17.5 |
| Gasoline | 1250 | 0.803 | 1.00 |
| Glycerin | 1904 | 1.26 | 2.34 |
| Glycol | 1480 | 1.019 | 1.511 |
| Honey | 2030 | 1.42 | 2.89 |
| Kerosene | 1324 | 0.81 | 1.072 |

| Material | $V_l$ | ρ | $Z_l$ |
|---|---|---|---|
| Mercury at 25 degrees | 1450 | 13.5 | 19.58 |
| Oil baby | 1430 | 0.821 | 1.17 |
| Oil corn | 1460 | 0.942 | 1.42 |
| Oil mineral | 1440 | 0.825 | 1.19 |
| Oil olive | 1445 | 0.918 | 1.32 |
| Oil SAE 20 | 1740 | 0.87 | 1.51 |
| Oil silicon | 960 | 0.818 | 0.74 |
| Oil transformer | 1390 | 0.92 | 1.28 |
| Trichlorethylene | 1050 | 1.05 | 1.1 |
| Water at 20C | 1480 | 1.00 | 1.483 |
| Water at 25C | 1496 | 0.998 | 1.494 |
| Water at 30C | 1509 | 1.00 | 1.509 |
| Water at 60C | 1550 | 1.00 | 1.55 |
| Water salt 10% | 1470 | | |
| Water salt 20% | 1600 | | |
| Water sea at 25C | 1531 | 1.025 | 1.569 |

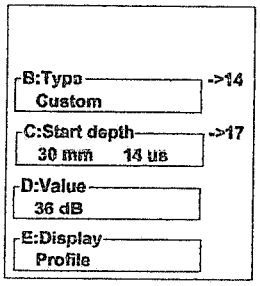
13
Filter menu



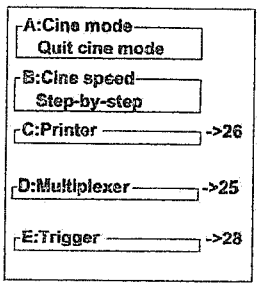

14
TGC Slope



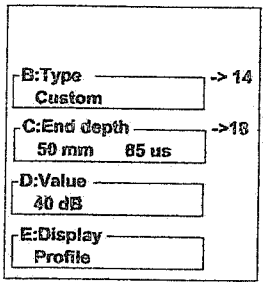

15
TGC Custom 1



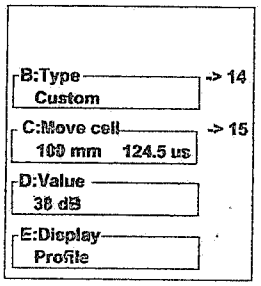

16
Utilities



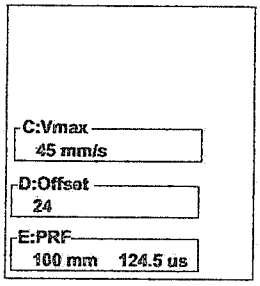

17
TGC Custom 2



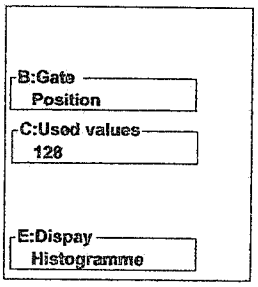

18
TGC Custom 3



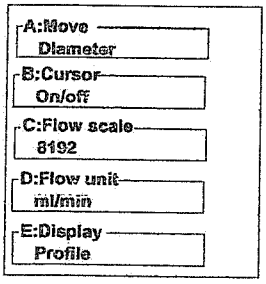

19
Velocity



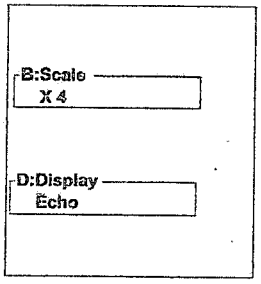

20
Statistic



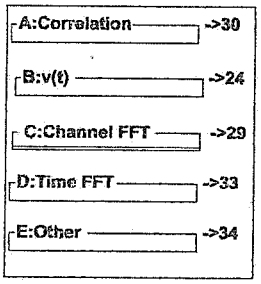

21
Flow



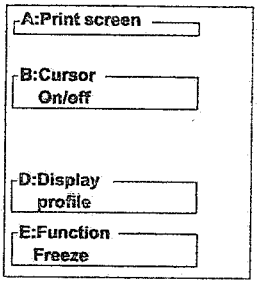

22
Display scale




23
Other display




24
V(t)



# 25 Table of available menus

1
Main menu

- A:Settings -> 2
- B:Cursor -> 9
- C:Disk -> 10
- D:Utilities ->16
- E:Fonction Freeze

2
Settings

- A:Parameters -> 3
- B:Filter ->13
- C:Compute -> 8
- D:TGC -> 14
- E:Velocity -> 19

3
Parameters

- A:Define -> 4
- B:Define all
- C:Save -> 7
- D:Recall -> 7
- E:Default

4
Parameters def. 1

- A:NEXT -> 5
- B:Start at 0.3 mm 0.4 us
- C:Resolution 0.3 mm 0.4 us
- D:Sensitivity medium
- E:PRF 100 mm 124.5 us

5
Parameters def. 2

- A:NEXT ->6
- B:Power medium
- C:Frequency 6 MHz
- D:Burst length 8 cycles
- E:Prf/profile 128

6
Parameters def. 3

- A:NEXT ->31
- B:Doppler angle 60 degrees
- C:Sound speed ->32
- D:Unit us axis
- E:Max gates auto

7
Parameters memo.

- B:Do save
- C:Do recall

8
Display

- A:Profile
- B:Echo -> 22
- C:Energy ->22
- D:Flow
- E:Other ->23

9
Cursor

- A:Flow section ->21
- B:Cursor on/off
- C:Move Up/Down
- D:Tracking on
- E:Statistic -> 20

10
Disk

- A:File -> 11
- B:Directory -> 12

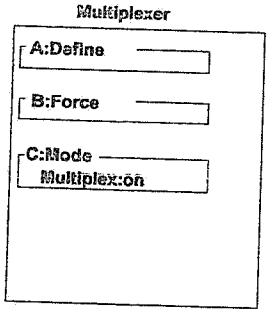
11
Disk File

- A:Store
- B:Recall
- C:Delete
- D:Auto record
- E:Get info

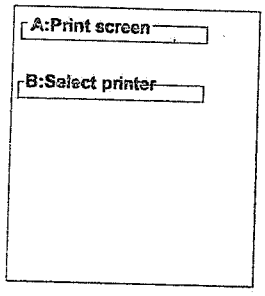
12
Disk Directory

- A:Remove
- B:Change drive B
- C:Save

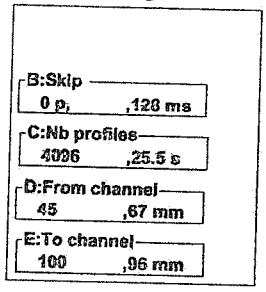
25
Multiplexer



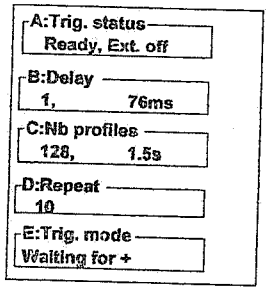

26
Printer



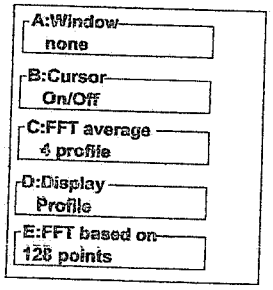

27
Memory



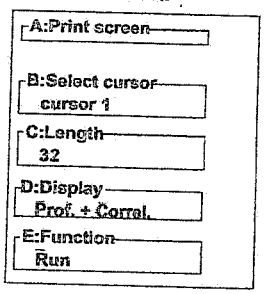

28
Trigger



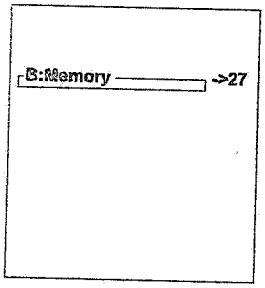

29
Channel FFT



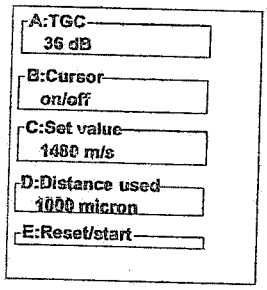

30
Correlation



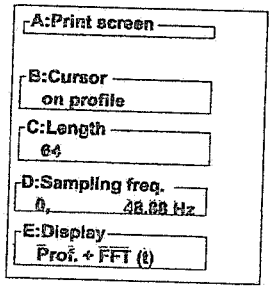

31
Parameters def. 4



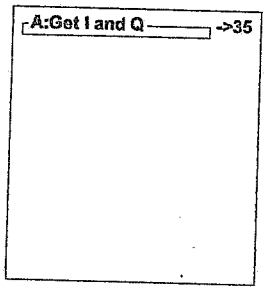

32
Sound speed



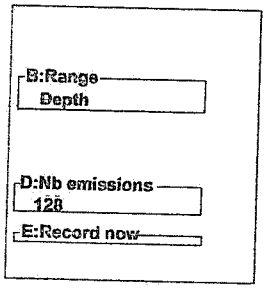

33
Time series FFT




34
Other




35
Get I and Q



# 26 Technical specifications

## Model: 1032

### Emission

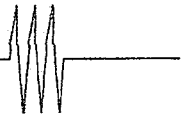
| | |
|---|---|
| Emitting frequency | 8 MHz, 4 MHz, 2 MHz and 1 MHz |
| Emitting power | Instantaneous maximum power for setting:<br>low = 0.5 Watt<br>medium= 5 Watt<br>high= 35 Watt |
| Number of emitted cycles | 2, 4 or 8 cycles |
| Pulse repetition frequency | 248 selectable values between 2040 µs and 64 µs, step of 8 µs |

### Reception

| | |
|---|---|
| Number of channels | variable between 224 and 10, step of 2 channels |
| Acquisition window | defined by the position of the first channel, movable by step of 1µs |
| Amplification (TGC) | |
| Slope mode | exponential amplification between two defined depth values<br>value at both depth variable between -40 and +40 dB |
| Custom mode | uniform amplification in a cell defined by the user between -40 and +40 dB<br>position and size of the cell variable by step of 3 mm (c=1500 m/s) |

### Resolution

| | |
|---|---|
| Lateral resolution | defined by the acoustical characteristics of the transducer |
| Longitudinal resolution | 1.2µs or 0.9 mm, minimum values<br>(c=1500 m/s, approximate value, defined at 50% of the received) |
| Display resolution: | distance between the center of each sample volume<br>0.375, 0.75 and up to 24 mm by step of 0.75 mm (c=1500 m/s) |
| Velocity resolution | maximum = 45.77 mm/s; minimum = 0.045 mm/s (c=1500 m/s)<br>Doppler frequency given in a signed byte format. |



## Ultrasonic processor

| | |
|---|---|
| Doppler frequency | computation based on a correlation algorithm<br>RF demodulated signals filtered by low-pass (220 kHz) followed by an IIR high-pass filter (cutoff frequency depending on PRF) |
| Number of emission / profile | between 8 and 512, any values |
| Detection level | 5 levels of the received Doppler energy may disable the computation |
| Acquisition time / profile | minimum: about 3 ms |
| filters on profiles | real time moving average:<br>based on 2 to 1024 profiles<br>zero values included or rejected<br>real time median, based on 2 to 32 profiles |
| Maximum velocity | 5.86 m/s for bi-directional flow<br>11.72 m/s for uni-directional flow (for 1 MHz (c=1'500 m/s)<br>variable positive and negative velocity range. |

## Memory

| | |
|---|---|
| Internal memory | variable size, memorization from 16 to 32768 profiles |
| Disk | recording of the data profiles and parameters on a 3 1/2" floppy.<br>or on hard disk<br>DOS compatible format |
| Configuration parameters | 5 saved configurations |

## Running mode

| | |
|---|---|
| Computation and display | velocity profile<br>Doppler energy<br>echo modulus<br>velocity profile with echo modulus or Doppler energy<br>flow versus time (maximum scale between 1 ml/min and 16384 l/min)<br>velocity versus time<br>histogram<br>Power spectrum of one gate<br>FFT of a time series of velocities<br>intercorrelation between 2 gates |
| Statistics | computation in real time of the mean value, standard deviation and histogram of the velocities located in a user's defined portion of the velocity profile |

| | |
|---|---|
| Cursor | display the velocity and depth value, tracking mode (follow the displayed curve)<br>definition of a circular section used for the flow rate calculation (integration of the velocity profile). |
| Trigger | by external signal, change in the logic state (TTL/CMOS level)<br>by keyboard action<br>selectable delay between 1 and 16384 profiles<br>selectable repeated acquisition procedure of bloc of profiles<br>automatic recording procedure |
| Utilities | freeze/run mode<br>print screen on printer or on TIFF file |
| Velocity component | automatic computation of the projected velocity component |
| Replay mode | replays a recorded measure from the disk |

## Others

| | |
|---|---|
| Power supply | 220 VAC 50 - 60 Hz |
| Humidity | =< 80% |
| Temperature | 5 - 35 degrees |
| Sizes | 48x42x17 cm |
| Weight | 13 Kg |

## Options

External keyboard

Multiplexer for 10 probes

Sound speed measuring unit

Ethernet adaptor

**Depths and velocities computed in the direction of the ultrasound beam**
**Specifications are subject to change without previous notice**

# A The sound speed measuring unit

The unit allows to measure the sound speed in a liquid by measuring with precision the time that is taken by an ultrasonic burst to propagate over a define distance.

## A.1 Before using it you should first:

- Install the probe.
  Any DOP1000 probes having an external diameter of 8.3mm could be installed in the unit.
  To install it, put a little silicon grease on the probe and introduce it slowly in a rotation movement.

- Install the micrometer
  If not already installed, do the same way as for the probe, and fixe it with the screw located at the bottom of the unit.
  CAUTION: Do not screw on the screw strongly!

- Fill up the unit with the liquid up to the top.

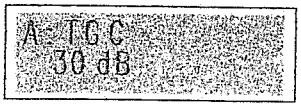
## A.2 Starting the measurement

- Set the velocimeter with the correct working frequency (frequency of the used probe)
- Go to the sound speed measuring menu by pressing from the main menu:

  - A:Settings
  - A:Parameters

- A:Define
- A:Next
- A:Next
- C:Sound speed

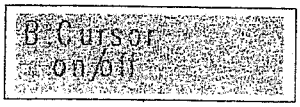
The velocimeter displays the received echo. You should set the TGC gain in order to remove any saturation. To do this:




- press A:TGC
- then use the UP and DOWN keys to select the desired value of the TGC.
  Reducing the emitting power may be necessary!

You should see the echo from the end of micrometric screw.

- Place the cursor in the middle position of the echo. To do this:




- press B:Cursor
- then use the UP and DOWN keys to move the cursor

- You must then define the distance used to measure the time of fly of the ultrasonic burst. This distance must be set in order to keep the cursor inside the echo of the micrometric screw when this screw is moved. The level of the echo should vary no more than 50%. In most cases a distance of 1 millimeter is a good choice.

- You should then start the measurement process. To do this:


- press E:Reset/start
  The cursor window displays a ? in front of the mea-

sured value.
- then turn slowly the micrometric screw exactly over the defined distance, the distance given inside the D key.

- The displayed value in the cursor window is the measured sound speed value.

- The measured value could then be introduced in the DOP1000 parameter. To do this:


- press C:Set value
- then press ENTER and input the measured sound speed value.

Note: It is suggested to realize many measurements for different positions of the cursor and for different values of the measuring distance. A statistical value could then be computed.

## A.3 Cleaning the sound speed measuring unit

It is recommended to clean the unit after each use. The transducer and the micrometric screw should be removed, cleaned and dried. The micrometer could be re-installed in the unit after cleaning.

# B The multiplexers

## B.1 Software installation

In order to use the multiplexer you should first install the software that will control it. This software is contained in the floppy disk delivered with the multiplexer (or the velocimeter if delivered at the same time).

In order to install this software follow the simple procedure below:

- exit the DOP1000 software by pressing Control C (CTRL C)
- place the floppy disk in the velocimeter
- type A:\UPDATE. The update procedure will:
  copy the files HDOP.EXE and PEROM.522 in directory C:\DOP.
  update the analog board if necessary
- check the file AUTOXEC.BAT. The last line should be HDOP

## B.2 Hardware installation

The next installation procedure is to connect the multiplexer to the velocimeter. To do it:

- connect the transmission cable coming out the multiplexer to the RS232 input of the velocimeter;
- connect the multiplexer power supply;
- connect the output of the multiplexer marked OUT to the transducer input of the velocimeter;

- connect the transducer to the inputs of the multiplexer marked IN1 and IN2 etc.

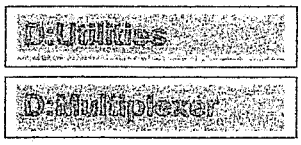
## B.3 Enabling the multiplexer

The multiplexer is controlled by the velocimeter by means of the RS232 serial port. The software enables acquisition procedures based on defined numbers of profiles acquired from each transducer connected to the multiplexer.

When the multiplexer is activated, the acquisition procedure follows these steps:

- acquire the defined number of profiles on the first transducer,
- then switch to the next transducer,
- acquire the defined number of profiles on this next transducer,
- If the number of profile of the next transducer is 0 or the last transducer have been acquired, switch back to the first transducer.
  otherwise repeat the 2 last steps.

In order to enable the multiplexer:




- from the main menu select the Utilities menu by pressing the D key.
- select the Multiplexer menu by pressing the D key.

A:Define

- Define the number of profiles that should be acquired by pressing the A key. A window is displayed in the center of the screen.

- use the arrow keys UP and DOWN to move the pointer to the channel that must be defined.
- select the channel by pressing SELECT. The value of the number of profiles that corresponds to that channel is than surrounded by a rectangle;
- modify the value by using the UP and DOWN arrow keys or by pressing ENTER return if an external keyboard is connected to the velocimeter;
- memorize the modification and enable the selection of an other channel by pressing SELECT;
- when all the desired channel have been setup, leave the menu by pressing CANCEL.

C:Mode multiplex: on

- select the multiplexer mode by pressing the C key and then the UP and DOWN arrow keys.

When the multiplexer is enabled the status window displays the number of the active transducer.

Note: An acquisition in multiplex mode could be used in conjunction with the trigger mode. In such a case the first transducer is always selected after the trigger signal and the defined number of profiles for the first

transducer will be acquired before switching to the next transducer.

B:Force

The velocimeter allows to the user to select only one of the connected transducer without enabling the multiplex process. This is realized through the key B:Force.

To force the selection of one transducer, from the multiplexer menu:

- press B:Force
- then use the UP and DOWN keys to select the transducer.
- press CANCEL to exit and validate the selection.

Note: This function allows to visualize the data profiles on all the connected transducers. It also should be used to check if the current settings are correct as the settings are the same for all transducers.

## B.4 Structure of a record in multiplex mode

When the multiplexer is enabled, each recorded profile contains a word which indicates the transducer attached to the corresponding profile. The position of this word inside a profile pattern is indicated by the table below

NB_PRO is the number of bytes used by each profile (constant) which is given by the word located at offset 104 in the table of the binary parameters.

**Structure of one profile**

| offset | description |
|---|---|
| 0 | These bytes give the coded Doppler frequency, the coded modulus or the coded Doppler energy. |
| NB_PRO - 10 | word reserved for the multiplex mode.<br>bit 0:0 if multiplexer disabled<br>1 if multiplexer enabled<br>bit 1:1 if selection is forced on a transducer<br>bit 2-11:number of the associated transducer (1...) |
| NB_PRO - 8 | 4 bytes that give the flow rate value in the selected flow rate unit (ml/min or l/min). |

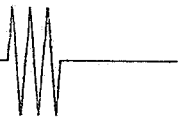
## B.5 Extracting ASCII values from a binary data file

The application software SIMUL, which could convert the data in a ASCII format, helps the user in the analysis of the measured velocity profiles and other values.

If the multiplexer was enabled during the acquisition the conversion program adds an ASCII column at the far right. This column indicates the number of the associated transducer attached to the

## B.6 Technical specifications

| | |
|---|---|
| Number of input channels | 10 (for DP0610), 4( for DP0604) |
| Switching time on to off | 0.1 ms |
| Switching time off to on | 0.5 ms |
| Contact resistance | 0.2 ohm |
| Maximum switching rate | 10 Hz (recommended) |
| Life expectancy | $10^9$ cycles (approximate value) |
| Power supply input | 9 Volt DC |
| Operating temperature | 10-40 degrees |



data found in the line. The figure below gives an example of such a conversion for an acquisition using also the trigger mode.

Example of an ASCII conversion in multiplex mode

| | | | | | | |
|---|---|---|---|---|---|---|
| 13.8 | 14.2 | 14.6 | 15.0 | 0.0 | 0.0 | 0.0 |
| 97.0 | 97.0 | 94.0 | 2.0 | 18.2 | 1.0 | 1.0 |
| 94.0 | 91.0 | 88.0 | 7.0 | 18,22 | 1.0 | 1.0 |
| 97.0 | 94.0 | 91.0 | 12.0 | 18,24 | 1.0 | 1.0 |
| 97.0 | 91.0 | 88.0 | 17.0 | 18,26 | 1.0 | 1.0 |
| 88.0 | 88.0 | 85.0 | 80.0 | 18,28 | 1.0 | 1.0 |
| 80.0 | 82.0 | 85.0 | 85.0 | 18,30 | 1.0 | 1.0 |
| 91.0 | 88.0 | 85.0 | 90.0 | 18,32 | 1.0 | 2.0 |
| 68.0 | 77.0 | 91.0 | 95.0 | 18,34 | 1.0 | 2.0 |
| 88.0 | 88.0 | 85.0 | 155.0 | 33,42 | 2.0 | 2.0 |
| 82.0 | 82.0 | 80.0 | 160.0 | 33.44 | 2.0 | 2.0 |
| 97.0 | 100.0 | 102.0 | 165.0 | 33.46 | 2.0 | 2.0 |

This line gives the depth of the selected channels in mm. The sound speed value contains in the parameters is used to compute theses values

This column gives the number of the associated transducer when the multiplexer is enabled. It is always the last column

This column gives the number of the Trigger sequence. This column only exist in Trigger mode.

This column gives the time stamp or the time at which the profile was acquired.

For more information about the application software please consult chapiter 21 of the DOP1000 User's manual.