DRAFT EDITION

UVP Monitor

Model UVP-DUO

With

Software Version 3

User's Guide

MET-FLOW

Release 5

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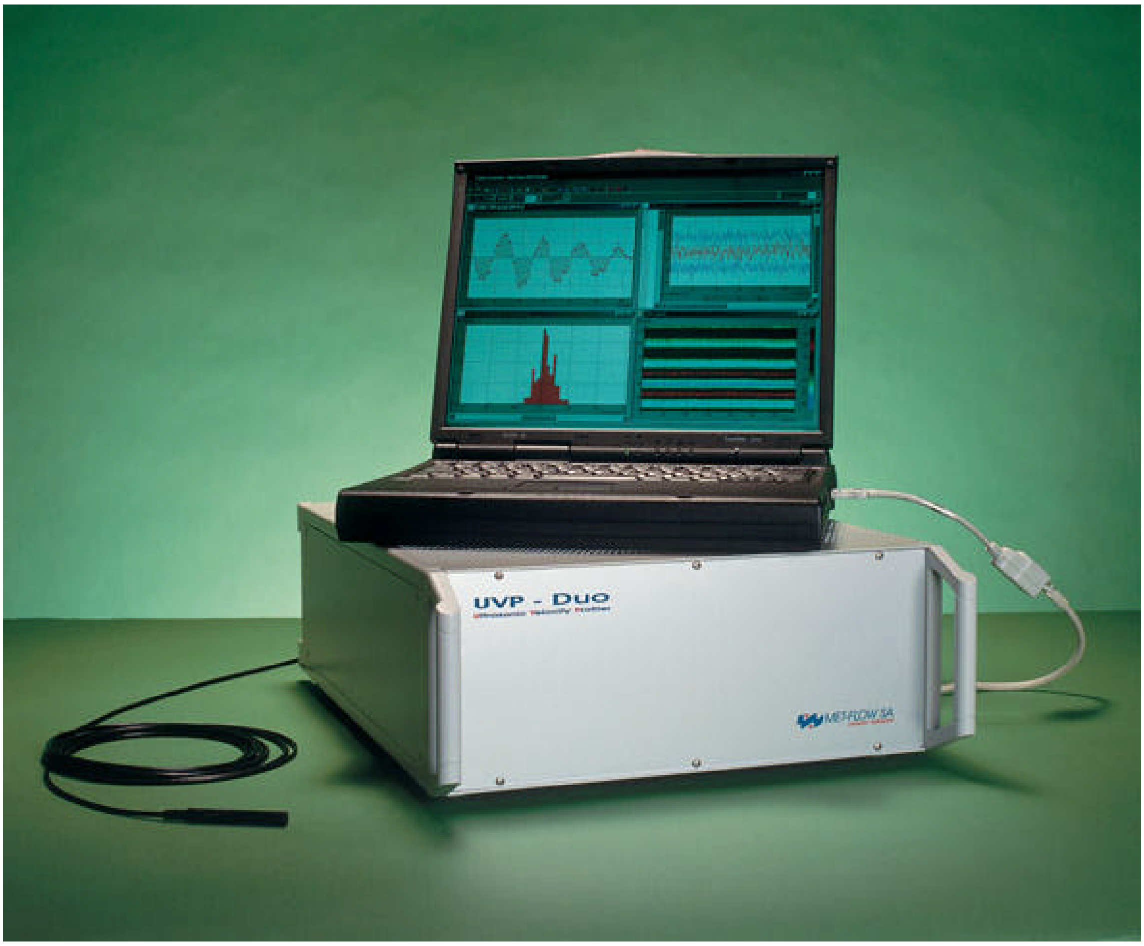

UVP Monitor Model UVP-DUO
With Software Version 3

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1. Nomenclature

For ease of reference, we collect and define here the symbol used throughout this User's Guide.

Symbol	Unit	Description
c	m/s	Sound velocity
$C_{Doppler}$	Hz	Doppler coefficient
C_{sound}	m	Sound speed coefficient (= *l/2*)
D	m	US (ultrasonic) transducer active diameter
d_{ch}	m	Channel distance
f_D	Hz	Doppler shift frequency
f_0	Hz	Basic frequency of ultrasound
F_{prf}	Hz	Pulse repetition frequency
N	m	Near-field distance of a US transducer
N_{ch}	1	Number of measured channels
N_{DU}	1	Number of Doppler units (from 10 to 2048)
N_{rep}	1	Number of profile measurement repetitions for complete profile measurement
p	bar	US acoustic pressure
p_0	bar	Reference on-axis acoustic pressure
P_{max}	m	Maximum measurable depth
R	1	Reflected US intensity
T	1	Transmitted US intensity
T_{DP}	s	Data processing time for a complete profile
T_{meas}	s	Measuring time (for a single profile)
T_{prf}	s	Time corresponding to F_{prf} ($T_{prf} = 1/F_{prf}$)
T_{samp}	s	Sampling time (time between stored profiles)
T_{SI}	s	Storing interval (time added to measuring time)
v	m/s	Velocity component into transducer axis
V	m/s	Liquid velocity component
v_{range}	m/s	Maximum measurable range of on-axis liquid velocity component
Δv	m/s	Velocity resolution
ΔT	s	Time resolution (measurement time for a single profile)

Symbol	Unit	Description
w	m	Channel width
W	m	Measurement window length
W_{end}	m	Measurement window end
W_{start}	m	Measurement window start
x	m	Spatial position
z	m	On-axis co-ordinate of US beam
Z	$kg\ m^{-2}s^{-1}$	Acoustic impedance [Ray]
α	1	Absorption coefficient
γ_0	deg	US beam divergence half-angle
θ	deg	US wave incidence angle to normal
λ	m	Wavelength of ultrasound
ρ	kg/m^3	Material density
τ	s	Time between ultrasound emission and echo detection

2. Introduction

2.1 Ultrasonic Velocity Profile measurement

The UVP (Ultrasound Velocity Profile) represents both a method and a device for measuring an instantaneous velocity profile in liquid flow along the ultrasonic beam axis by detecting the Doppler shift frequency of echoed ultrasound as a function of time.

Since each UVP transducer can measure one projection of a complete flow field, simultaneous measurement with several transducers makes complete measurement of the flow field possible.

Due to the propagation properties of ultrasound and to the analysis of its frequency information content, the following advantages over many other conventional methods can be cited:

- The ultrasound transducer can be placed outside a containing wall, thus avoiding the introduction of any disturbance to the flow field, or permitting application to an existing facility. It may also be possible to place a transducer behind an obstacle in a flow.
- Since the transducer is rather small (typically 8 mm diameter), it can also be placed inside the flow while generating only a very small disturbance of measured flow field.
- It can be used with opaque fluids such as dirty wastewater, liquid metals or chemical agents, to which optical methods like LDA or flow visualisation cannot be applied.
- Since it measures a velocity profile along a line, both directly and instantaneously, the measuring time can be largely reduced. This also enables one to measure a multi-dimensional field of fluid flow.
- Since it can detect the direction of flow (sign of Doppler shift) at each position, a *true* velocity vector can be determined.
- Since the Doppler shift frequency is directly related to the velocity value, the UVP does not require a calibration procedure.

No complex ultrasound beam-forming system is required between the transducer and the main measurement body, which results in ease of handling of the transducer. The only required condition is that the tested fluid should contain a sufficient amount of suspended small seeding particles, on which the ultrasound echo originates.

2.2 Applicability of UVP

The UVP can be used with various liquids over a wide range of flow configurations. The parameters of the UVP are designed mainly for water, since water is the most common fluid medium. Furthermore, the UVP can be used in single-phase fluid flows which are opaque (such as liquid metal, chemical agents, food materials or synthetic coolants) and to which conventional methods of velocity measurements cannot be applied. Due to properties of ultrasound propagation, however, great care has to be taken in multi-phase and multi-component flows - even in basic gas-liquid two-phase flow.

3. Principles of UVP operation

3.1 UVP principles

3.1.1 Functional principles of UVP

Principles of UVP operation are described on an example of flow with free surface.

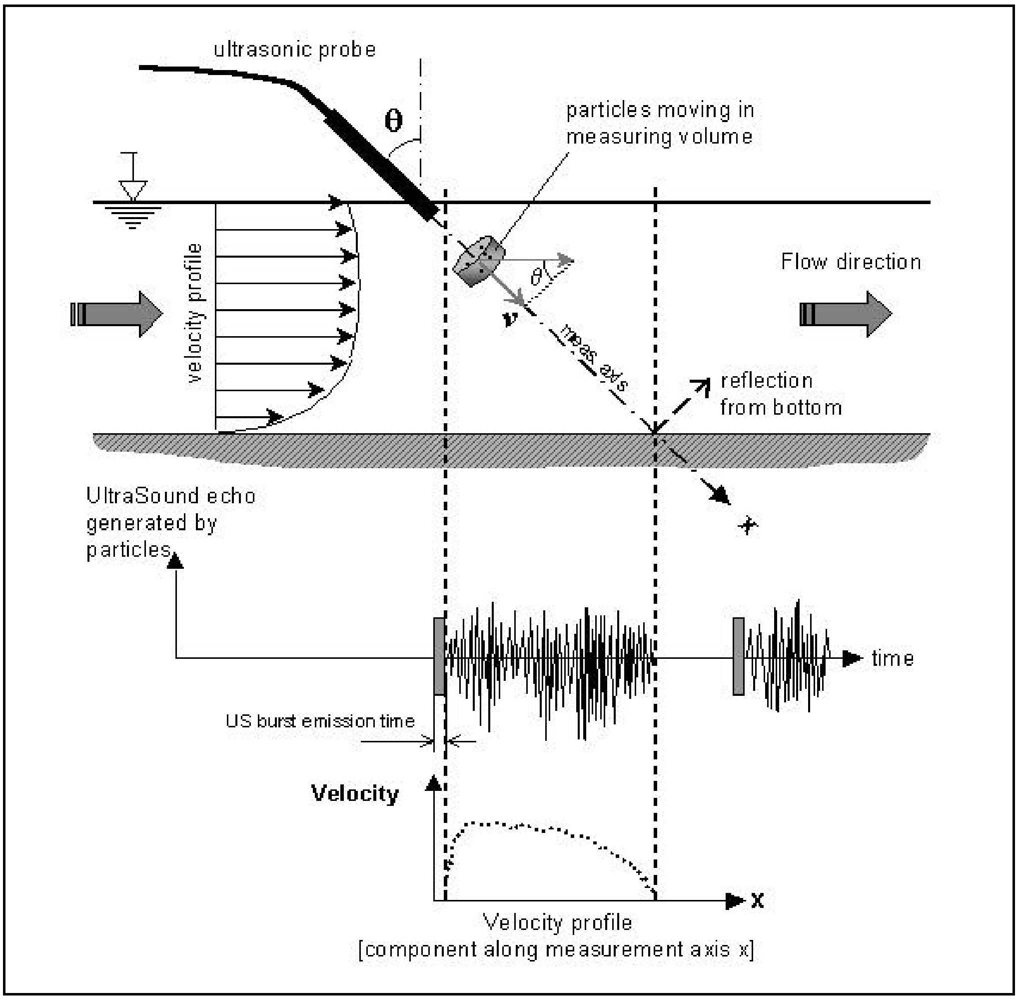


Figure 1 - Schematic picture of UVP velocity profile measurement on a flow with free surface.

An ultrasonic transducer transmits a short emission of ultrasound (US), which travels along the measurement axis Lm, and then switches over to receiving ('listening'). When the US pulse hits a small particle in the liquid, part of the US energy scatters on the particle and echoes back. The echo reaches the transducer after a time delay

$$t = \frac{2x}{c}$$

where t time delay between transmitted and received signal [s]
x distance of scattering particle from transducer [m]
c speed of sound in the liquid [m/s]

If the scattering particle is moving with non-zero velocity component into the acoustic axis L_m of the transducer, Doppler shift of echoed frequency takes place, and received signal frequency becomes ‘Doppler-shifted’:

$$\frac{v}{c} = \frac{f_d}{2f_0}$$

where v velocity component into transducer axis [m/s]
c sound velocity in liquid [m/s]
f_d Doppler shift [Hz]
f_0 transmitting frequency [Hz]

Note *Careful reader might ask, where does the ‘2’ in denominator come from? The classical Doppler shift formula considers a moving source of oscillations, and does not include ‘2’. In our case, both source of oscillations (transducer) and observer (also the transducer) are stationary, and the reflector moves. One Doppler shift is created by relative movement of reflector to source, and additional Doppler shift is created by relative movement of reflector to observer. Hence, twice as high Doppler shift results.*

From the Equation above, v can be expressed as

$$v = \frac{f_d}{\frac{2f_0}{c}} = f_d \cdot \frac{l}{2}$$

where λ wavelength of ultrasound in medium [m] :

$$l = \frac{c}{f_0}$$

Note: *It would be more logical to associate the ‘2’ in denominator with f_d instead of l, but for reasons of continuity we will follow the previous versions of UVP Manual. For the same thing, see also the definition of Sound speed coefficient.*

If UVP succeeds to measure the delay t and Doppler shift f_d it is then possible to calculate both position and velocity of a particle. Since we presume that scattering particles are small enough to follow the liquid flow, we can also presume that UVP Monitor has established the fluid flow component in the given space point.

The basic feature of UVP Monitor is the ability to establish the velocity in many separate space points along measurement axis.

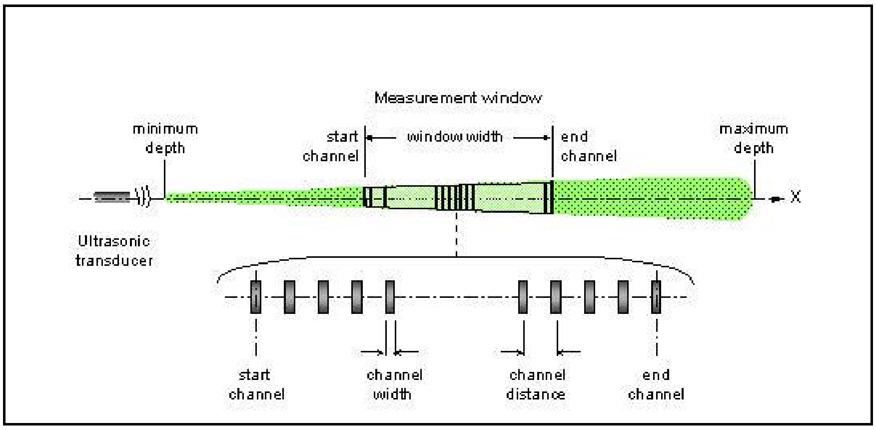


Figure 2 - Illustration of terms connected with 'measuring window'.

Figure 2 gives a graphic illustration of the measurement window, channel distance, starting depth, maximum depth, etc.

Please note that channel position is defined as position of channel centre.

3.1.2 Channel width

This is the width of a measurement volume and hence determines the spatial resolution. Channel width is given by formula

$$w = c\,\frac{n}{2\,f_0} = \frac{n\,\lambda_0}{2}$$

where w channel width [m]
c sound velocity [m/s]
n number of cycles per pulse
f_0 transmitting frequency [Hz]
λ_0 wavelength of ultrasound

(In the formula, 2 in denominator means that once the pulse has reached one end of the measured cylinder it has to cover twice the distance to the other cylinder end to come back at the same point.)

For UVP Monitor, the most frequently suggested number of cycles per pulse to optimise echo vs. spatial resolution is 4. With transmitting frequency 4 MHz and sound velocity in water 1 480 m/s, the minimum theoretical measurable channel width would be 0.74 mm. However, Met-Flow transducers can generate a minimum of 2 cycles per pulse.

Why is channel width only one half of the US burst length and not the total length (see previous Equation)? Consider the following Figure 3, illustrating a 4-wavelength burst travelling through a theoretical measurement volume of 2 wavelengths set against transducer face (no transfer time from volume to transducer in receiving mode):

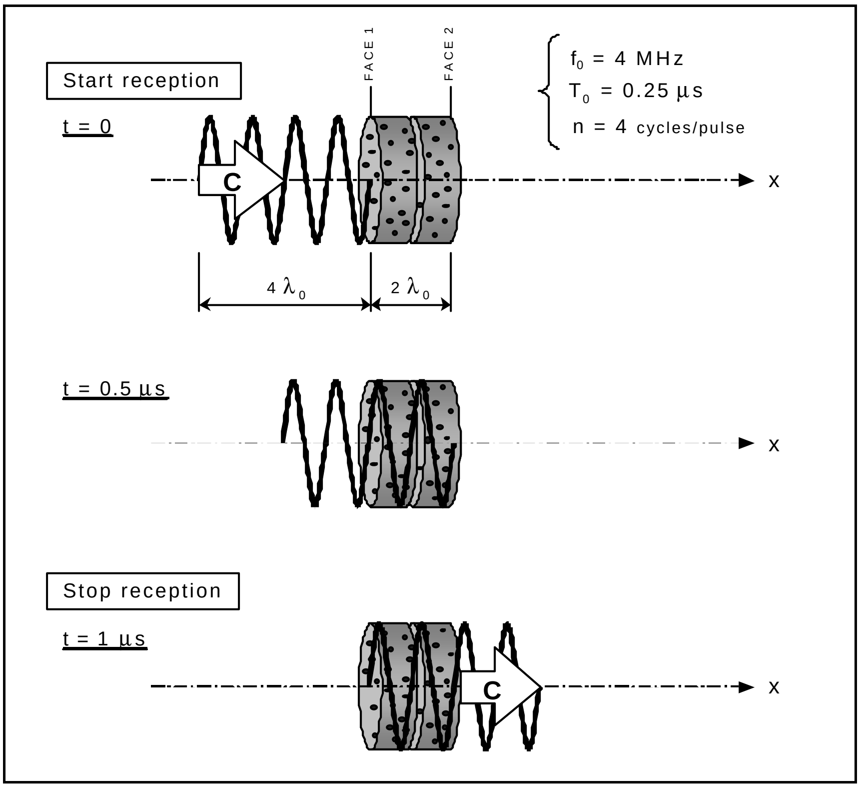


Figure 3 - Illustration to explanation of Channel width

At *t = 0 ms*, burst front reaches face 1, the close particles start generating echo, the transducer starts reception of the latter with no delay.

At *t = 0.5 ms*, burst front reaches face 2, the distant particles start to generate echo that will reach the transducer 0.5 ms later.

At *t = 1 ms*, the end of burst reaches face 1 and close particles stop generating echo while echo from face 2 just reaches the transducer. Reception mode for the considered channel switches off before receiving echo generated from particles beyond face 2.

Thus reception time lasted 4 periods T_0 while echo from particles contained in a 2-wavelength volume has been measured.

Switch time: For practical considerations, the transducer switch time between transmission mode and reception mode is negligible.

Note: ***With increasing number of cycles per burst, channel width increases, and two adjacent measuring volumes might overlap - see also 'Channel distance' and 'Overlapping'.***

3.1.3 Channel distance

This is the distance between centres of two adjacent measurement volumes. The channel distance remains constant throughout the measurement window, i.e. from channel 0 to channel (N_{ch} -1), where N_{ch} is a number of measured channels (from 10 to 2048 for UVP-DUO hardware with software Version 3). It can be varied in integer multiples of the spatial resolution (i.e., channel width) selected.

3.1.4 Overlapping

The "overlapping" phenomenon is literally the overlap of two consecutive measuring volumes due to a *channel distance* set smaller than the *channel width* itself, depending on the US burst length.

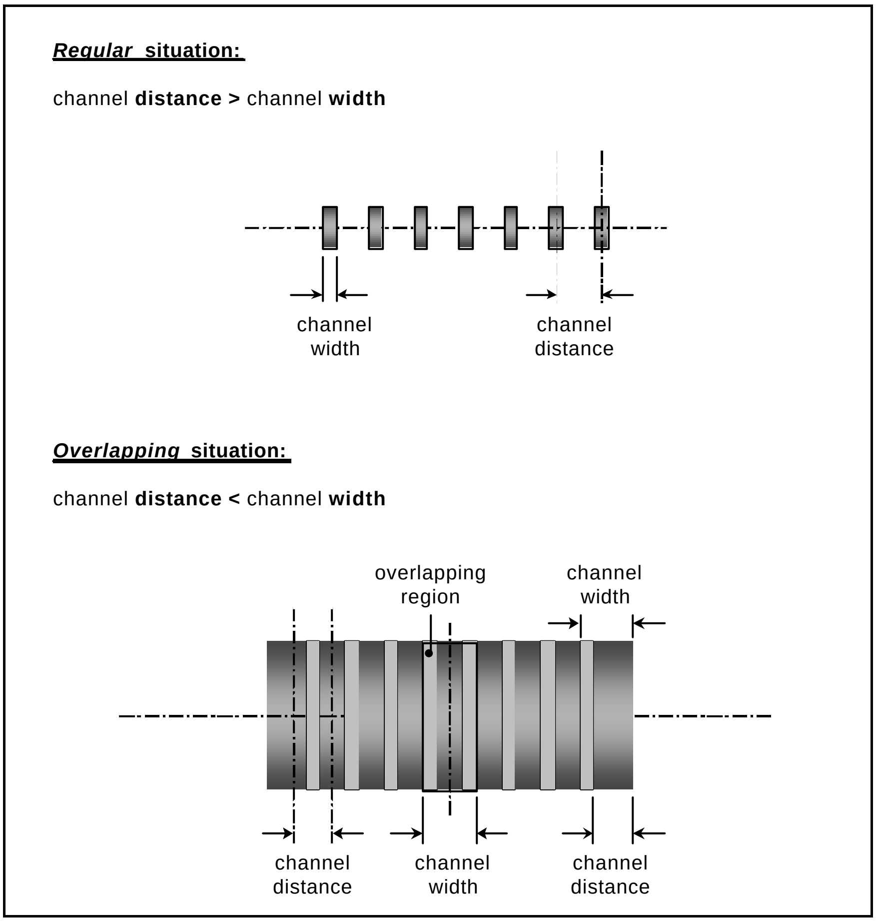


Figure 4 - Illustration to the explanation of Overlapping

To explain overlapping in more detail we can use the previous example of a 4-cycle 4 MHz pulse (burst length = 4 λ_0, channel width = 2 λ_0), but with a channel distance set at half of channel width (channel distance = λ_0).

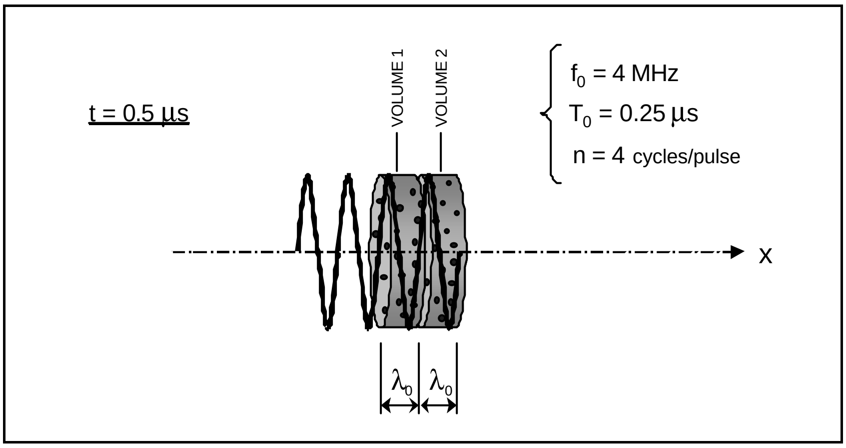


Figure 5 - Illustration to detailed explanation of overlapping

As previously, at *$t = 0\ \mu s$* echo generation of the first measurement volume starts at the same time as transducer reception, storing the signal in the first channel.

At *$t = 0.25\ \mu s$* echo generation of the second volume starts while transducer is still receiving echo from the first volume.

At *$t = 0.5\ \mu s$* stops the reception of first channel and starts immediately reception of the second channel (storing the signal in the second channel), as echo generated by the second volume starts effectively to reach transducer face.

BUT volume 1 is still generating echo that will be measured and also stored in channel 2. This phenomenon is called overlapping.

Consequently, a spatial averaging is made for each velocity channel taking into account velocities of neighbouring channels**, spatial resolution being dependent on channel width and not channel distance**. The result is smoothing of velocity profile, which can be critical for flows with strong variations of velocity gradient.

3.1.5 Measurement window

Measurement window length is defined as the distance between the centre of channel 1 (starting channel), and the channel N_{ch} (window-end channel) centre. This is given as

$$W = (N_{ch} - 1) * \text{channel distance}$$

where W — measurement window length [mm]
N_{ch} — selected number of channels [1]

In the case of UVP-DUO hardware and software Version 3, N_{ch} can be selected from 10 to 2048.

Measurement window end position W_{end} is defined as start-channel position W_{start} plus measurement window length:

$$W_{end} = W_{start} + W = W_{start} + (N_{cr} - 1) * \text{channel distance.}$$

The window-end position W_{end} has to be smaller than the maximum depth (that is, maximum depth $\geq W_{end}$). Values of window-end position are limited automatically by software when setting channel distance and starting position, to the value

$$W_{end} = P_{max} - 2 * \text{channel distance.}$$

3.1.6 Maximum measurable depth

The maximum measurable depth is determined by the *pulse repetition frequency* F_{prf}:

$$P_{max} = \frac{c}{2F_{prf}}$$

where	P_{max}	maximum measurable depth [m]
	c	sound velocity [m/s]
	F_{prf}	pulse repetition frequency [1/s]

The relation expresses the fact, that it is impossible to ping a new US pulse into liquid before the echo from previous pulse returns from the maximum measurable depth (most distant channel).

The maximum measurable depth increases with decreasing F_{prf}.

3.1.7 Measurement of Doppler shift frequency

Establishment of Doppler shift frequency in a certain channel is the crucial part of UVP measurement. There exist several methods of measurement of short frequency bursts. UVP-DUO uses time domain algorithm.

Since a Doppler-shifted echo burst from a certain channel is generally much shorter than the time corresponding to the required frequency measurement, it is necessary to obtain the required information by analysis of several echoes resulting from several repeated US pings. The situation – for a single channel – is depicted on Figure 6.

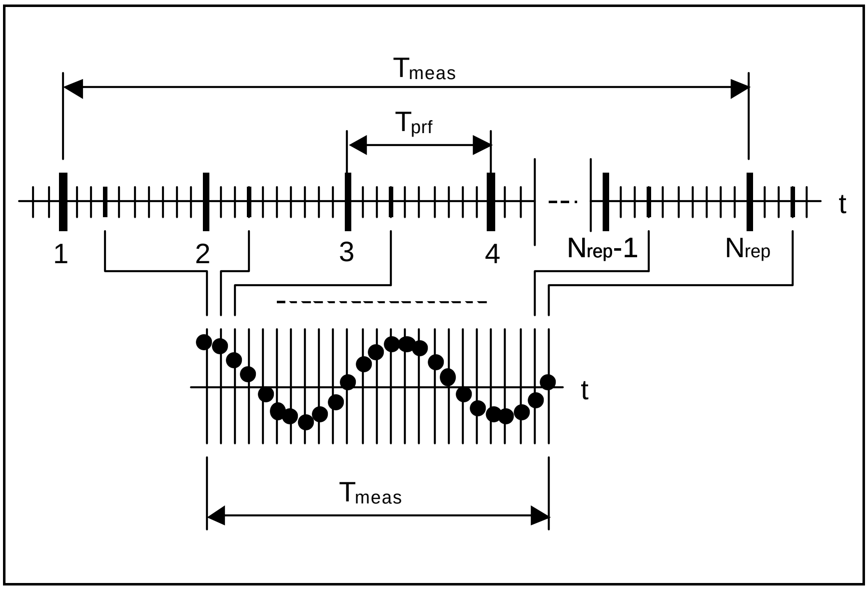


Figure 6 – Establishment of Doppler shift frequency for a single channel

In the above Figure, $T_{prf} = 1 / F_{prf}$, and $T_{meas} = N_{rep} \times T_{prf}$. Thick vertical lines represent repeated pings (numbered 1 to N_{rep}). Channel 3 is selected for explanation.

During each US ping, a single sample of Doppler shift frequency reconstruction is sampled (see lower part of the Figure 6). When N_{rep} pulses is sent and N_{rep} samples is taken, it is then possible to establish the Doppler shift frequency e.g. by zero crossing method.

The same process is done inside UVP Monitor in parallel for each active channel. Later the Doppler shift frequency for each channel is converted to velocity, and channel velocities are synthetised to a single velocity profile.

From the described procedure results that for higher N_{rep} it is possible to establish the Doppler shift frequency more precisely and more robustly in presence of noise. On the other hand, the higher is the selected N_{rep}, the longer it takes to measure the complete profile, and the lower is the resulting time resolution of UVP measurement.

3.1.8 Maximum measurable velocity range

Due to the Nyquist sampling theorem related to F_{prf}, the maximum detectable Doppler shift frequency is limited to one half of F_{prf}

$$f_{Dmax} = F_{prf} / 2$$

This implies that there is a limitation on the maximum velocity range, which can be measured by a certain F_{prf} (see also Paragraph 3.1.11, Flow direction and aliasing, Page 3.11). This limit is:

$$V_{\mathrm{range}} = \frac{c\,F_{prf}}{2\,f_0}$$

where
V_{range} maximum measurable velocity component range [m/s]
f_0 ultrasound basic frequency [Hz]
F_{prf} pulse repetition frequency [1/s]
c sound velocity [m/s]

From the above two equations, the following constraint exists for this method of measurement:

$$P_{\max} * V_{range} = \frac{c^2}{4\,f_0}$$

Since for a given measuring situation both c and f_0 are constant, the product

$$P_{max} * V_{range}$$

is also constant. This means that, for a given transmitting frequency, we have to compromise between maximum measurable depth, and maximum measurable velocity range.

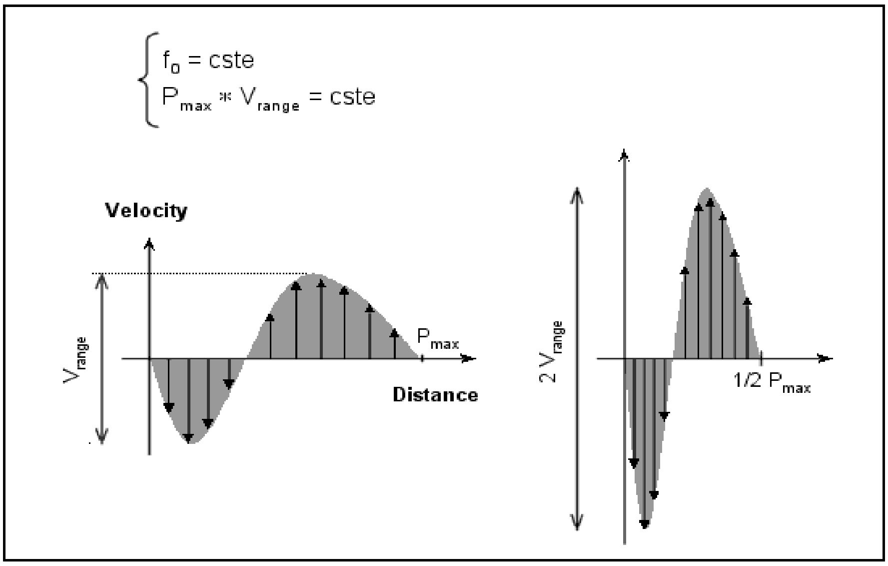


Figure 7 - Compromise between maximum measurable depth and velocity

Please note that the product value can be changed by change of used US frequency f_0. With lower f_0 higher velocities and longer 'reach' can be achieved. (Alas, the penalty for increased velocity range is decreased spatial resolution…)

The possibility to optimise measurement conditions is the reason for the availability of more US working frequencies in a single UVP Monitor model.

3.1.9 Velocity resolution

We can now determine the velocity resolution. From the equation above, we can derive that

$$V_{range} = \frac{c^2}{4 f_0 P_{\max}}$$

$$\Delta V = \frac{V_{range}}{N_{DU}} = \frac{V_{range}}{256}$$

where ΔV velocity resolution [m/s]
N_{DU} number of 'Doppler units' [1]

Velocity resolution is the least resolvable difference in velocity.

Number of Doppler units means number of possible velocity values coming from digital signal processor. In other words, UVP is not able to distinguish more velocity values than is number of available bit combinations. For 8-bit word, used in UVP-DUO digital signal processor, N_{DU} = 256 values.

When higher resolution is required, V_{range} must be smaller. This requires that the maximum depth P_{max} be larger (i.e., F_{prf} be smaller). The table below shows some possible combinations for water measurements.

f_0 [MHz]	P_{max} [mm]	V_{range} [mm/s]	P_{max}*V_{range} [mm^2/s]	ΔV [mm/s]
0.5	100	10,952	1,095,200	42.78
	750	1,460	1,095,200	5.70
1	100	5,476	547,600	21.39
	750	730	547,600	2.85
2	100	2,738	273,800	10.70
	750	365	273,800	1.43
4	100	1,369	136,900	5.35
	750	183	136,900	0.71
8	100	685	68,450	2.68
	750	91	68,450	0.36
(c = 1 480 m/s)				

Note: ***The table above shows theoretical values only. P_{max} also depends on F_{prf} (pulse repetition frequency) and can change. This is why the table serves for orientation only. During practical measurement, other limitations apply (e.g. absorption might be limiting for the maximum measurable distance).***

3.1.10 Doppler Coefficient and Sound Speed Coefficient

The raw data, which is generated and recorded on the disk, is in units of frequency detected during the measurement time. Thus the Doppler shift frequency f_D can be obtained from the raw data using the formula

$$f_D = raw\ data * C_{doppler}$$

The Doppler coefficient is given by

$$C_{Doppler} = \frac{F_{prf}}{N_{DU}} = \frac{F_{prf}}{256}$$

where
- f_D Doppler frequency [Hz]
- *raw data* data measured by UVP in internal units [1]
- $C_{Doppler}$ Doppler coefficient [Hz]
- F_{prf} pulse repetition frequency [Hz]

Doppler coefficient has physical meaning of the smallest measurable Doppler frequency difference.

Velocity along beam axis is given by

$$v = C_{sound}\, f_d$$

and the sound speed coefficient is given by

$$C_{sound} = \frac{c}{2 f_0} = \frac{l}{2}$$

where
- C_{sound} sound speed coefficient [m.s-1.Hz-1= m]
- v velocity component into transducer axis [m/s]
- f_0 US basic frequency [Hz]
- λ ultrasound wavelength [m]

Please note that **sound speed coefficient has physical meaning of half of the ultrasound wavelength.** This e.g. directly enables to calculate channel width:

$$w = n\,C_{sound} = \frac{n\,l}{2}$$

where	w	measurement channel width
	n	number of emitted US cycles.

The data can be converted to a velocity using the formula

$$V = raw\,data * C_{Doppler} * C_{sound} * \frac{1}{\sin q}$$

where	q	US wave incidence angle to flow normal [deg]
	V	liquid velocity [m/s]

The angle q is defined in Figure 1. In the Equation right member, the product of the first two factors gives the measured Doppler frequency shift, the third member means ultrasound (half) wavelength, and the last member recalculates the transducer on-axis measured velocity projection to real flow velocity in a given direction.

These coefficients are also calculated in the UVP software, and displayed in each data file in Info section.

3.1.11 Flow direction and aliasing

In Section 3.1.6 (Page 3.7) relation for maximum measurable velocity has been derived. Here it is necessary to say that the derived Equation does not fully describe phenomena called 'aliasing'.

Nyquist theorem shows that maximum velocity measurable by UVP is directly given by pulse repetition frequency F_{prf}. However, Nyquist theorem in its full form (less known to general public) does not refer to highest measurable frequency, but to highest measurable frequency bandwidth.

This has rather important implication. Let us presume that some signal is sampled with certain sampling frequency (in our case, F_{prf}). Nyquist theorem then states that highest measurable bandwidth is $F_{prf}/2$. When the real (signal) frequency is lower than $F_{prf}/2$, the measured frequency agrees with the signal frequency. If signal frequency reaches $F_{prf}/2$, the measured frequency folds back into the low frequency region. With further increase of signal frequency, the measured frequency increases again, up to a point of $(2^* F_{prf}/2)$. With increasing signal frequency, the process repeats. Effective result of aliasing phenomena is, that a single indicated frequency (velocity) can correspond to several real flow velocities, differing by F_{prf} multiples:

$$f_D = f_{meas} + k^* F_{prf} \qquad \text{for } k = +/- (0, 1, 2, \ldots)$$

The maximum measured range f_D then corresponds to the velocity measurement range v_{range}.

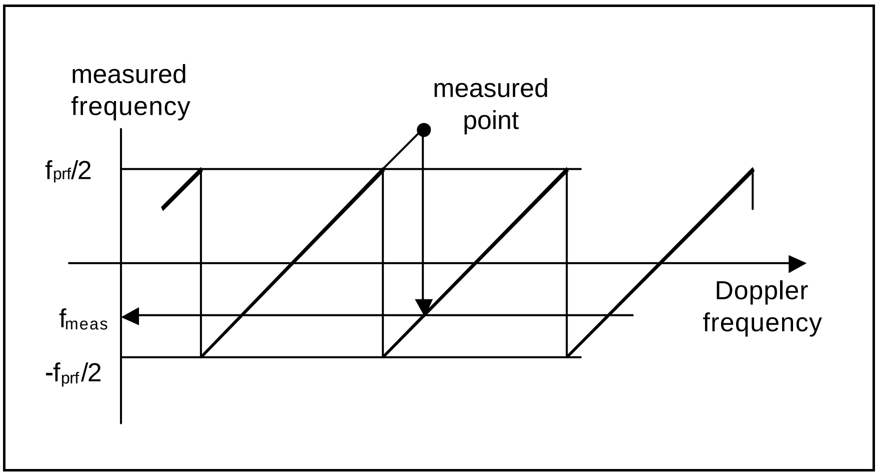


Figure 8 – Frequency aliasing

It is therefore up to the user how to interpret the measured data. One possibility is to ‘instruct’ the UVP software to interpret the measured data as symmetrical around zero velocity. Since there is an even number of bit combinations, measurement range will be ‘off-balance’ by a single *Dv*:

$$v_{\max} = \frac{v_{range}}{2} - \Delta v$$

$$v_{\min} = \frac{v_{range}}{2}$$

The matching section from Parameter set-up table is on the Figure 9.

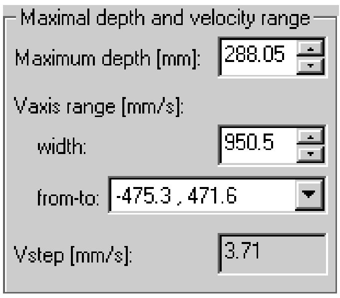


Figure 9 – Symmetrical velocity range illustration

Please note that ΔV is calcutated, and therefore not open for editing.

Asymmetrical velocity range can be chosen as well, as seen from rolled-down list box on Figure 10, from zero to $v_{range} - \Delta v$, or from $-\left(v_{range} - \Delta v\right)$ to zero.

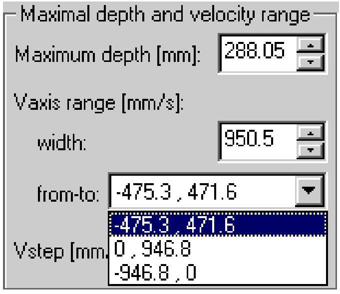


Figure 10 – Asymmetrical velocity ranges

Larger values of velocity could be measured as well, always with the same absolute velocity range V_{range} (thus with smaller relative velocity range). Since confusion in interpretation might arise, software Version 3 limits the possibility to measuring the offered three velocity ranges.

Note: *Indicated velocity range does not send any instructions to the measurement hardware. It should be viewed purely as a note for graphical software how to describe y-axis when plotting and tabeling results. In extreme, velocity range could be put into Notes to data file as well.*
This is also a reason why software saves data in 'Doppler units' (which correspond to bit combination coming out of digital signal processor), and only interprets the measured velocity later, more or less as an afterthought.

Practically, during measurement, aliasing effect demonstrates itself when measured speed goes up to the upper (plotted on top of graphing area), and when further increase of velocity happens, plotted velocity 'jumps' to the very bottom of graph. With further increase of velocity, it goes up to the top, jumps down etc.

The same applies for decreasing (negative) velocity.

Aliasing effect can be used for measuring high fluid velocities, which do not fulfil the $P_{max}*V_{range}$ limitation.

Warning ***There is no way how to recognize which frequency (and velocity) harmonics is measured (or how many times 'around the graph' the velocity has overflown. Met-Flow therefore does not suggest to less experienced users to use aliasing for high velocity measurements. Experienced users should use aliasing with care, and should always have UVP-independent velocity measurement method available as reference for aliased measurement.***

3.1.12 RF Gain

Since the attenuation of ultrasound in liquid and solid media follow an exponential law, distant particles give weaker echo than particles closer to the transducer. The amplification of the received echo is therefore adjusted so that this attenuation is compensated for. The amplification is time/distance dependent, as illustrated in Figure 11, and is called the gain distribution. The RF gain factor modifies the slope of the gain distribution.

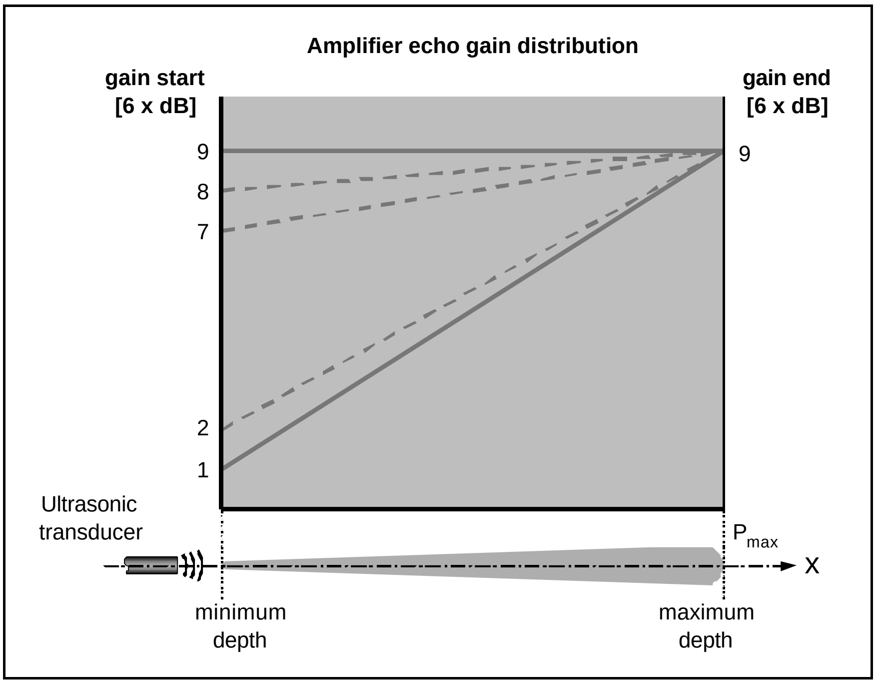


Figure 11 - Amplifier gain distribution as function of measuring distance

The gain distribution can be adjusted by setting its start and end values. Both can be set from factor 1 to factor 9. When both are set at the same value, the distribution is constant (flat). A factor of one is equivalent to 6dB.

Note ***Please note that the amplifier gain distribution changes continuously (without gain steps). This has deep positive consequences in UVP's signal processing and it presents one of several things that make UVP a superior instrument.***

3.1.13 US Emission Voltage

An overall amplification gain may also be controlled by changing the strength of ultrasound emission through the change of voltage applied to the transducer (namely, US emission voltage). Depending on the kind of liquid, maximum depth, condition of reflectors, etc., the user will need to optimise these parameters.

3.1.14 Time resolution

The time resolution of the measurement of a single profile is determined by the data acquisition time, which itself depends on the pulse repetition frequency F_{prf} or the maximum depth. It is given by the number of repetitions N_{rep} used in the Doppler shift calculation and:

$$\Delta T = \frac{N_{rep}}{F_{prf}}$$

where *DT* complete profile measuring time [s]
N_{rep} number of profile measurement repetitions (default = 32)
F_{prf} pulse repetition frequency [1/s]

Examples are given in the following table.

P_{max} [mm]	F_{prf} [Hz]	ΔT [ms]
100	7 400	4.3
200	3 700	8.6
750	987	32.4

The table is calculated for c = 1 480 m/s (water) and N_{rep} = 32 (default).

3.1.15 Measuring time

In principle, the minimum time interval between measured profiles is equal to the time resolution ΔT:

$$T_{meas} = \Delta T$$

where T_{meas} measurement time for a single complete profile
ΔT measurement time for a single complete profile (Time resolution)

Since measurement of a single complete profile requires several ‘pings’, the higher the *“# of repetitions”*, the longer is measurement time for a single complete profile.

3.1.16 Sampling time

For data acquisition, user can select either minimum time interval, which is established by UVP as function of set up parameters, or measuring period can have any selected value longer than the minimum period.

Sometimes it is useful for the user to slow down data acquisition. This can be the case when longer time series are measured and the user wants to limit the data file volume. This is why it is possible to set certain additional delay between measured profiles.

Please note that at every beginning of a multi-profile measurement the DSP (Digital Signal Processor) is internally calculating an averaged "single profile sampling time" from the first 10 profiles (which is displayed on the status bar) in order to have digital feedback on sampling time (accuracy ± 1 ms).

3.1.17 Number of repetitions and Cycles per pulse

Depending on the condition of the working fluid – that is, the concentration of reflecting particles in the flow – it may be useful to change N_{rep} (number of repetitions) and *Cycles per pulse* (number of cycles in a pulse, setting its length). When the concentration is low and the echo is weak, one or both of these parameters can be increased to improve estimates of the measured velocity. There is, however, a penalty: time resolution and/or spatial resolution is sacrificed. Based on our experience, we have found that the values (N_{rep}=32, *Cycles per pulse* = 4) are optimal. Thus, we have set these to be the default values.

3.2 Basic ultrasound beam properties

UVP practical applicability heavily depends on ultrasound beam properties, and for every user it is very important to understand the basics of ultrasound beam properties. This is why we are giving some of the basic definitions and relations here. For a more complex description of generation and characteristics of US waves, the reader is advised to consult literature. Here we very simply present those aspects most necessary for successful application of UVP measurement method.

3.2.1 Ultrasonic wave

Any sound generated with frequency above the human upper hearing limit of about 20 kHz is called ultrasound. The most commonly used ultrasound range for research and industrial purpose may vary from 100 kHz to 50 MHz, depending on application.

Although ultrasound behaves similarly to sound it has a much shorter wavelength, which means that its wave characteristics are more pronounced, and it can also be echoed by very small reflectors (particles).

Ultrasonic waves propagate mechanical vibrations in a medium in form of different longitudinal and shear waves. Longitudinal wave is a compression wave in which the particle motion is in the same direction as the propagation of the wave. Shear wave is a wave motion in which the particle motion is perpendicular to the direction of the propagation.

A wave absorbed, scattered in a medium, or reflected and refracted at the interface of different materials, changes its wave mode. An exact description of such processes is very complex, and we will not consider it here.

For UVP purpose, only longitudinal waves will be considered.

A wave is expressed in terms of the pressure field, where p_0 corresponds to the peak pressure. Wavelength λ is expressed as

$$\lambda = c / f$$

where	λ	wavelength [m]
	c	sound velocity [m/s]
	f	sound frequency [Hz]

3.2.2 Acoustic impedance

Acoustic impedance is material property, expressed as the product of the material density and the sound velocity:

$$Z = \rho * c$$

where	Z	acoustic impedance [kg m^{-2} s^{-1}]
	ρ	material density [kg/m^3]
	c	sound velocity [m/s]

A unit of Acoustic impedance Z is called ‘Rayleigh’ (or Ray), larger practical unit is ‘MRay’ (1,000,000 Rays). (John William Strutt, third Baron Rayleigh, 1842-1919, British physicist.)

3.2.3 Reflection and refraction on interface

An interface is a boundary surface between two media having different acoustic impedances.

When the ultrasonic wave reaches an interface with an incident angle θ_1 , the following mathematical relation applies between the intensities of the incident wave, and the reflected wave:

$$p_r = \frac{Z_2 \cos\theta_1 - Z_1 \cos\theta_2}{Z_2 \cos\theta_1 + Z_1 \cos\theta_2} . p_i$$

where	p_i	incident wave intensity [Pa]
	p_r	reflected wave intensity [Pa]
	Z	acoustic impedance of media [1]
	θ	US wave incidence angle to normal [deg]
	index 1	relates to medium 1
	index 2	relates to medium 2.

By defining the reflection coefficient R as the ratio between the reflected intensity to the incident intensity, we obtain:

$$R = \frac{p_r}{p_i} = \frac{Z_2 \cos\theta_1 - Z_1 \cos\theta_2}{Z_2 \cos\theta_1 + Z_1 \cos\theta_2}$$

Similarly, we define the transmission coefficient as the ratio of the transmitted intensity to the incident intensity, we get

$$T = \frac{p_t}{p_i} = 1 - R = \frac{2 Z_2 \cos\theta_1}{Z_2 \cos\theta_1 + Z_1 \cos\theta_2}$$

Obviously, the wave, which does not reflect, will transmit (not considering absorption).

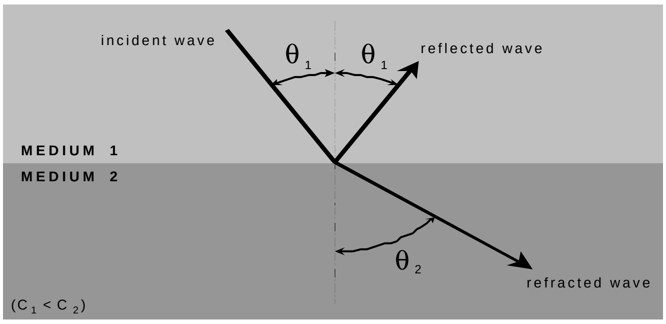


Figure 12 - Illustration to Fresnel's law

Ultrasound refraction obeys Fresnel's law (Augustin Jean Fresnel, 1788-1827, French physicist):

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{c_1}{c_2}$$

When $\theta_2 = 90°$ in the equation, the whole of the incident wave will be reflected, and the matching θ_1 is called the 'Critical angle'. For Critical angle applies:

$$\theta_1 = \sin^{-1}\left(\frac{c_1}{c_2}\right)$$

The critical angle can be easily achieved when the ultrasonic wave travels from a medium with lower sound speed to a medium with higher sound speed. This is usually the case of plastic models with water, which is the most often used combination in experimental hydraulics. Even if the angle is below the critical limit, careful attention is needed in the choice of material and angle, due to the extreme diminution of the transmission coefficient *T*.

For illustration, some pairs of materials used in UVP technique and critical angles are given in the following Table.

Material 1	Material 2	c_1 [m/s]	c_2 [m/s]	$\theta_{critical}$ [deg]
Water	Plexiglas	1 480	2 760	32.4
Water	Polyamide	1 480	2 400	38.0
Teflon	Water	1 350	1 480	65.8
Water	Iron	1 480	5 900	14.5
Water	Aluminium	1 480	6 320	13.5
Water	Brass	1 480	3 400	25.8
Water	Glass	1 480	5 200	16.5
Mercury	Iron	1 450	5 900	14.2
Glycerol	Polyamide	1 920	2 400	53.1

The critical angle is sometimes very small, and it can be more advantageous to bring the transducer into direct contact with the fluid, perhaps through a port in the channel wall.

Note ***The careful reader has already easily recognised the similarity of the US equations above with those valid for optical reflection and refraction. Since more similarity applies, this field is also sometimes called 'US beam optics'.***

3.2.4 Sound velocity and Acoustic impedance of selected materials

The sound velocity and acoustic impedance of selected liquids and vessel materials are presented in the following Table. These values can be used without too much error under normal conditions. A combination of liquid and solid is recommended so that the acoustic impedance ratio at the interface is between 2 and 3.

Medium	Density [10^3 kg/m^3]	Sound velocity [10^3 m/s]	Acoustic impedance [10^6 kg/m^{2}s]
Water (20° C)	0.98	1.483	1.5
Glycerol	1.26	1.92	2.5

Oil (mineral, light)	0.83	1.44	1.19
Mercury	13.6	1.45	19.7
Ice	0.92	3.20	2.9
Aluminium	2.7	6.32	17
Brass	8.6	3.4	29.2
Copper	8.9	4.70	42
Glass (borosilicate)	2.5	5.2	13.8
Tin	7.3	3.32	24
Iron	7.7	5.90	45
Plexiglas	1.19	2.76	3.3
Epoxy resin	1.1 - 1.25	2.4 - 2.9	2.7 - 3.7
Polyamide	1.1 - 1.2	2.2 - 2.6	2.4 - 3.1
Polystyrene	1.06	2.35	2.5
Teflon	2.2	1.35	3.0

All the above values of sound speed and impedance should be taken with some reserve, since many materials can differ in sound speed due to production technology process, or ageing.

Interested reader can find many more materials, together with description of measurement of empirical data, on the Internet address **www.ultrasonic.com**. Another source of practical information on ultrasound properties can be found on **www.krautkramer.com**, and on many other Web sites.

3.2.5 Absorption

During propagation, the energy in a sound wave either is transformed into another form, or is lost due to scattering by impurities in the medium. Both processes contribute to the "Absorption" of the sound wave. Along the line of propagation, the absorption is expressed by the exponential law of absorption – 'Beer's law' (Augustus Beer, 1825-1863, German physicist):

$$p(z) = p_0 \exp(-\alpha z)$$

where
- p acoustic pressure [Pa]
- p_0 reference acoustic pressure on transducer [Pa]
- α absorption coefficient [1/m] (also called 'absorptivity')
- z distance [m]

The absorption coefficient depends on the material, US wave frequency, temperature, and other possible parameters. For practical measurement, it is very important to make a good choice of medium and wall material with not very high absorption coefficient.

4. Hardware description

4.1 UVP-DUO series

The features common to all models in the UVP-DUO line are:

Emitting frequency	0.5, 1, 2, 4, 8 MHz
Emitting voltage on transducer	30, 60, 90, 150 V (for 50-Ohm transducers)
Emitted cycles per pulse ([1])	2 to 32 cycles, by step of 1
Pulse repetition frequency ([2])	244 Hz to 92 500 Hz
Number of channels	Selectable from 10 to 2048 channels
Receiving amplification	Exponential, time-dependent, for compensation of distance attenuation
Space resolution - longitudinal ([3])	Approx. 0,5 microseconds (transducer-dependent)
Space resolution - lateral ([4])	Defined by used transducer
Channel distance	Variable, from 0,37 mm in water (medium-dependent)
Velocity range resolution	1/256 of velocity range (1 LSB)
Raw echo acquisition	Same spatial, temporal and range resolutions as velocity
Repetition rate (emissions per profile) ([5])	8 to 240, step of 1
Acquisition time per profile ([6])	Variable, minimum 1 ms
Doppler shift detection algorithm	Time domain or frequency domain (FFT)
Triggering	External signal (TTL) or keyboard
Time delay between profiles	0 to 65 000 ms
Recording capacity	Up to your remote computer hard disk capacity
Configuration parameters saving	Unlimited number of configuration files can be saved
Measurement signals	5 'transducer' connectors (single channel model) or 20 'transducer' connectors (multiplexer model)
Interface signals	'Raw echo' (max 0,7 V) output, 'pulse repetition frequency' output, 'window start gate' output, 'trigger' input, 'remote' connector, 'service' connector
Remote control interface	Ethernet 100 Base-T (RJ-45 'remote' connector)
Remote computer operating system	Windows 98 / SE / ME or Windows NT 4 / 2000 / XP
Display	External display - up to your remote computer characteristics
Power supply	110/220 V, 50/60 Hz
Size of instrument casing	340 x 130 x 400 mm
Weight	9.3 kg
Operating conditions	Temperature 0-40°C, storage –20-60°C relative humidity 30-80%, non-condensing
Export packaging	Sturdy aluminium case (ordered separately)

(1) Increasing number of emitted cycles improves signal quality but decreases longitudinal resolution.
(2) Maximum pulse repetition frequency is limited by maximum measurable depth, i.e. by time of flight of ultrasonic signal to a distant point and back to transducer.
(3) The least number of waves in a pulse is two. Longitudinal space resolution depends on ultrasonic frequency (wavelength) and also on agility of used transducer. Met-Flow transducers are very agile and therefore converge to the theoretical resolution limit.
(4) For ultrasonic beam divergence values see the Transducers data sheet.
(5) When using high repetition rate (many emissions per profile), sliding averaging in time is achieved.
(6) Acquisition time depends on the ultrasound flight time to the maximum depth point and back, and on the repetition rate.

4.1.1 Models with integrated multiplexer

In applications where it is desired to obtain a spatial mapping of the flow characteristics (*flow mapping*), the UVP-DUO with an integrated multiplexer is the ideal solution. In these units, both the multiplexer and its controller are integrated into the UVP. Using the supplied software, any of the channels can be selected at random and in any combination. As a result, selecting the order in which the transducers are switched, preparing the timing sequence, etc. are easily accomplished. The sequence and timing of multiplexer channels are controlled from UVP-DUO software.

The multiplexer comes with 20 output channels multiplexed by relay circuits.

4.1.2 Models without multiplexer

If customer does not require multi-transducer measurement capability (e.g. if UVP-DUO is used for industrial measurement of a single profile), UVP-DUO without multiplexer can be delivered for lower price.

4.2 UVP-DUO hardware description

The UVP is designed in a different way than previous UVP models. All measurement functions are contained in an UVP-DUO unit, while software with all its controlling and analysis functions is installed on a remote computer. UVP-DUO and remote computer are connected by an Ethernet link.

Since all controlling functions are accomplished through software, UVP does not have any controlling elements.

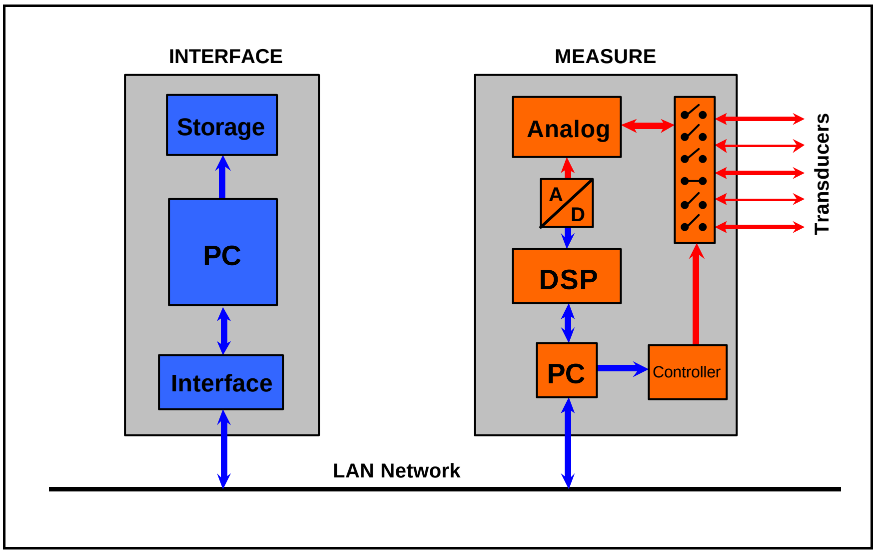


Figure 13 - Block diagram of an UVP-DUO Monitor

4.2.1 UVP-DUO unit

On the front panel of the UVP-DUO there is a power switch and a LED diode indicating Power On state.

Figure 14 – UVP-DUO back plate

On the back panel of the UVP-DUO are connectors for an echo signal output (named 'ECHO'), ultrasound pulse repetition frequency trigger signal output ('PRF'), external trigger input ('TRIGGER'), and window start signal output ('GATE'). There are also BNC connectors for the transducers ('TRANSDUCER') - the number of connectors depends on the model. Models with integrated multiplexer have 20 BNC connectors numbered 'CH1' to 'CH20'. Models without multiplexer have five BNC connectors, one connector for each ultrasonic frequency. When multiplexer models work with switched off multiplexer, then the first five connectors correspond to the five connectors for different ultrasonic frequencies. Connector 'CH1' corresponds to the (lowest) frequency 0.5 MHz, connector 'CH2' corresponds to 1 MHz, connector 'CH3' corresponds to

2 MHz, connector 'CH4' corresponds to 4 MHz, connector 'CH5' corresponds to 8 MHz.

Warning:	***The user should ensure that the connector and transducer are matched appropriately. Incorrect connecting of wrong-frequency connector could lead, under certain conditions, to permanent damage to transducer and/or UVP-DUO electronics.***

In addition, there is connector on the back panel for 'SERVICE' serial port, and an Ethernet port 'REMOTE'.

The echo signal output (ECHO) is used to monitor the ultrasound emission and received echo. Displaying this signal on an oscilloscope provides information in the most convenient form for adjusting parameters, transducer settings, etc. It is particularly helpful in recognising the position of a wall or obstacles in the flow.

Note: ***We strongly recommend that the echo signal be monitored in all investigations. It is the only reliable way how to make sure that what you measure is not an artefact caused by false reflection from walls etc.***

The ultrasound pulse trigger signal ('PRF') supplies the timing signal for an ultrasound pulse emission. This output is usually connected to the external trigger input of an oscilloscope.

The external trigger ('TRIGGER') is used to trigger the start of the measurement of a profile.

The power line, fuse holder and power connector are fitted on the back panel.

In the following table is an overview of UVP's external connectors and their functions.

Connector	Description	Explanation
ECHO	Echo Signal	BNC connector to oscilloscope for monitoring a received echo signal.
PRF	Pulse Trigger Signal	This signal supplies the timing for an ultrasound pulse emission. Connect this output to the external synchronisation input of an oscilloscope.
TRIGGER	Trigger	BNC connector to an external trigger signal-generating circuit. The trigger signal defines the start of profile storing.
CH1 – CH20	Transducers	BNC connectors for the transducers. The UVP-DUO with multiplexer has twenty BNC connectors - labelled CH1, CH2, … CH20. The first five connectors are labelled 0.5, 1, 2, 4, and 8 MHz. Ensure that the transducer and connector are matched appropriately.
SERVICE	Serial Port	External serial cable connection for setting up TCP/IP address.

Connector	Description	Explanation
REMOTE	Ethernet port	The Ethernet port for connection to remote computer network (LAN).

4.3 Preparation for operation

4.3.1 Safety precautions

Warning: ***UVP-DUO Monitor uses high voltage, which is potentially dangerous to your life. It is strictly forbidden to remove the cover of UVP-DUO box with line voltage cable connected to mains power supply. Doing so would expose you to electrical shock.***

4.3.2 Power Supply

The line voltage is 117/240V AC, 50/60 Hz (pre-set at the factory to end-user's expected local voltage). Grounding of the power line is necessary. UVP power consumption is about 50W. Surges on the power line should be avoided.

Warning: ***Before the first powering on the UVP Monitor, check the line voltage on the voltage selector! Every effort has been made to deliver the UVP Monitor to you with correct voltage set, but Met-Flow cannot be responsible for any damage on the UVP Monitor caused by powering the UVP Monitor with wrongly selected power line voltage.***

Note: ***Network the UVP-DUO before powering on.***
We recommend a warm-up time of the UVP-DUO hardware of at least one minute after switching on the UVP-DUO Monitor. UVP-DUO contains an embedded PC computer, which needs some time to boot-up.

4.3.3 Networking the UVP-DUO monitor

Just connect the REMOTE connector with a remote computer or LAN by an Ethernet cable. Network the UVP-DUO before powering on.

4.3.4 Transducer

Even though ultrasound transducers are relatively robust, and electronic filtering of signal in the UVP eliminates some signal frequencies caused by external sources of vibration, special care should be paid to transducer mounting. When the transducer is mounted against a solid surface (e.g., the outside wall of a container), any air gap between the wall and the top surface of the transducer may prevent or disturb the propagation of the ultrasound wave, resulting in an unsatisfactory measurement. To handle such cases, some ultrasound jelly is supplied with your UVP, which provides good coupling between the transducer and the mounting surface. A pea-sized amount of jelly on the working surface of a transducer will do.

Excessive operating temperature ***at the transducer*** may cause its permanent damage. The nominal operating temperature of the common TN-Series transducer is up to 60°C.

An excessive heating up of a transducer can also be caused by powering of a transducer not acoustically connected with the measured media (US energy does not leave the transducer), while simultaneously selecting very long pulse length and high US emission voltage. Your finger is sufficient to check the temperature. If you cannot hold your finger on a transducer because it is too hot, UVP use should be interrupted, and transducer fit improved.

Warning: ***Always check the working temperature of transducers that are operated in the air. Met-Flow is not responsible for damage to transducers caused by excessive heating of transducer.***

5. Software Version 3

5.1 Software – introduction

All the UVP-DUO software Version 3 has been rewritten from scratch and made into integrated, full-featured Win32 application, which collects data from UVP-DUO hardware, displays them on-line, saves them to disk, analyses, and exports files for use in other applications.

The software Version 3 merges all useful features of the former On-line and Review XW software Version 2. Many analysis features have been added - velocity histograms, auto-correlation analysis, cross-correlation analysis, and power spectrum. New software also reads former profile format *prf* and *dat* files. In addition, Flow mapping has been significantly improved and is now well ahead of any comparable software.

UVP-DUO software Version 3 is supplied on a CD, accompanying UVP-DUO hardware.

Note: ***All UVP-related software supplied by Met-Flow is copyrighted to Met-Flow and Optek. You are not allowed to de-compile or reverse-engineer the software, or to do anything, which would infringe Met-Flow's copyright.***

5.1.1 Remote computer

In full version for data acquisition, or as a demo/emulator, or as a data post-processing software, the supplied software will run successfully on almost any IBM PC-compatible computer fulfilling or exceeding the following requirements:

Pentium processor, at least 32 MB RAM memory, VGA graphics card, color monitor with at least 560x480 resolution, 20 MB free space on hard disk, Ethernet port, and Win32 operating system (Windows 98/ME/NT/2000/XP).

Windows 95 is not supported.

5.1.2 Software Version 3 installation

Just insert the Met-Flow CD into a CD drive of the computer where software Version 3 should be installed. Run the Setup.exe file by double-clicking it from the Explorer, or by using *Start | Run* box. Follow the instructions of the Setup Wizard.

During installation, the Setup Wizzard will ask for a 16-digit alphanumeric *Serial Number*, which has been supplied with your original software (Demo software version does not require *Serial Number*).

The Serial Number serves as a software key. It includes your coded personal User ID number, assigned to you by Met-Flow during purchase.

The User ID number can be viewed in *Help | About*.

It is impossible to install Version 3 software without a valid *Serial Number*.

When installing Version 3 software on a standard PC-compatible computer for post-processing and review of measurement results, install the software in the same way.

5.1.3 New software Version 3 features

The main new features of software Version 3 are

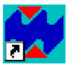
- Selectable number of measurement channels in profile from 10 to 2048
- Echo level is displayed and saved within data file
- Turbulence statistics graphs and tables - average, variance, skewness, kurtosis
- Velocity histogram of each channel
- Period enhancement graphs
- Improved flow rate calculations
- Auto-correlation and cross-correlation of any channels
- Power spectrum of any channel
- Flow mapping
- Average and median smoothing of profiles and channels
- New file format stores all measurement data in a single file
- Unlimited record length
- Fast reading of long files
- File information preview in Open file dialog
- All UVP-XW older file formats are read
- Unlimited editable comments to all data files
- Substantially improved block handling
- Improved multi-transducer data handling
- Multiplexer table saved within data file
- Perfect Windows MDI user interface
- Full compliance with Windows interface guidelines, incl. context-sensitive menus
- Full Clipboard support
- Full window cascade and tile support
- Multiple zooming and inverse-zooming of all graphics by mouse-drawing
- Velocity display scaling
- Profile graph scale axis in mm or channel number
- Time series graph axis in seconds or profile number
- Printing of all graphics windows and tables
- Print preview of all prints
- Clipboard copying of all graphics as bitmap or enhanced metafile
- Mouse selection and Clipboard copying of all tables
- Export of all results as txt or csv files
- Export of all results as Tecplot files
- Selection of unsmoothed or smoothed data export
- Many other smaller improvements.

5.2 Software description

5.2.1 Starting the software

Switch on both the UVP-DUO and software host computer by appropriate Power switches, and wait until the PC boots.

To start the software Version 3, double-click the Version 3 icon



or, click *Start | Programs | UVP| Version 3 Software.*

To quit the Version 3, click *File | Exit* from the main menu, or click the Close window button at the very top right window corner.

Note: ***Multiple copies of software Version 3 can be launched for data analysis. This is useful when it is desired to compare results from different data files.***
Only once instance of software can acquire data at a given time.

5.2.2 The main window

After starting the software Version 3, the main window opens on the display. The window is depicted on Figure 15.

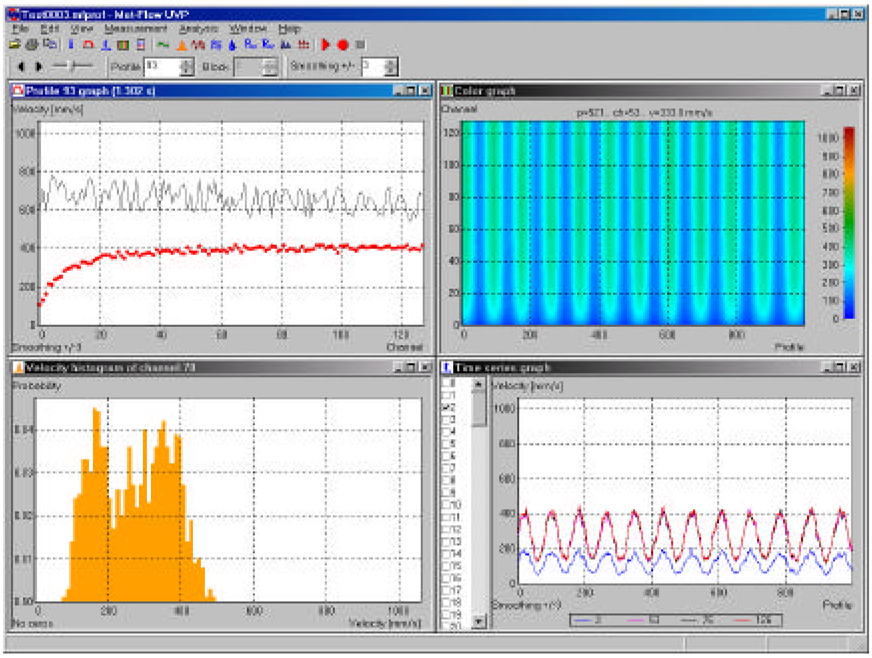


Figure 15 - Version 3 Software main window

5.2.2.1 Window configuration saving

When closing the program, the program saves the last used layout of the secondary windows opened within the main (primary) window ('client area'), and uses it when opening the program next time. This is why the layout of opened secondary windows can differ from what you see on the Figure 15. This is a very useful feature since it allows you to set up window configuration most fitting your needs and use it next time when you open the software.

When selecting *Test measurement parameters* or *Start measurement*, only some of the windows are on-line active: Profile graph, and Time series graph. Other windows would be inactive. This is why software Version 3 saves data acquisition window configuration separately, and uses it whenever Test measurement parameters or Start measurement are initiated.

You can change data acquisition window configuration during data acquisition. A newly created configuration will be saved and used for future data acquisitions, as long as it is not changed later.

When data acquisition is completed, the analysis window configuration returns to the previously used analysis configuration.

The main window consists of title bar, menu bar, window body, and status bar.

5.2.2.2 Title bar

Title bar displays title bar icon, currently opened file name, application name, and window buttons. This complies with Microsoft data-oriented design policy.

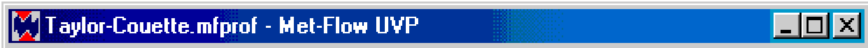


Figure 16 - Title bar

5.2.2.3 Menu bar

Menu bar consists of the following pull-down menus: *File, Edit, View, Measurement, Analysis, Window, Help.*

Figure 17 - Menu bar

File menu contains standard *Close, Save, Save As…* menu items for opening and saving files. *Open…* item opens a personalised open file dialog with preview of UVP parameters saved within the data file. It is therefore possible to review file parameters without opening the file. This allows for easy and fast browsing through data files in a data folder.

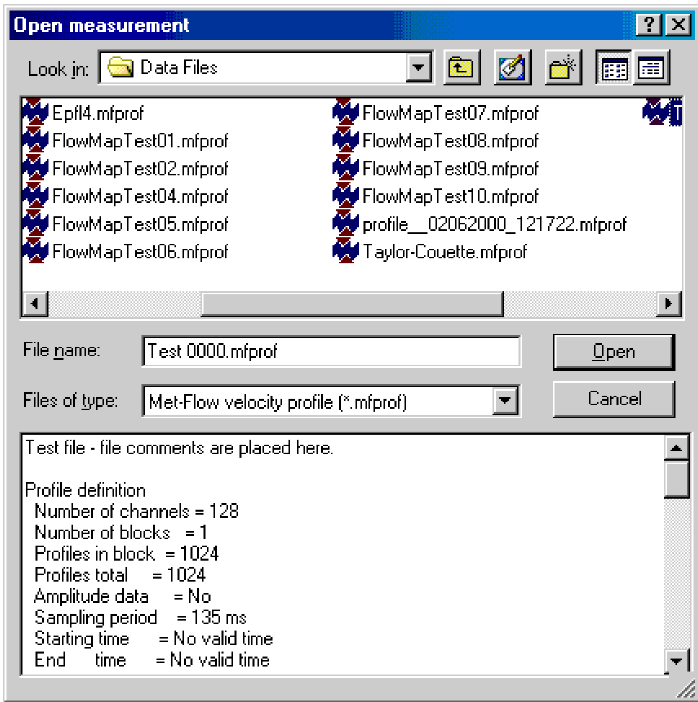


Figure 18 - Open file dialog with UVP parameter preview

Export… item is used for exporting measurement results as txt or csv files. *Export* also includes *Separate transducers* item for 'breaking' multiplexer multi-transducer files into separate single-transducer data files.

Page Setup…, *Print Setup…*, *Preview*, *Print…* are standard printing-handling items.

Exit item terminates the program execution.

Edit menu This menu consists of a standard *Copy* item, and three edit items:

- *Edit Angle* edits the ultrasonic transducer angle to the main flow's normal - see Figure 19.
- *Edit Multiplexer* parameters opens editing of 'multiplexer table' where multiplexer sequence and timing is set.
- *Edit Notes* adds and edits comments and notes to the currently opened or created data file. There is no limit for length of notes. Notes can be added or edited at any time, are saved with file, and shown on Open file parameter preview.

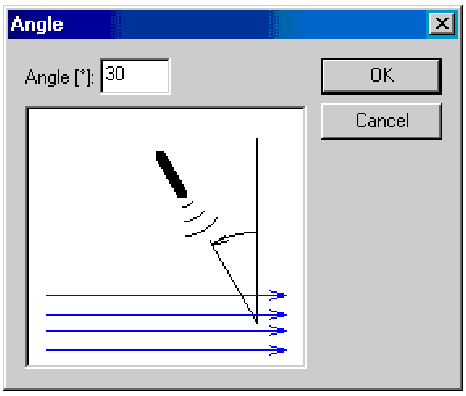


Figure 19 - Edit angle dialog

View menu contains *Tool bar* and *Status bar*, *Distance axis variable*, *Time axis variable*, *Velocity display scale*, and *Options…*

- *Tool bar* and *Status bar.* Clicking repetitively these items displays and hides tool bar and status bar. Displayed bar is marked by check mark.
- *Distance axis variable* selects distance axis variable scale between distance in [mm] and distance in [channel number], in all relevant windows. Select whatever option is more convenient for your case.
- *Time axis variable* selects time axis variable scale between time in [s] and profile in [profile number], in all relevant windows. Select whatever is more convenient for your case.
- *Velocity display scale* changes velocity scale of a displayed graph. For example, selecting 'X 2' on profile graph decreases graph vertical scale twice, which increases apparent graph amplitude twice. The feature is useful for display of graphs with small amplitude. Use 'Full scale' option to return to original size.
- *Options…* This opens a dialog with tabs containing selectable options to every window. The dialog opens on options belonging to a window, which currently has focus (highlighted title bar), but you can select any tab (by clicking by

mouse into its header) to change options for any window.
Options dialog can also be opened by clicking by mouse right button into a window. Context-sensitive menu opens. Select Options… by left mouse button. The dialog opens on a relevant tab. More about options see at respective window descriptions.

Measurement menu contains four items: *Instrument address, Test measurement parameters, Start measurement* and *Stop measurement*

- *Instrument address*, see dialog on Figure 20.
  If software Version 3 works without UVP hardware (data analysis), select the 'Local Instrument' option. In this case, Version 3 cannot collect measurement data, of course, but it can read, analyse and save files.
  Setting up of Ethernet connection between UVP-DUO and its host computer, or between host computer and LAN (Local Area Network) is described in Appendix: Communication set-up, Page 15.1. Nevertheless, it can be sometimes tricky. In case of problems, please consult your network manager.

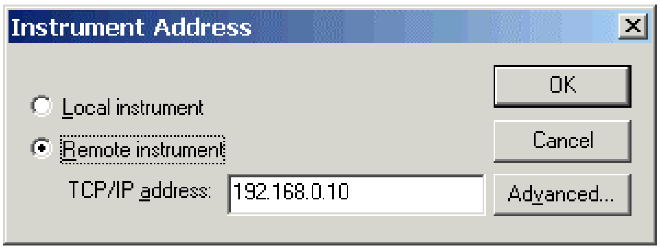


Figure 20 - Instrument connection settings

- *Test Measurement Parameters.* The latter opens a rather a complex wizard-style dialog with two pages, which enables to set up all UVP measurement parameters and multiplexer parameters, and run the measurement, but it does not save data into file. It is described in detail in Section 5.4, Test measurement, Page 5.35. After filling appropriate parameters and clicking OK, UVP Monitor starts pinging and collecting test data (without saving them).

- *Start measurement* opens a complex wizard-style dialog with three pages, very similar to that for Test measurement parameters. In addition, it allows editing file name of saved data, and adding notes to the measurement. It is described in detail in Section 5.5, Data saving, Page 5.43. After filling appropriate parameters and clicking OK, UVP Monitor starts pinging, collecting test data, and saving them in a file.

- *Stop Measurement.* It stops the running measurement. Both test measurement and real measurement are broken. In case of real measurement, the data file is saved, anyway, with appropriate comments visible in the 'Measurement info' window, see Figure 21.

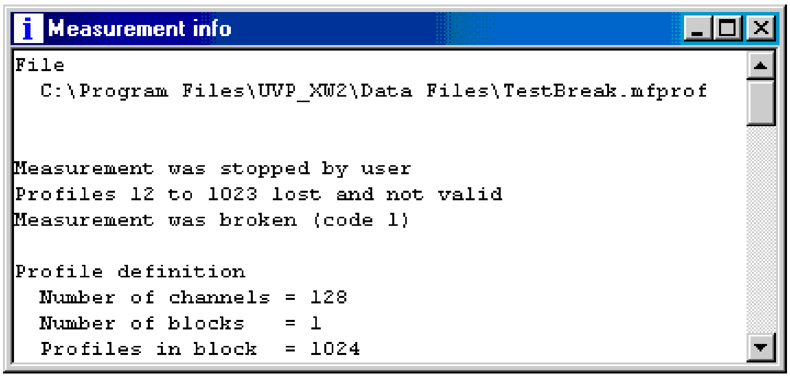


Figure 21 - Broken measurement message example

Analysis menu contains fourteen items, and includes all Analysis windows. This menu is described in a separate section.

Window menu contains standard Windows items for handling and arranging open windows (*Close All*, *Cascade*, *Tile Horizontally*, *Tile Vertically*, *Arrange Icons*), and list of currently opened windows.

Help menu contains standard Windows *Help* items, plus *About…* information.

5.2.2.4 Tool bar

There are actually two bars. The upper tool bar contains following icons:

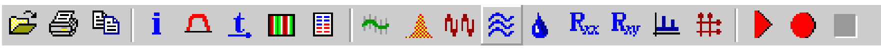


Figure 22 - Upper tool bar with icons

The icons have the following meaning (from left to right):

Open (file), *Print*, *Copy* (to Clipboard), *Measurement info*, *Profile graph*, *Time series*, *Color graph*, *Profile table*, *Average and statistics* graph, *Velocity histogram*, *Period enhancement (time)*, *Period enhancement (profile)*, *Flow rate*, *Auto-correlation*, *Cross-correlation*, *Power spectrum*, *Flow map*, *Test measurement parameters*, *Start measurement*, *Stop measurement*.

Clicking any icon either opens the matching window, or the matching dialog. Its functions are described in a separate section.

The lower tool bar contains some or all of the following controls (from left to right):

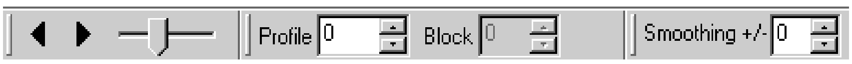


Figure 23 - Lower tool bar with controls

Two arrows mean '*Start/Stop movie backwards*', and '*Start/Stop movie forwards*'. These buttons work 'push-on, push-off'. Click once and movie starts moving. Click again, movie stops. The slider controls *Movie speed* (left–slow, right–fast). Three 'spin boxes' are used for selection of *Profile* and *Block* (if used), and for *Smoothing* selection. Its function is described with appropriate window description. All the controls in the lower tool bar are context-sensitive, and are visible only if they make sense for a window with focus. Other spin boxes can also appear on the toolbar.

5.2.2.5 Status bar

When no measurement is run, status bar displays tooltips belonging to the icon a mouse pointer is placed on.

When measurement is run, status bar displays name of file into which the current measurement is being saved, measurement validity indicator and bar, and measurement progress indicator and bar, indicating data collection progress. Validity 99% means that 1% of measured data is rejected.

Figure 24 - Status bar

5.2.2.6 Text windows

Text windows include Measurement info, Profile table, Average and statistics (one tab), and Flow map (two tabs).

Text windows can be resized; nevertheless they intentionally do not scale fonts while resizing. This improves readability because fonts remain the same size. All text windows can be scrolled whenever necessary. Scroll bar appears automatically whenever necessary.

All text windows support copying into Clipboard (<Ctrl + C>). This is very useful for copying data into reports and presentations. For copying into Clipboard, select (highlight) a cell or a block of cells by dragging a mouse and click <Ctrl + C>. Only the highlighted selection will be copied into Clipboard.

Specifically, it is possible to copy texts and tables directly into Microsoft Word and Excel. When copying tables or parts of tables into Word, the Clipboard also automatically adds matching table column name. Data in a table copied into Word are tab-separated.

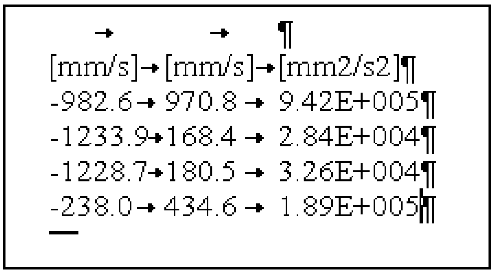


Figure 25 – Copying Table into MS Word

Please note that all text windows can be print-previewed and printed.

All text windows have context-sensitive pop-up menu, which is displayed by clicking right-hand mouse button into a window.

5.2.2.7 Graphics windows

Graphics windows include Profile graph, Time series, Color graph, Average and statistics (four tabs), Velocity histogram, Period enhancement, Flow rate, Auto-correlation, Cross-correlation, Power spectrum, Flow map (one tab).

All graphics windows support copying into Clipboard, which is very useful for copying data into reports and presentations. Full content of graphics window is copied.

Two options can be selected for copying to Clipboard. Copy as Bitmap copies the graphics window as bitmap. Copy as Vector copies the graphics window as an Enhanced Windows Metafile.

Specifically, it is directly possible to copy graphics directly into Microsoft Word.

Please note that all graphics windows can be print-previewed and printed.

All graphics windows have 'hot' cursor. When mouse cursor enters graphing area, it changes its shape from arrow to cross-hair. Co-ordinates of the cross-hair centre are displayed inside the window. This allows for precise evaluation of co-ordinates of points selected by cursor.

All graphics windows have context-sensitive pop-up menu, which is displayed by clicking right-hand mouse button into a window.

All graphics windows can be zoomed in. Just click by mouse into upper left corner of your area of interest and draw rectangle by moving mouse diagonally to right bottom. Then release the mouse button. The drawn rectangular area will expand to fill the window. Simultaneously, all scales are re-drawn. You can repeat zooming as many times as you wish. To un-zoom the window, just double-click by mouse into a window.

Inverse-zoom compresses all currently displayed window area into a mouse-dragged rectangle. To achieve this, push <Shift> or <Ctrl> key and drag rectangle by mouse. After releasing mouse button, inverse-zooming operation will commence.

All graphics windows have context-sensitive pop-up menu, which is displayed by clicking right-hand mouse button into a window.

5.2.3 Smoothing, Averaging

In several graphical windows, smoothing of measured profiles can be executed. This concerns Profile graph and Time series windows.

Due to a finite number of measurements and due to turbulence in measured liquid, measurement points lying next to each other differ by their statistical dispersion. Dispersion can be quite high especially for high turbulence and low number of ping repetitions. This is why a possibility to 'smooth' measured profiles and time series is introduced.

Two methods of smoothing are available in the software: average and median.

Average smoothing replaces the measured value in a certain point by arithmetic average of several measurement points lying around a point of concern. Please note that smoothing number of points is added to BOTH sides of a calculated point. This means that smoothing value +/-3 actually averages 7 points.

Median smoothing replaces the measured value in a certain point by median of the values in a certain smoothing interval. In practice, this means that all points from interval around a point of concern are sorted according to their value, and value of point of concern is replaced by their median (point in the middle of the sorted points). Please note that smoothing number of points is added to BOTH sides of a calculated point. This means that smoothing value +/-3 actually takes into account 7 points. Median smoothing is very efficient way of removing ‘shot’ type of noise, where a single value is significantly out of sequence, e.g. dropout of a value in a single point of measurement.

Note: *As smoothed point nears the beginning or end of graph, not all points necessary for smoothing might be available. In such case, the used computational algorithm decreases smoothing value for a given point according to number of symmetrical neighbouring points available. This means that ends of a graph are smoothed with lower smoothing.*

An example of different smoothing types is on following Figure 26 (unsmoothed profile, Figure 27 (average-smoothed profile), and Figure 28 (median-smoothed profile).

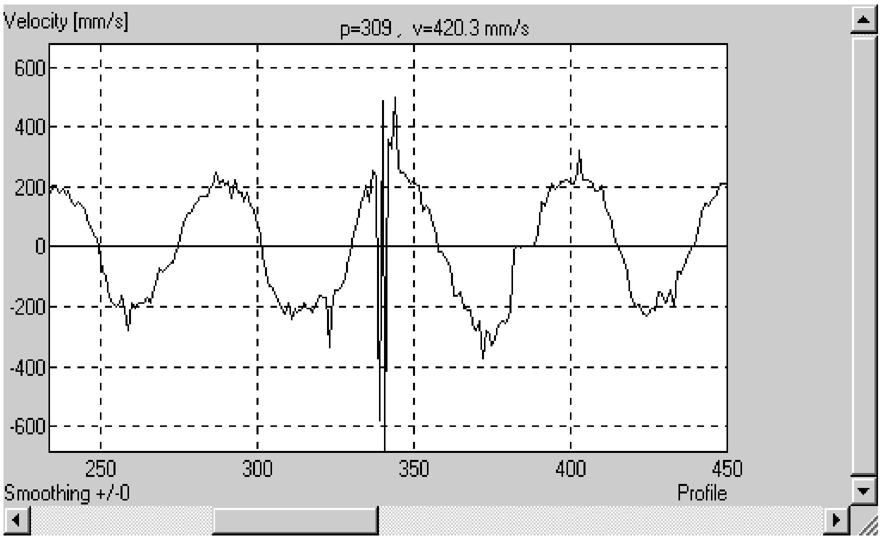


Figure 26 - Unsmoothed time series example

While average smoothing can nicely remove small high-frequency ripple, it cannot handle larger point discontinuity.

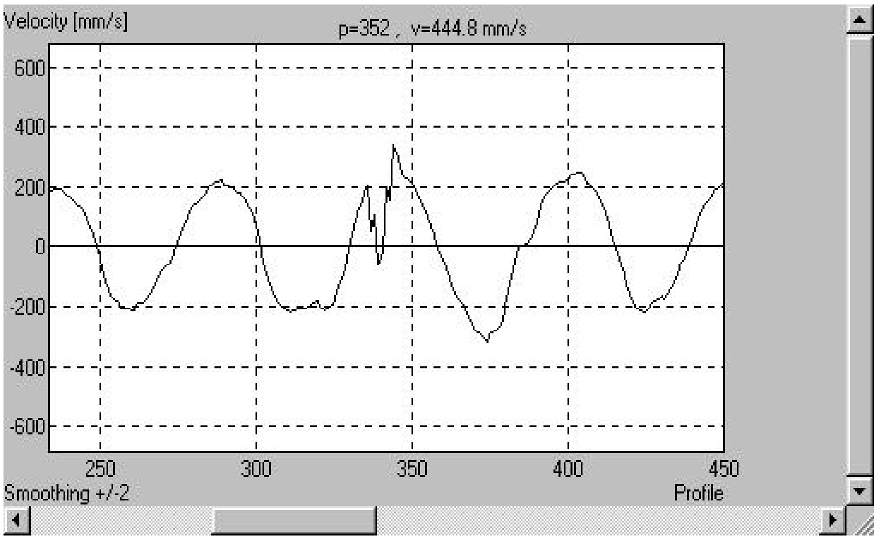


Figure 27 - Average-smoothed time series example (+/- 2)

Median smoothing has almost completely removed big discontinuity, which is dominant on unsmoothed profile.

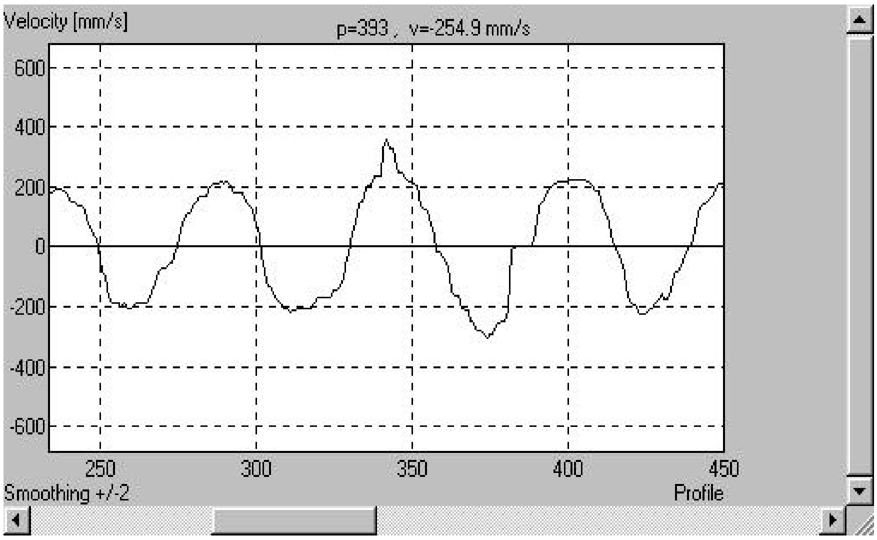


Figure 28 - Median-smoothed time series example (+/- 2)

In all examples, smoothing value of only +/- 2 has been used.

Selected type of smoothing applies for all windows of the running instance of the software. When changed, all respective windows are recalculated. Type of smoothing can be changed either from pop-up menu (right mouse button), or from Options…

Please note that smoothing goes along time axis, i.e. it is best observed on 'Time series' graph.

Differently expressed, each measured channel is smoothed separately.

5.2.4 Exclude zeros function

For various reasons, UVP Monitor sometimes does not succeed to measure certain profile point. Usually, the reason for this is lack of reflecting particles, too weak signal, or reflections. Such 'empty' points are then replaced by 'zero' value of velocity.

When doing smoothing and averaging, such 'artificial' velocity points can be excluded from measurement evaluation by 'excluding zeros'.

5.2.5 Exclude negative, Excluse positive function

Similar function, removing bad data points from smoothed data set, is executed by 'Exclude negative' or 'Exclude positive'. When measuring near the top of velocity range, some of measurement values can 'overflow' and fall into other side of the graph (see Aliasing). When performing smoothing from such data, overflown (or underflown) data can cause considerable havoc. This is why it is possible to exclude such data by the above functions (in mono-directional flows only!).

Selected type of data exclusion applies for all windows of the running instance of the software. When changed, all respective windows are recalculated. Type of data exclusion can be changed from pop-up menu (right mouse button), and are present in pop-up meny only when smoothing is set to non-zero value.

Note: ***Please do not confuse 'Exclude zero', 'Exclude negative' and 'Exclude positive' for similar items found in pop-up menu in Velocity display scale: 'All values', 'Positive and Zeros only', 'Negative and zeros only'. These items influence drawing of graph and its y-axis only. When 'All values' are selected, a bipolar graph is drawn. When 'Positive and Zeros only' or 'Negative and zeros only'are selected, software draws unipolar graph and skips the discriminated velocity values.***

5.2.6 Export to Tecplot

For presentation graphics and graphics postprocessing, all UVP measurement results can be exported into third-party Tecplot software.

Tecplot is plotting software with extensive 2- and 3-D capabilities for visualizing data from analyses, simulations and experiments. Tecplot helps explore data, produce informative 2- and 3-D views, create presentation-quality plots and animations, and share your results via the Web.

Tecplot is a product and trademark of

Amtec Engineering, Inc.
13920 SE Eastgate Way Suite 220
Bellevue, WA 98005
U.S.A.

Detailed information on Tecplot can be found on http://www.amtec.com/ .

To export data files into Tecplot format, select File | Export, select the result file to export, and in the File Export dialog select *Save as type… Tecplot (dat).*

The dat file type can be directly read by Tecplot. Met-Flow guarantees created file compatibility with Tecplot 8.0 and higher. It is very probable, that older versions of Tecplot can read these files as well, but were not tested by Met-Flow.

Work with Tecplot is fully described in Tecplot manual, and is not handled here.

Tecplot software is not a part of UVP software and is not available from Met-Flow.

5.3 Data analysis

Windows are described in the same order as their respective icons appear on the upper Tool bar, from left to right.

5.3.1 Measurement info window

The window contains all measurement status information and notes, including profile definition, sound speed, maximum depth and velocity range, measurement window parameters, measurement angle and C-factors, signal parameters, RF gain, trigger mode, multiplexer parameters and multiplexer table.

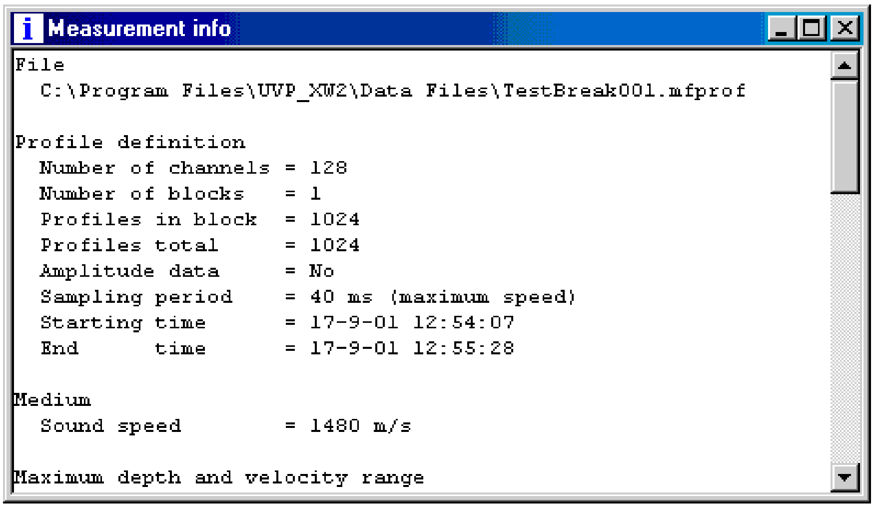


Figure 29 - Measurement info window

Click into window with right mouse-button to open a context -sensitive pop-up menu belonging to the window, see Figure 30.

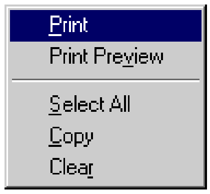


Figure 30 - Measurement info, pop-up menu

The menu is very basic because Measurement info window does not have any specific options.

5.3.2 Profile graph

This is one of the most significant windows in the UVP software. During data acquisition, it displays measured profiles on-line, and during off-line data analysis, it displays saved velocity profiles (red dots). Simultaneously, it displays the amplitude of raw US echo, returning to transducer (grey line). The amplitude of raw echo is saved with data.

It is possible to display/ hide the raw echo amplitude graph by checking/ unchecking the box *'Read amplitude'* in the second measurement dialog.

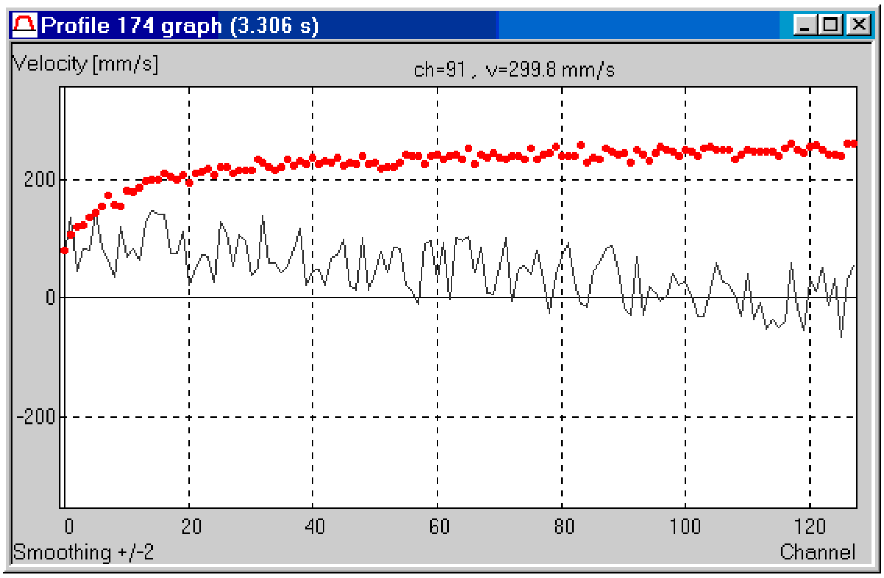


Figure 31 - Profile graph window

In window title bar the displayed profile number (and matching time from measurement start) are displayed. Once the cursor gets into the profile window, it changes into an active 'cross-hair' and its co-ordinates are displayed on top of the window. This enables to precisely measure co-ordinates of any measured point.

Profile window is controlled by several controls on a tool bar, see below.

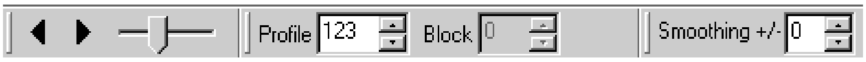


Figure 32 - Profile graph tool bar

A desired profile is selected by a 'Profile' spin box, eventually by 'Block' spin box, if more than single block of data is used (this is always the case with multi-transducer file).

Context-sensitive pop-up menu (click right mouse-button) contains several items:

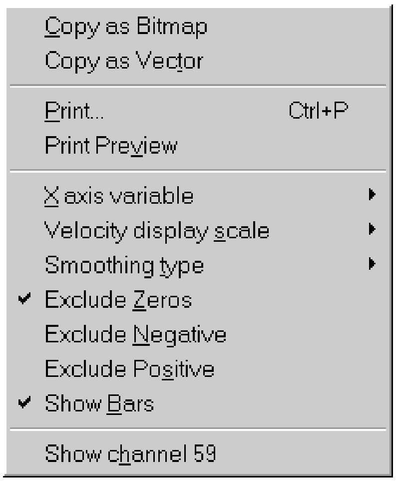


Figure 33 - Profile graph pop-up menu

- X–axis variable can be selected either in distance [mm], or in number of measurement channels.
- Velocity display scale changes y-axis scale without changing UVP parameters. This is a display-graphics operation only.
- Smoothing type – average or median. Smoothing can be set up from 0 (no smoothing) to +/- 99. Realistic smoothing values will be most probably under 10.
- Exclude Zeros, Exclude Negative, Exclude Positive. These options show in pop-up menu ONLY when non-zero smoothing value is set. For zero smoothing, they are hidden. Checking these options excludes selected values from averaging operations made inside smoothing.
- Show Bars. When checked, fills a bar to each data point, see Figure 34.
- Show channel… If you point a mouse pointer on a certain measured channel and click the right mouse button, the number of appropriate channel appears then in pop-up menu. Click this item, and software will open a window with time series graph (i.e. history) of the selected channel.

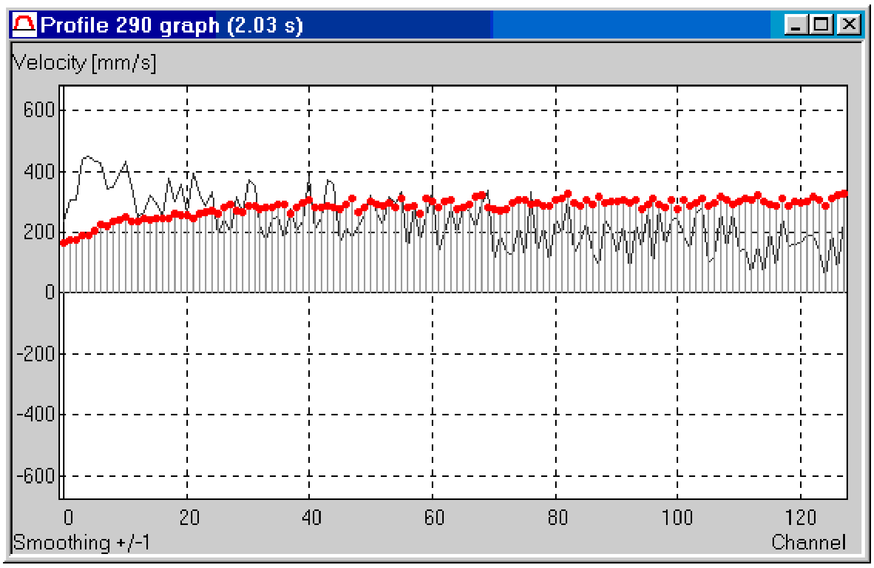


Figure 34 – Profile graph with bars

5.3.3 Time series graph

Time series graph shows velocity time series (history) in a selected spatial point (channel) or in several selected points (channels). This is also one of the most significant windows in the UVP software. During data acquisition, it displays velocity time series up to the last measurement on-line, and during off-line data analysis it displays saved velocity time series in selected point(s).

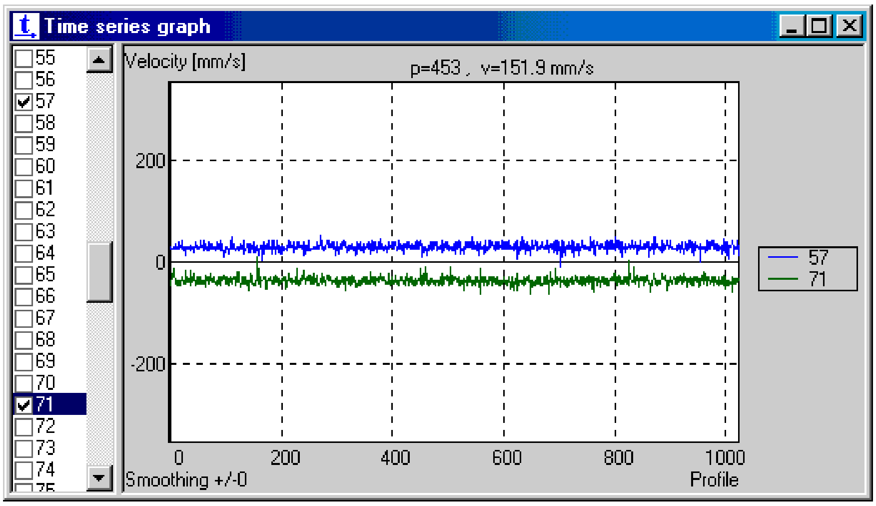


Figure 35 - Time series window (with multiple selection)

The number of displayed channel(s) is indicated in the right part of window, together with the matching line color (in the example above, Channels # 57 and 71 are displayed).

The window works in two modes of series selection: Single selection and Multiple selection.

Multiple selection mode allows several time series from different measurement channels to be displayed simultaneously, as in Figure 35. Selection is then controlled by check boxes at the left side of the window. Any number of series can be selected for simultaneous display. Selection can be deleted by clicking right mouse button into check boxes and clicking 'Clear All'.

Single selection mode displays only single series, but allows for fast change and sequential scrolling through channels by a 'Channel' spin box in a lower Tool bar.

Figure 36 - Time series tool bar

Selection between modes can be made from context-sensitive pop-up menu, or from Options…

Note: ***When no Channel is selected, no graph plot shows.***

Context-sensitive pop-up menu (click right mouse-button) contains several items:

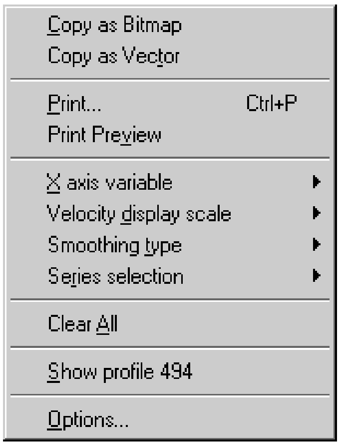


Figure 37 - Time series graph pop-up menu

- *X–axis variable* can be selected either in time scale [s], or in profile number.
- *Velocity display scale* changes y-axis scale without changing UVP parameters. This is a display-graphics operation only.
- *Smoothing type* – Average or Median. Smoothing can be set up from 0 (no smoothing) to +/- 99. Realistic smoothing values will be most probably under 10.
- *Series selection* can toggle between single and multiple selections.
- *Clear All* – deletes all channel selections (in multiple selection mode only).
- *Show profile…* If you point a mouse pointer on a certain measured profile and click the right mouse button, the number of appropriate profile appears then in pop-up menu. Click this item, and software will open a window with profile graph of the selected profile.

Smoothing can be applied to time series as well.

To Time series window following options apply, see Figure 38.

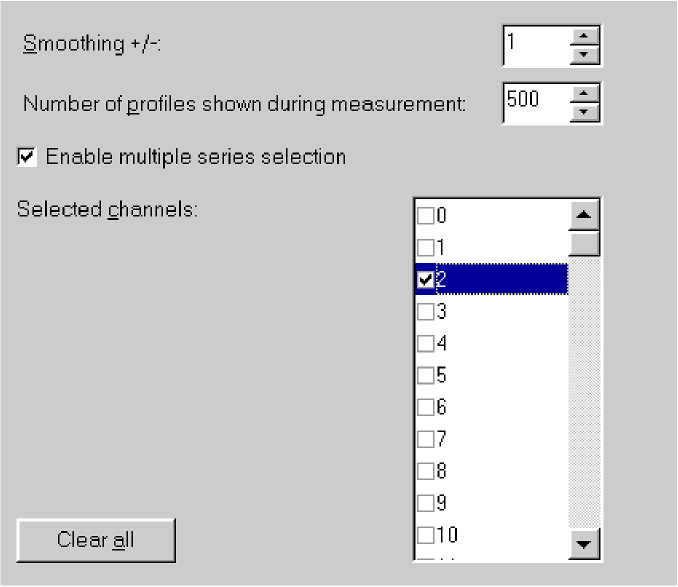


Figure 38 - Time series options

- *Smoothing* sets the same variable as *Smoothing* in the Toolbar.
- *Number of profiles shown during measurement* sets how many profiles are displayed in the Time series window during data acquisition.
  NOTE: When saved file is reviewed, the set value is ignored and window displays full length of time series graph, no matter how many profiles are included in reviewed file.
- Enable multiple series selection check box has the same function as Series selection item in pop-up menu. Channels can then be selected either in Options… dialog, or directly in the Time series window.
- Clear All button clears all checked boxes of multiple selection.

5.3.4 Color graph window

Color graph window enables quick overview of the entire data file. Each profile is represented by vertical line in the graph. It uses color-coding to display velocity in profile.

During data acquisition, the window is not active. During off-line data analysis, it displays saved velocity profiles in the whole file. An example of color graph display is on Figure 39.

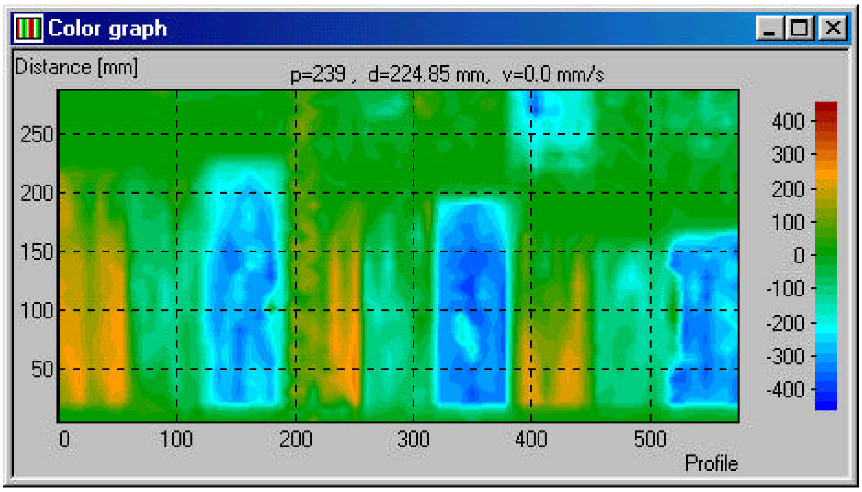


Figure 39 - Color graph window

Color scale used for velocity coding is depicted on the right side of the window.

Color graph window can be zoomed.

Color graph window always depicts the whole file, whatever number of profiles in the file. This is advantageous with large files, which otherwise would have to be scrolled.

Color series window does not have any controls in the lower Tool bar.

Context-sensitive pop-up menu (click right mouse-button) contains several items:

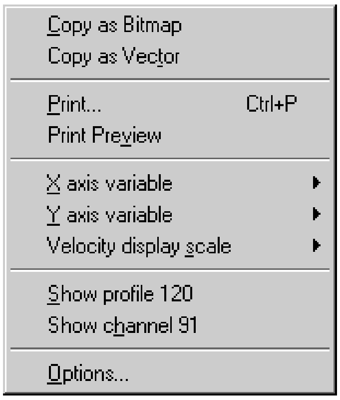


Figure 40 - Color graph pop-up menu

- X–axis variable can be selected either in time scale [s], or in profile number.
- Y–axis variable can be displayed either in distance [mm] or in channel number.
- Velocity display scale changes color scale without changing UVP parameters. Selecting higher number on display scale makes color-coding more 'dense'. This is especially useful where small near-zero velocities are measured. Changing display scale is a display-graphics operation only.
- Show profile… If you point a mouse pointer on a certain measured profile and click the right mouse button, the number of appropriate profile appears then in pop-up menu. Click this item, and software will open a window with profile graph of the selected profile.
- Show channel… If you point a mouse pointer on a certain measured channel and click the right mouse button, the number of appropriate channel appears then in pop-up menu. Click this item, and software will open a window with time series of the selected channel.

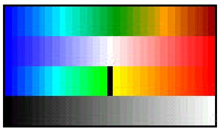
Mfprof file type can contain practically unlimited number of measured profiles, and color graph always displays the whole file. This is why color graph window does not depict every single profile, but averages the map and replaces it by a reasonable number of points. If data file contains smaller number of profiles, data for display are interpolated. Number of displayed points can be selected in Options… With large files, possible recalculation of all data can take some time. To cut down this time (especially when older slower computer is used), it is also possible to choose number of displayed color levels. Since software calculates levels of constant velocity across the complete file, decreasing number of color levels significantly speeds up the calculation. Select number of levels prudently.

To Color graph window following options apply, see Figure 41.

Figure 41 - Color graph options

- Grid size sets calculation grid for color graph interpolation, separately for x and y direction.

- Number of color levels sets number of calculated color levels.
- Color palette. Four different color palettes are available.



The first palette contains all colors and is ‘linear’. Second palette contains only different shades of red and blue, and it is very well suited for enhancing flow field sign. The third palette also includes all colors but has black line in zero velocity, and is very well suited for displaying zero velocity borders. Finally, yet importantly, the fourth palette is black-and-white only, and is suitable for printing color graphs on B/W printers.

5.3.5 Profile table

This is the numeric representation of profile graph. Single profile velocity co-ordinates are displayed here.

Profile 356 table (4.984 s)

	0	1	2	3	4	5	6	7	8	9
0	0.0	25.3	50.6	57.8	21.7	-10.8	18.1	-350.5	-375.8	-390.2
10	-386.6	-379.4	-321.6	-383.0	-346.9	-354.1	-357.7	-364.9	-368.6	-328.8
20	-339.6	-332.4	-307.1	-303.5	-307.1	-296.3	-343.3	-346.9	-372.2	-375.8
30	-350.5	-325.2	-310.7	-328.8	-346.9	-350.5	-357.7	-383.0	-357.7	-314.4
40	-350.5	-350.5	-346.9	-328.8	-303.5	-328.8	-303.5	-303.5	-285.4	-281.8
50	-321.6	-328.8	-325.2	-321.6	-328.8	-321.6	-350.5	-336.0	-375.8	-386.6
60	-401.1	-430.0	-426.4	-430.0	-411.9	-411.9	-422.8	-408.3	-346.9	-336.0
70	-350.5	-343.3	-325.2	-339.6	-328.8	-328.8	-314.4	-310.7	-303.5	-303.5
80	-267.4	-263.8	-285.4	-242.1	-238.5	-195.1	-104.8	-133.7	-122.9	-61.4
90	3.6	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0	-3.6
100	0.0	0.0	3.6	7.2	0.0	36.1	21.7	7.2	14.5	3.6
110	3.6	-28.9	-25.3	-7.2	-7.2	7.2	32.5	36.1	25.3	28.9
120	10.8	57.8	21.7	18.1	21.7	-47.0	-39.7	-43.4		

Figure 42 - Profile table

To make table more transparent, positive velocity values are printed in red fonts, and negative velocity values in blue fonts. Zeros are red.

Profile table can be copied to Excel via Clipboard. Only highlighted parts are copied. To highlight a block, click by mouse to its upper left corner, and draw rectangle. Rectangle is being highlighted ‘on the fly’.

Profile and Block (if blocks are used) selections are controlled by two spin boxes on a lower Toolbar, see Figure 43.

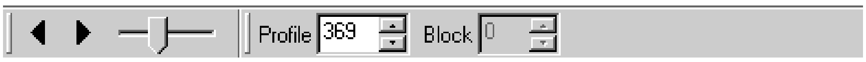


Figure 43 - Profile table tool bar

Profile table can also be run as a movie, in both directions, see controls on the lower Toolbar.

Profile table columns width can be resized by mouse dragging, similarly as is the case in Excel. Put pointer between column headers. Pointer will change to double arrow. Click mouse button and drag to increase/ decrease column width.

Profile table has only very basic context-sensitive menu (Print, Print Preview, Select All, Copy).
Profile table does not have any Options.

5.3.6 Average and Statistics graph

This is a very powerful window with five tabs: Average, Variance, Skewness, Kurtosis, and Table.

For theory basics and definitions, see Turbulent statistics basics, Page 8.1

All four graphics tabs use common x–co-ordinates and options, see Figure 44.

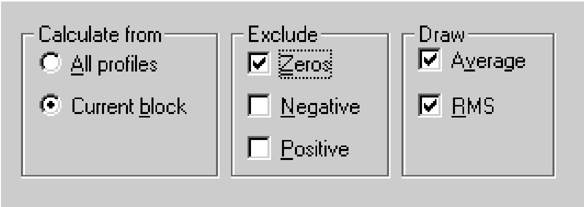


Figure 44 - Average and statistics options

All of these options are also in context-sensitive pop-up menu, Figure 45.

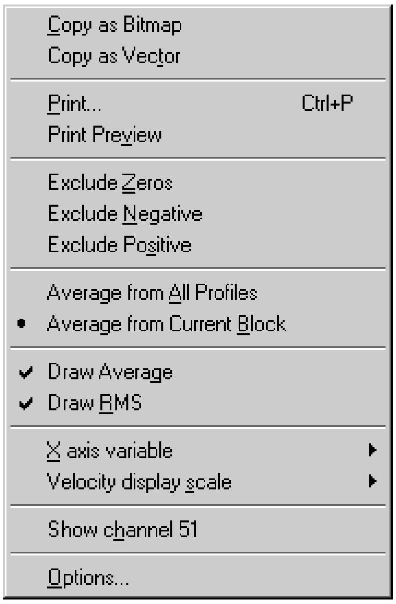


Figure 45 - Average and RMS pop-up menu

- *Calculate from.* Average and statistics can be calculated either from a current block, or from the whole data file.
- *Exclude.* Certain values of velocities can be excluded from calculation. Usually it is practical to exclude zeros, since channels with no value measured are displayed with zero value.

- *Draw*. It is possible to select drawing of Average only, RMS only, or both.
- *X–axis variable* can again be expressed in distance [mm] or channel.
- *Velocity display scale* changes y-axis scale without changing UVP parameters. This is a display-graphics operation only.
- *Show channel…* If you point a mouse pointer on a certain measured channel and click the right mouse button, the number of appropriate channel appears then in pop-up menu. Click this item, and software will open a window with time series of the selected channel.

Average graph

The graph plots average profile value and RMS value for the current block or for the whole file, see Figure 46.

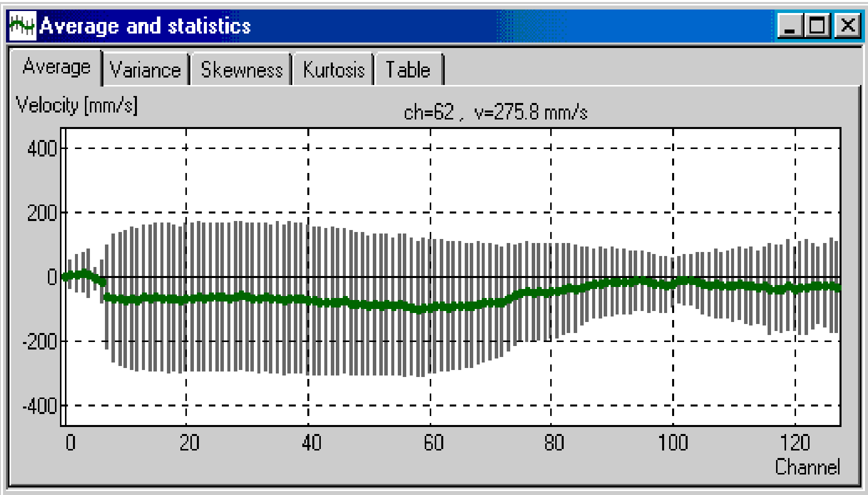


Figure 46 - Average and RMS graph

Variance, Skewness and Kurtosis

These are second, third, and fourth statistical moments. Their respective graphs tabs are similar in handling.

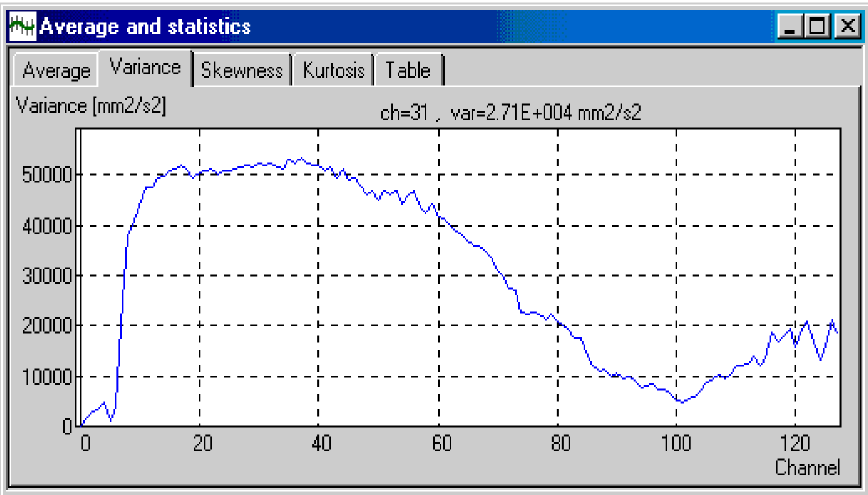


Figure 47 - Variance graph

Variance, skewness, and kurtosis use auto-scaling of the y–axis, and this is why they do not have the possibility to change vertical display scale.

Physical meaning of statistical values above is as follows:

Average. First statistical moment, also called ‘modus’. Average indicates the mean value of measured velocity points.

Variance is a measure of distribution ‘width’. The higher the variance, the wider the distribution is.

Skewness is a measure of asymmetry of distribution. Since variables are in the third power, skewness can reach both positive and negative values.

If S=0, distribution is symmetrical.

For S<0, velocity distribution is ‘skewed’ to the left (the larger tail of a distribution is on the left), to lower velocity values.

For S>0, velocity distribution is ‘skewed’ to the right (the larger tail of a distribution is on the right), to higher velocity values.

Kurtosis is always positive (variables in fourth power). Kurtosis shows if distribution is flatter on top of distribution (as e.g. top-hat distribution), or if it has narrower peak. Comparable Gaussian (Normal) distribution has kurtosis (flatness) value K=3.

Note: *Variance, skewness and kurtosis units are NOT in [mm/s] as is the case of average, but are normalized.*

Table

Table lists all measured and calculated values, displayed in the Average and Statistics window, plus ‘Valid samples [%]’. Valid samples column indicates possible elimination of data by ‘Exclude Zeros’, ‘Exclude Positive’ and ‘Exclude Negative’ values. When no data are excluded, Valid Samples is 100%.

Ch	Distance [mm]	Distance *cos [mm]	Average [mm/s]	RMS [mm/s]	Variance [mm2/s2]	Skewness	Kurtosis	Valid samples [%]

Figure 48 – Average and Statistics table

Valid samples is a very useful measure of how many data have been eliminated from calculation, and indirectly also represents an indicator of UVP signal quality. Since UVP hardware replaced non-measured points by zeros, the number of zeros in the resulting file is a good measure of signal quality.

To evaluate signal quality, click ‘Exclude Zeros’ in pop-up menu or Options… The closer the Valid samples value is to 100%, the better was the signal.

5.3.7 Velocity histogram graph

Velocity histogram graph displays histogram of velocities in a selected channel. This window is not active during data acquisition.

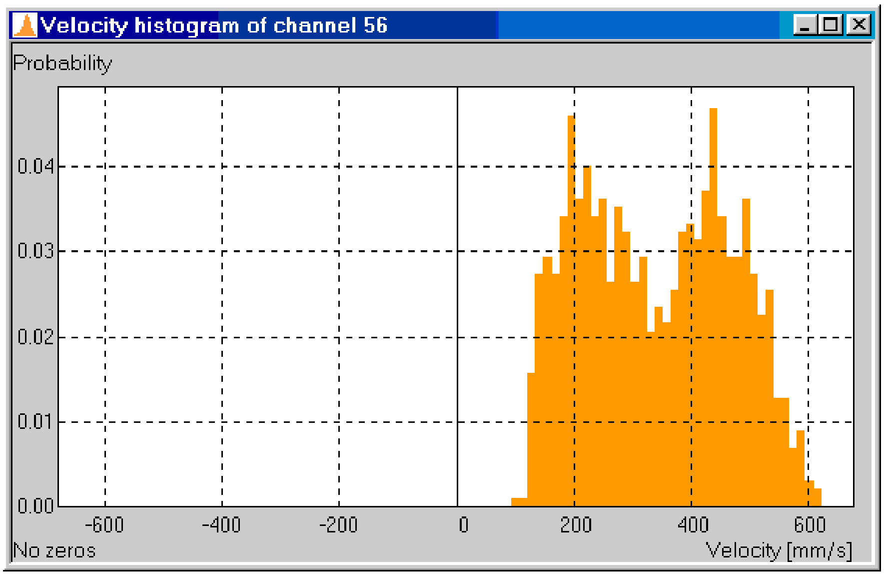


Figure 49 - Velocity histogram graph window

In window title bar, the displayed channel number is displayed. Once the cursor gets into the profile window, it changes into an active 'cross-hair' and its co-ordinates are displayed on top of the window. This enables to precisely measure co-ordinates (velocity and probability of the velocity in a given block or file) of any selected point.

The velocity histogram window is controlled by two controls on a tool bar.

Figure 50 - Velocity histogram tool bar

A desired channel is selected by a 'Channel' spin box, eventually by 'Block' spin box, if more than single block of data is used (this is always the case with multi-transducer file).

Context-sensitive pop-up menu (click right mouse-button) contains several items:

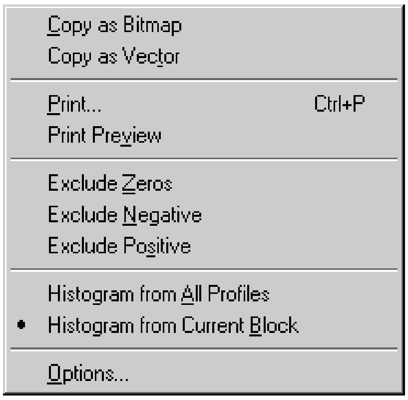


Figure 51 - Velocity histogram graph pop-up menu

These are standard graphics items *Copy* and *Print*, plus selection between *Calculate from Current Block*, or *Calculate from All Profiles*.

Unwanted values can be excluded from histogram by clicking *Exclude Zeros*, *Exclude Negative*, and *Exclude Positive* (values). Since UVP hardware replaces non-existent measurement points by zeros, it is therefore possible to calculate histograms from correctly measured points only.

Options for Velocity histogram window contains *Current block/ All profiles* selection, and *Number of intervals* selection.

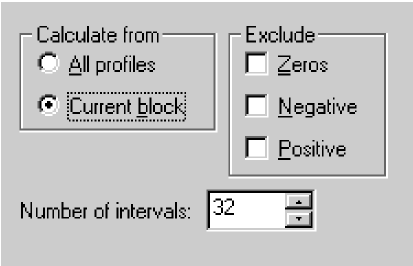


Figure 52 - Velocity histogram options

Number of intervals can be selected from 2 to 1024; however, it is not suggested to select too high number if data file is not sufficiently large. Smaller number of data would be scattered into too many intervals. For the beginning, 64 intervals might do for most files.

5.3.8 Period Enhancement (Time) graph

Many events in hydraulics have periodical character. This includes piston pumps, repeated opening and closing of valve, slowly rotating large mixers and other events. This is why UVP Monitor allows for phase averaging and resulting enhancement of periodic events.

Two graphics windows handle period enhancement. Both show the same effect and calculate the same data, but the first shows results as period-enhanced time series for a selected channel, and the second shows results as period-enhanced profiles for a selected phase.

Period enhancement (time) graph example is shown on Figure 53.

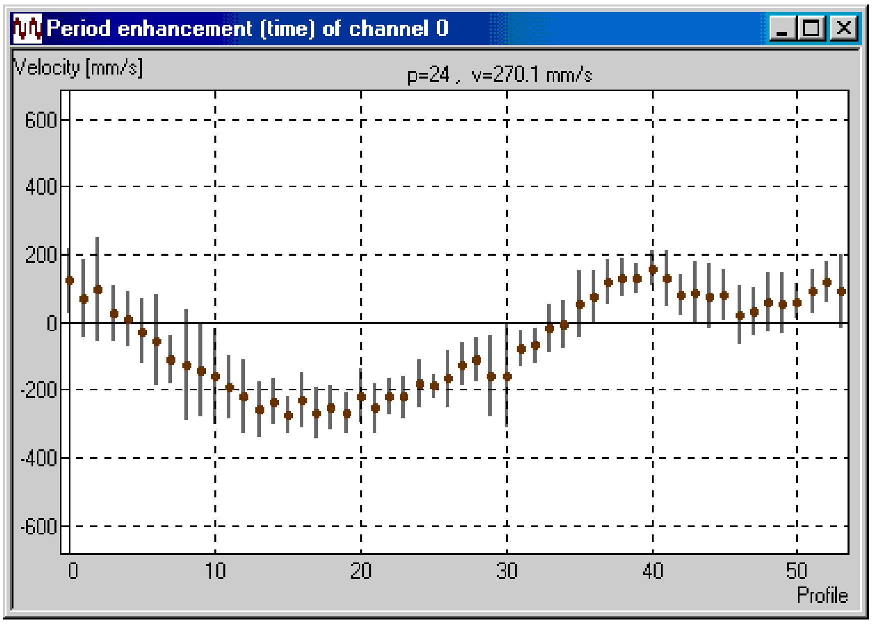


Figure 53 – Period enhancement (time)

Period enhancement is controlled by the following controls (Figure 54):

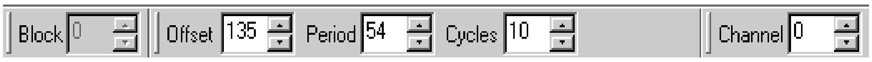


Figure 54 – Period enhancement (time) tool bar

- Block spin box is used for block selection only when more blocks is used.
- Offset selects the first profile where period enhancement begins. Profiles before the set Offset are not taken into account.
- Period sets the length of periodic event in number of profiles.
- Cycles controls the number of phase-averaged periods.
- Channel number selects the period-enhanced channel.

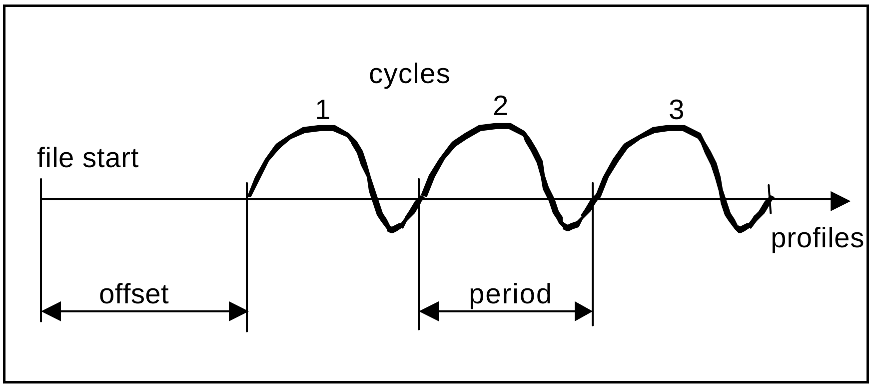


Figure 55 – Explanation of Offset, Period, Cycles

Offset can reach any value from 0 to the last file profile. Since there is only a limited number of profiles remaining for phase averaging, the product of Period and Cycle must always be less than number of remaining profiles. This is checked automatically by the software.

The pop-up menu belonging to the Period enhancement (time) is on Figure 56.

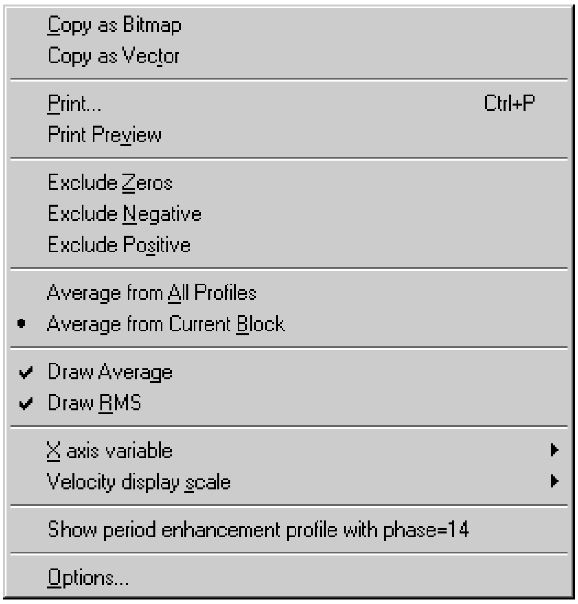


Figure 56 – Period Enhancement (time) pop-up menu

The menu contains standard items, plus some window-specific items:

- Draw Average/ Draw RMS controls if average and/or RMS values are drawn (similar to Average window).
- Show period-enhanced profile with phase = nn, where nn is profile number calculated from beginning of period (not from beginning of file!). The nn value can only reach the value of period length.

The Options… for the window are shown on Figure 57.

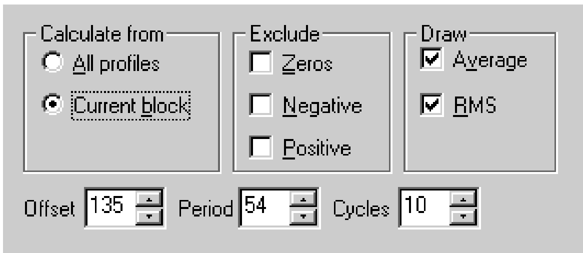


Figure 57 – Period enhancement (time) options

The Options include similar items as the pop-up menu.

5.3.9 Period Enhancement (Profile)

For explanation of window function, see Period enhancement (time). The Period enhancement (profile) only shows the results as if 'viewed from the other side of the fictional 3D profile –channel – velocity diagram'. Resulting curves of this window are phase-averaged profiles.

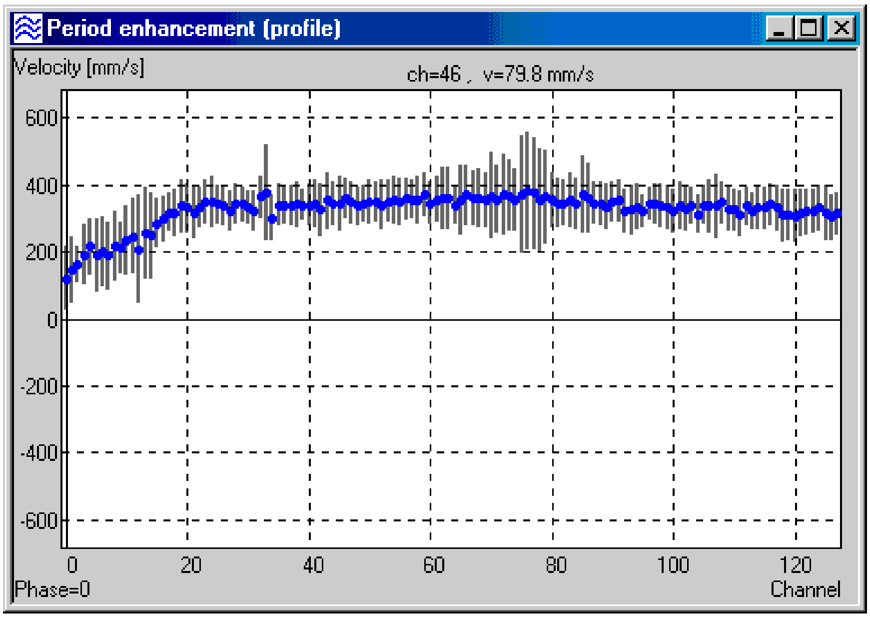


Figure 58 - Period enhancement (profile) window

The window is controlled by the following controls (Figure 59):

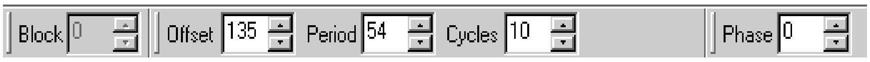


Figure 59 – Period enhancement (profile) controls

All terms Offset, Period, Cycles have the same meaning, but instead of Channel selection, as in Period enhancement (time), the selection of displayed profile is made by Phase selection (phase is expressed in profile number from the beginning of period).

Both pop-up menu and Options… are almost identical to Period enhancement (time).

5.3.10 How to set up Period Enhancement parameters

In the following example, file 'Cyclic.mfprof' is used.

First, look at the Color graph file, which will give you a 'panoramic' view on the file:

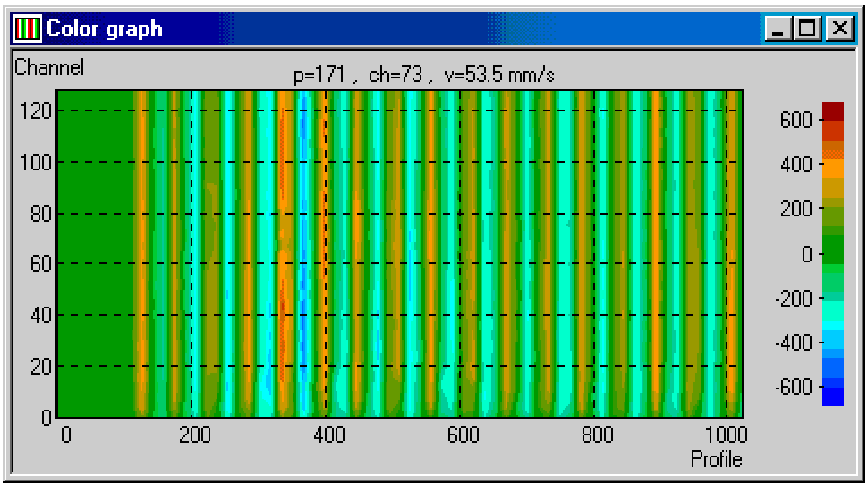


Figure 60 – Color graph of periodic flow

You can see that the fow is periodic, but the beginning of file (left part of the graph) does not show any periodicity. By pointing by mouse to the beginning of periodicity, establish the profile where periodicity begins (approximately Profile 170 in our case). This will be the Offset.

Open the Period Enhancement (Time) window. Set up the Offset (to 170 in our example).

Now it is necessary to establish Period length. Two methods can be used:

(a) Move cursor over several periodicities in Color graph, and by reading periodicity length from cursor co-ordinates establish Period length. Use more periods for more precise measurement.

(b) Use Power Spectrum window to establish the periodicity. The first large peak from left shows frequency belonging to the basic period. Place cursor to the peak (zoom into peak if necessary) and read periodicity on top of the window.

Set up the measured value into Period control.

Now select number of Cycles, which you want to use for period enhancement. Use at least two periods (more is better if you have sufficient file length available). On Period enhancement (time) graph an enhanced periodicity should show.

For periodicity setting up, use some channel from the center of measurement window (say, Channel 50). Marginal channels can be sometimes misleading.

Now try to fine-tune the Period. Click Period plus/ minus one or two profiles and observe the RMS drawn on the graph. The smaller the RMS, the better the used Period estimation. Use the Period value with the smallest indicated RMS. The Power spectra-measured periodicity and RMS-optimized periodicity should not differ by more than one profile.

Now after the parameters are correctly set up, you can view, print or export period-enhanced time series for different channels (selected by Channel control).

Period Enhancement (Profile) is set up in the same way. First set up Period Enhancement (Time), and then open Period Enhancement (Profile) window for the same parameters. List through period-enhanced profiles by changing the Phase controls (phase is expressed in profiles).

5.3.11 Flow rate window

Sometimes UVP Monitor can be used as a flowmeter. This is in situations when flow through channel or pipe has such geometry that from measurement of a single profile the total throughflow can be anticipated.

Two geometries are supported in the software: wide rectangular (parallel) channel and circular channel (pipe) fully filled with water.

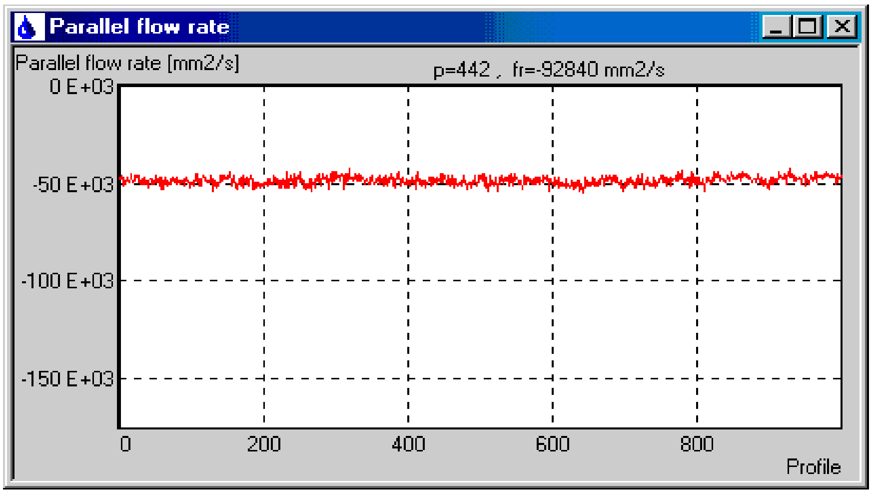


Figure 61 – Flow rate window

Several parameters must be set up before measurement:

- *Type of channel* (Parallel or Circular). This is set up either from pop-up menu, or from *Options…*
- *Transducer angle*. This is set up in *Edit | Edit Angle…*
- *First and Last channel*. Some of the measurement channels at beginning and end of measuring profile need not be valid. This is why these parameters can be eliminated from calculation by setting up the First channel and the Last channel, which come into calculation, from the *Tool bar* or from *Options…*

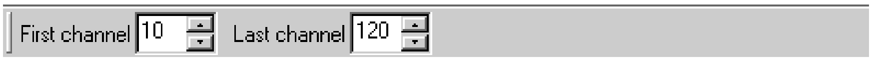


Figure 62 – Flowrate toolbar

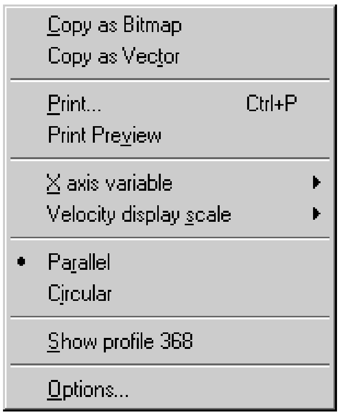


Figure 63 – Flow rate pop-up menu

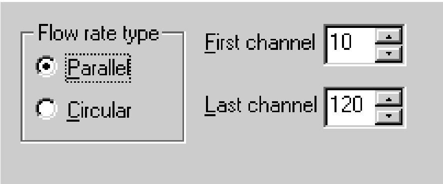


Figure 64 – Flow rate Options

Flow Rate is a nice feature but should be used with caution. Always be careful when estimating 3D throughflow from a single measured profile! The following conditions should be met during its use:

Parallel flow rate

Calculation expects two-dimensional flow in wide rectangular channel with no sidewall boundary layer. This condition is fulfilled in wide channels only. Other condition is constant water level during measurement. Since Parallel flow rate is calculated per channel unit width, do not forget to multiply calculated throughflow by channel width in [mm] to receive throughflow. Slight changes of channel width can also be used for throughflow calibration with independent external flowmeter.

Circular flow rate

Pipe diameter is calculated from oblique length between First channel and Last channel, with consideration of transducer angle. Calculation expects full circular pipe and axisymetrical flow. Good axisymmetrical flow distribution can only be found on straight pipe sections, which are distant from bends (say, 10 pipe diameters). If flow is changing sign, the condition should also be fulfilled downstream. This makes the measurement section rather long (20 diameters).

For formulas calculating the flow rate, see Appendix 13, Page 13.1.

Always remember that, due to hydraulic conditions above, throughflow measurement results are more or less precise estimates of real 3D flow, made from single profile measurement.

More precise measurement of throughflow can be achieved with use of more transducers and flow-mapping feature.

5.3.12 Autocorrelation window

Auto-correlation finds relations between different parts of the same time series. Practically this means finding periodicity in certain time series. For more details on theory of Autocorrelation, please look at Section 8.3.1 of this User's Guide.

Figure 65 shows an example of autocorrelation function indicating strong periodicity. Reader can view a color diagram of the used file on Figure 60 (file 'Cyclic.mfprof').

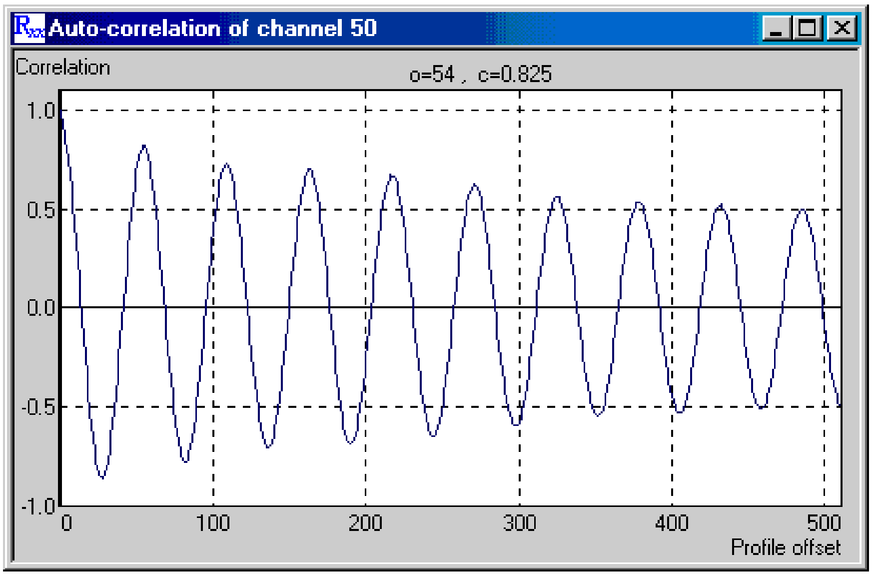


Figure 65 – Autocorrelation of channel with strong periodicity

Note that the graph shows that for $t = 0$, $R_{xx}(0) = 1$, as defined in Section 8.3.1.

Periodicity of autocorrelation function and autocorrelation value can be measured by cursor, see co-ordinates above the graph.

Autocorrelation graph is auto-scaled. Since maximum possible offset (t) is half of file length, x-axis is always one half of file length, whether expressed in [number of profiles], or in [mm].

Autocorrelation does not have any parameters to set, except Channel number.

Figure 66 – Autocorrelation toolbar

Pop-up menu and Options also include standard items only.

5.3.13 Cross-correlation window

Cross-correlation finds relations between different measurement channels. Practically this means finding how flow in one channel is influenced by events in other channel. For more details on theory of cross-correlation, please look at Section 8.3.2 of this User's Guide.

Figure 67 shows an example of cross-correlation function indicating strong influence of one channel on another channel. (Actually, this graph has been taken from UVP Emulator.)

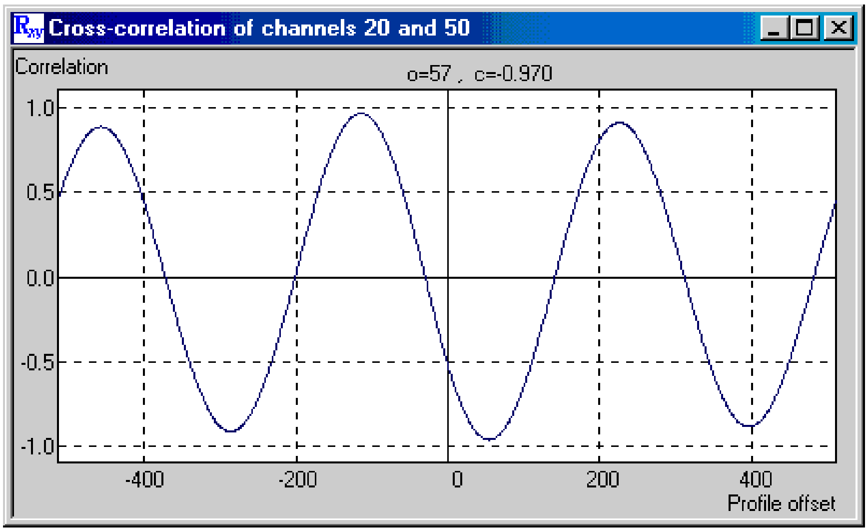


Figure 67 – Cross-correlation window

Note that cross-correlation function is not even, and can have any value at zero point. Cross-correlation function offset can be both positive and negative, each maximum half of file length.

When calculating cross-correlation function, it is necessary to select two channels, which are then cross-correlated. One of them is called a 'pivot' channel. Both channels are selected from tool bar.

Figure 68 – Cross-correlation toolbar

Pop-up menu and Options… include standard Copy/Print items only.

5.3.14 Power spectra window

A power spectrum is an important indicator of state of the flow. Basics of power spectra theory can be found in Section 8.4, Page 8.4.

Power spectra window displays results of turbulent power spectra analysis. An example of power spectra window is depicted on Figure 69.

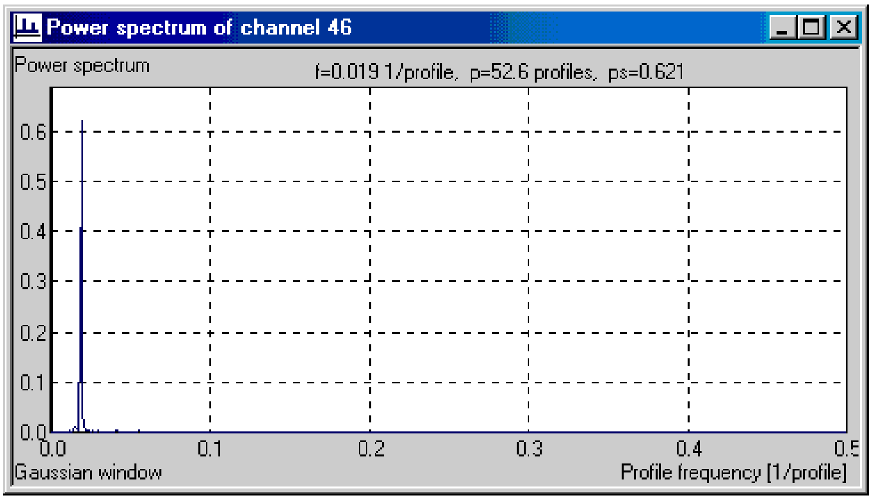


Figure 69 – Power spectrum window

Power spectra x-axis can be expressed either in profile units, or in time units [s]. Changing of x-axis description also changes representation of cursor co-ordinates above graph.

Upper power spectra range is limited by profile sampling frequency. To achieve higher frequency, set up UVP parameters for fast measurement (small *# of repetitions*, small *Maximum depth*).

Lower spectra range is limited by length of record. For lower limit, acquire long data files. Use 2^n profile length (1024 and longer) for efficient Fourier transform and spectra calculation.

For shorter data files, windowing is necessary. Version 3 Software provides for several windowing functions, for their definitions see Section 8.4.

Generally, Gaussian windowing function is a safe bet.

Power spectra window does not have any parameters to select, just Channel number from Tool bar, and windowing function from pop-up menu or options.

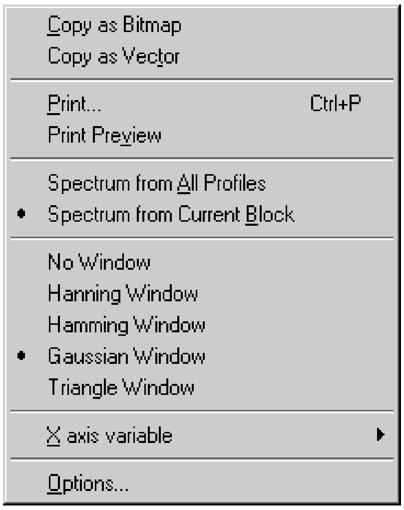


Figure 70 – Power spectra pop-up menu

Power spectra pop-up menu items are standard, with exception of windowing functions.

Power spectra Options… have similar items as pop-up menu.

5.4 Test measurement

Up to this point, the User's Guide has been describing analysis of existing UVP data files. Now it is time to acquire some new data. Software Version 3 allows for two modes of operation with active transducer:

- Testing of operation and measurement parameters (no data saving)
- Data acquisition (measured data are saved into file).

This Section handles the first item.

5.4.1 Setting of instrument address

Since UVP-DUO hardware is controlled from remote computer, UVP software communicates with UVP-DUO hardware by way of TCP/IP protocol. This is why it is necessary to set up TCP/IP addresses first.

Before starting the set-up procedure, make sure that UVP-DUO and the host computer are connected by null-modem (lap link) cable.

The host computer also has to have its Ethernet card/adapter activated and its TCP/IP address set. This procedure is different for each operating system, and is briefly described in an Appendix 15. Before starting to set up connection with UVP/DUO, check that this host computer address is set.

Warning	***The host computer can also be operated within a local network, it can use more than one Ethernet cards, or even more complex setup. In such case, do not attempt to change these settings, and consult your Network Manager. Changing computer's TCP/IP address can have disastrous effect on network operation.***

To set up an UVP-DUO TCP/IP address, proceed as follows:

From main menu, click *Measurement | Instrument address…*

The following *Instrument connection settings* dialog appears, see Figure 71.

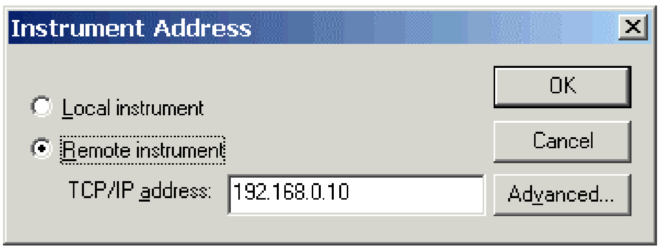


Figure 71 – Instrument connection settings dialog

Click *'Remote instrument'* radio button. (Software Version 3 operates as *'Local instrument'* only when being operated as an upgrade on older UVP-XW model.)

Now click the *'Advanced…'* button. The following dialog appears, see Figure 72:

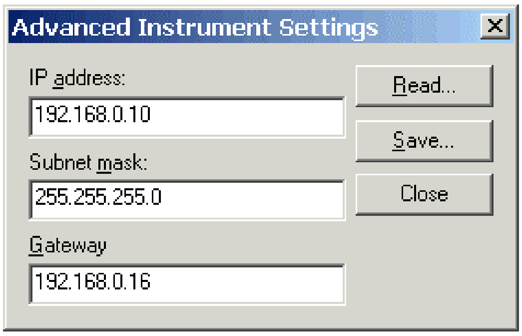


Figure 72 – Advanced instruments setting dialog

UVP-DUO comes with a TCP/IP address already preset (see also Figure 72). To read the UVP-DUO address, click *'Read…'*. Version 3 will then read the actual TCP/IP addresses from UVP-DUO, and display them in the dialog.

Warning	***These addresses can also be edited (e.g. by Network Manager…). Do not try to edit TCP/IP addresses if you are not sure what you are doing.***

Before reading addresses, it is necessary to select a Comm port:

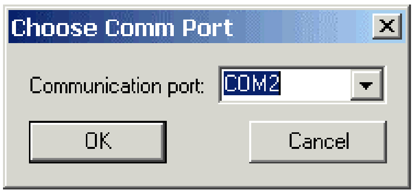


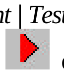
Figure 73 – Choose Comm port dialog

Choose the suitable COM port, where the null-modem (lap link) cable is connected, and click <OK>.

When TCP/IP addresses are satisfactorily set, click 'Save…'. Software will then save the TCP/IP addresses within the host computer.

This will return you to the Instrument connection settings dialog.Finalize setting by clicking <OK>.

5.4.2 Setting up Test measurement parameters

Test measurement is initiated from main menu by selecting *Measurement | Test measurement parameters*, or click the Test measurement parameters icon  on a Tool bar. (The icon reminds of 'Play' icon on voice and video recorders.) A wizard-style dialog opens.

All test measurement parameters are set from a single dialog, depicted on Figure 74.

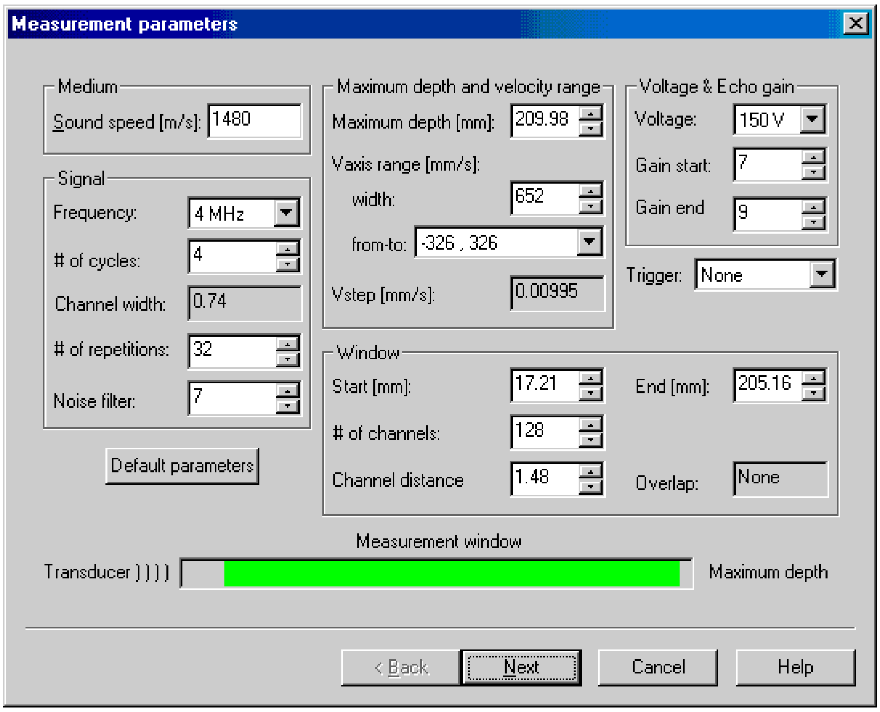


Figure 74 – Test parameters window – Measurement parameters tab

Note: ***For relations between measurement parameters, see Section 3.1, Page 3.1.***

There are several groups of parameters in the dialog.

Medium group consist of a single item:

- *Sound speed.* As far as the UVP measurement is concerned, the sound velocity is the parameter that identifies the type of fluid. Although in general the sound velocity depends on density, temperature, etc., an appropriate single value has to be supplied. *This is a fundamental number for the UVP because it is used to compute the values of other parameters.* For fresh water enter 1,480 m/s if no more specific value is known.

Signal group consists of following items:

- *Frequency*. Here a transducer working frequency is set. Select between 0.5, 1, 2, 4, or 8 MHz, corresponding to transducer and hardware version used.
- *# of cycles*. The more working cycles (number of wavelengths in the emitted burst) are emitted within a single pulse, the better the echo signal, but the wider the channel width.
- *Channel width.* This is a calculated parameter. It depends on Sound speed, Frequency and Number of cycles. If *Channel width* exceeds *Channel distance*, *Overlap* occurs and is indicated in the (measurement) Window section.

- *# of repetitions*. This is a number of repeated pings (pulses) done for a single valid profile measurement.
- *Noise filter*. The higher the number set, the higher is the signal recognition level. Setting up Noise filter too low can result in more error measurements. Setting up Noise filter too high can result in missing measurement points.

Warning	***The selected US frequency must fully comply with the working frequency of an ultrasonic transducer(s) used for the measurement! Otherwise, wrong operation or even damage to instrument might result.***

Trigger list box sets up trigger mode. Normally no trigger is used and data acquisition starts by clicking dialog <Next> and <Measure> button, and after UVP gets ready. Since before data acquisition UVP hardware executes testing, this might take several seconds. In order to start profile acquisition in response to a triggering signal, Trigger must be set to either *Manual* (from display or keyboard) or to *Positive* or *Negative* (external trigger TTL signal (0–5 V/ min. 20 ns) from BNC connector at the back plate of UVP-DUO). To prepare then the UVP to accept a trigger signal, click <Measure> button. Finally, profile acquisition begins when the trigger signal is received. In Manual mode, a small dialog is opened (see Figure 75), and data acquisition starts either by clicking <OK> or by pressing any key on the keyboard.

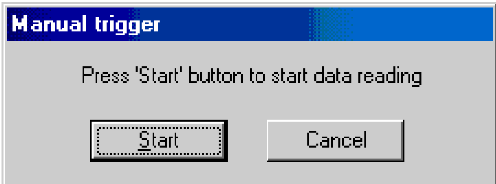


Figure 75 – Manual Start dialog

Maximum depth and velocity range section sets up maximum measurable depth (and indirectly interval between US pulses) and velocity range.

- *Maximum measurable depth [mm]*. The maximum depth is directly related to the pulse repetition frequency of the ultrasound burst. The measurement window must lie between the top surface of the transducer and the maximum depth. The longer the maximum measurable depth, the lower the maximum measurable transducer on-axis velocity. This parameter can be varied in accordance with measurement requirements as well as the flow configuration.
- *Velocity range [mm/s]* displays the maximum measurable velocity. This is directly related to Maximum measurable depth, and only one of these parameters can be set up independently. For further details, see *Maximum depth and Maximum velocity*, Paragraph 3.1.6, Page 3.7. For higher velocity range, select lower US Doppler frequency transducers.
  Velocity range can be either symmetrically spread around zero velocity, or from zero to positive, or from zero to negative. Nevertheless, the total range remains the same. Select the option you prefer from a list box.

- *Vstep [mm/s]* is the maximum velocity resolution, given by UVP-DUO bit sampling. This is a calculated value.

Measurement window section controls parameters of measurement window.

- *Start [mm].* Distance between the active surface of a transducer, and position of the first channel. This parameter is useful in positioning the measurement window to avoid a wall or disturbed region of flow (due, for example, to the transducer).
- *End [mm].* is calculated from *Start* and *Channel distance*. Therefore, if measurement window end is edited, Channel distance changes, and vice versa.
- *# of channels*. Here there is a great change in comparison with previous software. While in 'old' UVP-XW software the number of channels was fixed to 128, in UVP-DUO software Version 3 the Number of channels can be selected from 10 to 2048.
- *Channel distance [mm].* Distance between channels (i.e., two measurement volume centres). Again, Channel distance can be either selected, or results from selection of measurement window End and Number of channels. Modifying Channel distance changes the End of the measurement window.
- *Overlap [%].* This is a value calculated from Channel distance and pulse length. It is the ratio between the common overlapped volumes of two adjacent measurement volumes, by one measurement volume.

Measurement window indicator bar is placed at the bottom of Test parameters tab. On the left side of indicator is the active end of transducer, on the right side is the Maximum measurable depth. Active measurement window is indicated by green bar length. Since all the dialog re-calculates values in real time, transitionally bad parameters can be set up (e.g. during editing of values). In such case, indicator turns red.

When user attempts to start measurement with non-valid parameters (by clicking <Next> button), software displays warning with explanation and returns back into the previous dialog. In this way, it is impossible to start measurement with non-valid parameters.

Gain and Voltage group of parameters handles US transmission intensity and receiver amplifier gain.

- **US Voltage.** US Emission voltage parameter sets the peak-to-peak voltage applied to the transducer. The selection is 30–60–90–150 V. The setting for this parameter depends on the strength of the ultrasound attenuation, and the concentration of reflectors in the liquid, and needs adjustment to give the best profile.
- **Gain Start** - gain at the beginning of reception period
- **Gain End** - gain at the end of reception period.

One unit corresponds to the value of 6 dB.

The factory default settings for RF gain are for water. In general, different types of liquid have different ultrasonic attenuation coefficients. If the working fluid is not water, it may be necessary to adjust the slope of the amplification gain distribution (exponential) so that an adequate echo signal is received. The slope of the amplifier gain distribution is defined using the Start and End values.

Default parameters button. This button sets up a set of 'reasonable' parameters for measurement in water. Its purpose is to get UVP measuring and displaying some values.

The following parameters are set:

- Sound speed 1,480 m/s
- # of cycles 4
- # of repetitions 32
- V-axis range symmetrical around zero
- Voltage 150 V
- Gain start 7
- Gain end 9
- Sampling time minimum.

5.4.3 Data Acquisition - Setting up transducers and timing

After setting up measurement parameters, click <Next> button to proceed to Data Acquisition dialog. The following dialog opens, see Figure 76.

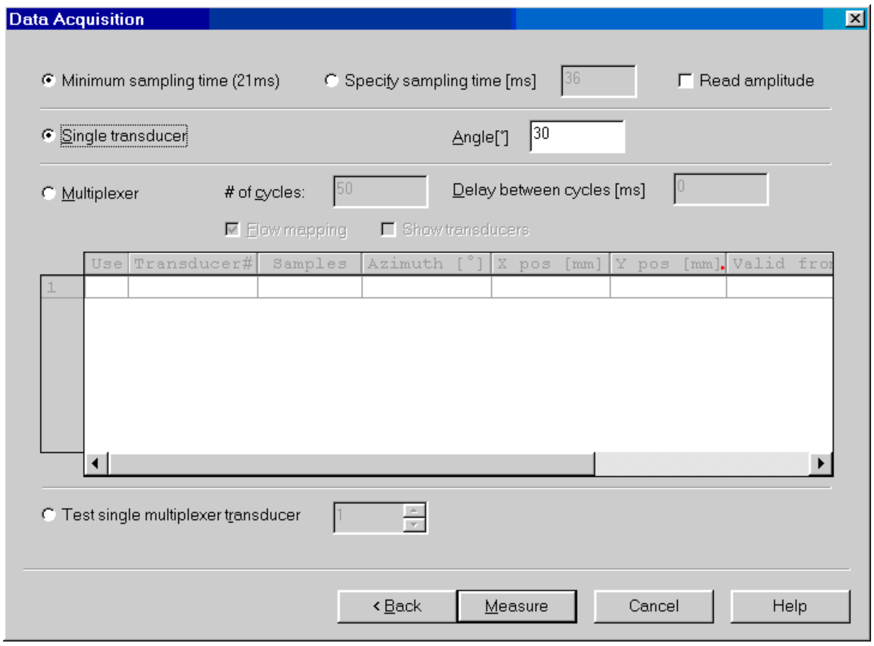


Figure 76 – Test parameters window – Transducers tab

The following radio buttons and fields have to be filled or selected:

- *Minimum sampling time* or *Specify sampling time [ms]*. If Minimum sampling time is selected, then software collects data 'as fast as it can'. Please also note that here the minimum sampling time is indicated. Minimum sampling time is dependent on selected measurement parameters (Sound speed, Maximum depth, # of repetitions, # of [multiplexer] cycles).
  Sometimes it is advantageous to collect data more slowly. In such case, it is possible to specify sampling time [ms].

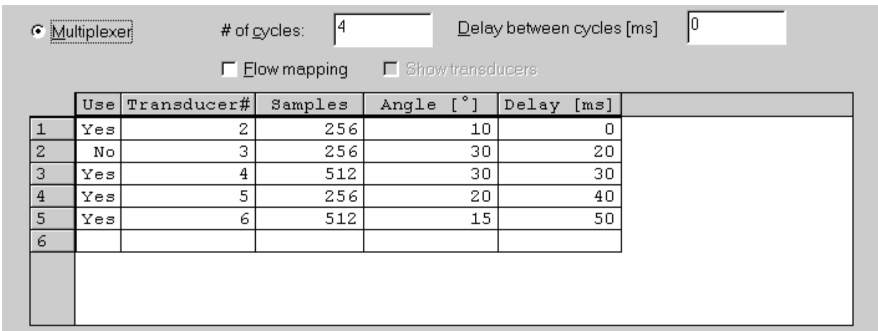
- *Read amplitude.* This feature allows for reading and displaying Doppler echo amplitude. This feature partially replaced the use of oscilloscope for monitoring Doppler echo. It is especially useful for recognition of unwanted US reflections.

Note: ***In new software Version 3, sampling time has different, clear-cut, definition when compared with old UVP-XW Release 2 software. Now 'sampling time' means overall time distance between saved measurement profiles, whatever time of measurement is.***
If sampling time is 100 ms, then software collects 10 profiles per second.
It is also impossible to use shorter Sampling time than is measurement time, since software checks for correct parameters.

- *Single transducer.* If single-transducer use is intended, select *Single transducer*, and edit number of profiles acquired in a single data file. It is a good idea to acquire 2^n profiles, since 2^n makes an efficient Fourier transform and therefore it makes efficient correlation and power spectrum. Default file length of 1024 profiles is suggested.
- *Multiplexer*. If more than one transducer are used, click Multiplexer. When using multiplexer, it is necessary to fill in the multiplexer table.
- *Flow mapping.* If this box is checked, software will be ready for flow mapping. Some of angle definitions change meaning etc. For flow mapping details, see Section 5.6, Flow mapping, Page 5.46.
- *Angle [°]*. This is the same transducer-to-flow-normal angle as set in Edit | Edit Angle menu.
- *Test single multiplexer transducer [number].* When setting up measurement, it is useful to test a single transducer in real time. Select the transducer you want to observe from the list box.

5.4.4 Multiplexer table

Multiplexer table can be edited only when Multiplexer is selected. Multiplexer table is depicted on Figure 77. Multiplexer table is also printed in Measurement info window and saved in data file (only active transducers).



	Use	Transducer#	Samples	Angle [°]	Delay [ms]
1	Yes	2	256	10	0
2	No	3	256	30	20
3	Yes	4	512	30	30
4	Yes	5	256	20	40
5	Yes	6	512	15	50
6					

Figure 77 – Multiplexer table

Only one transducer can be active at any time. For each transducer, the following data have to be filled in:

- *Use [Yes – No]* describes if a transducer will be used for data acquisition or skipped. Toggle Yes/No by double-clicking by mouse.
- *Transducer #* is a number of transducer, which is the same as transducer connector number on multiplexer output.
- *Samples* means number of profiles acquired by UVP during each sweep through multiplexer table.
- *Angle [°]*. This is the same transducer-to-flow-normal angle as set in Edit | Edit Angle menu.
- *Delay* is time delay (waiting time) between end of data acquisition from the current transducer, and start of data acquisition from the next transducer.
- *# of cycles* defines how many times will software repeat its sweep through entire transducer table.
- *Delay between cycles [ms]* defines delay (waiting time) between acquisition cycles.

Example: *(see the Figure 77 above) The following measurement sequence is set up: Switch to Channel 2, execute profile measurement 256 times and then wait 10 ms. Then switch to Channel 4 (Channel 3 is not used!), execute profile measurement 512 times and then wait 30 ms. Then switch to Channel 5, execute profile measurement 256 times and then wait 40 ms. Then switch to Channel 6, execute 512 meausements and then wait 50 ms. Then return to the beginning of the cycle (then wait 0 ms), and start a new cycle. Repeate the whole cycle 4 times.*

5.4.5 Test measurement execution

After setting up all parameters and data acquisition, click <Measure>. This starts measurement execution.

During test run, measurement results can be viewed online, however, only the following windows are available for on-line viewing: Measurement information, Profile graph, Profile table, and Time series graph. Other windows are dimmed.

For single transducer, test measurement runs indefinitely, until stopped manually.

To stop the measurement, either from menu click Measurement | Stop Measurement, or click the Stop icon from Toolbar.

Note: ***During each data acquisition, software gives higher priority to data acquisition, and only during remaining time, it updates display. This is why, on slower computers, display blinking can be visible. We therefore suggest having only one or two active windows open during data acquisition.***

No saving of data takes place during test measurement.

5.5 Data saving

Once you have mastered test measurement, it is very easy to make full measurement with data saving.

To initiate measurement from menu, click *Measurement | Start Measurement…*, or click the red *Start* icon from *Toolbar*. (The icon reminds the 'Record' symbol from voice and video recorders.) The Measurement parameters wizard-style dialog opens. Only two things are different in full data acquisition dialog: setting file name, and editing measurement text notes.

5.5.1 File name

File name is entered in the Data Acquisition dialog. At bottom part of the dialog, there is an editing box for file name, with standard Browse… button and dialog, see Figure 78.

Figure 78 – File name edit box

File name can be entered by hand, or selected from Browse… dialog. Software Version 3 also provides for automatic file naming. The following rules apply:

Default path and file name suggested in the Edit box is the last open or created file name, with a number at the end of file name.

- If there is no number at the end of file name, software adds a number ‘1’.
- If there is a number at the end of file name, software increments it by ‘1’.
- If there was no previously opened file, software uses the last file displayed in *File* menu.
- All created files have extension ‘mfprof’ (for **M**et-**F**low **Pr**ofile **F**ile), whether it is shown in the edit box, or not.

Example: *If the last open file was ‘Test’, then the next automatically named file will be ‘Test1’.*
If the last file name was ‘Test1’, then the next file name will be ‘Test2’.

Please note that such file numbering system always places files into selected folder, and that measurement sequence of files is clearly recognizable. Files do not have any time information in its name since they contain time information inside the file.

Format of files is binary. If export of data is desired, please use *File | Export…* feature from the main menu.

5.5.2 Measurement text notes

Measurement notes can be added to each file. Measurement notes can be of unlimited length. Measurement notes are saved with data file.

More notes can be added any time later, and saved with file.

To edit *Notes* before measurement, click the <Notes…> button in the *Measurement Parameters* dialog. The *Notes* dialog appears, see Figure 79:

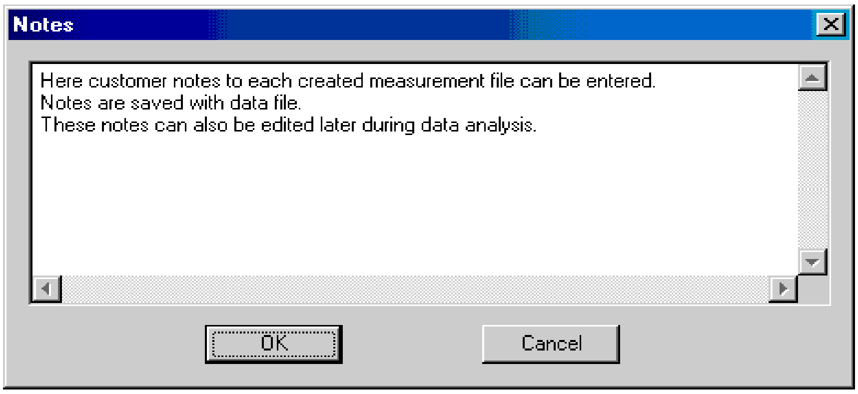


Figure 79 – Measurement notes

It is strongly suggested to provide rich comments and notes to measured data files.

5.5.3 Measurement templates

The most probable measurement parameters for next file are measurement parameters from previous file.

This is why when opening *Measurement parameters* dialog, software Version 3 also copies all measurement parameters (including Multiplexer table) from previously opened file, or from previously opened Test measurement parameters.

This feature allows for creation of unlimited number of measurement templates. Any measurement file can actually be used as template.

To use measurement template, just open a data file with desired measurement parameters, click *'Start measurement'*, and name the newly created file to its desired name and path. All parameters of the former (template) file will be copied into the new file, with the exception of Notes, of course.

5.5.4 Measurement execution

After all parameters are set (and possibly test measurement run), click <Measure> from Data Acquisition dialog. This will initiate measurement.

You can always stop running measurement by clicking from menu Measurement | Stop Measurement, or by clicking red icon Stop  from Toolbar.

Measurement can have practically unlimited number of profiles, nevertheless, keep in mind that very long files can take a lot of space on your hard disk.

A typical mfprof-type file with 128 channels in profile and 1024 profiles takes approximately 273 kB on hard disk, but can be zipped to 97 kB by external software.

If you intend longer time span measurement, specify longer Sample time between measured profiles.

With 1 profile-per-second (Sample time = 1000 ms), 24-hour measurement only takes 86,400 profiles, which corresponds to approximately 26.5 MB file size. This is a quite manageable file size.

5.6 Flow mapping

5.6.1 What is flow mapping

Flow mapping means using multiple transducers for simultaneous measurement of a complete 2D flow field.

It is necessary to emphasize that flow mapping should be attempted only AFTER a user gets VERY familiar with UVP technique and UVP Monitor instrument. If a user has problems while handling single-profile measurement, it is not very likely that he or she could handle field mapping with many transducers where problems multiply and precision of measurement depends on the worst measured profile.

Although flow mapping is generally possible for three-dimensional space for 3 components of flow, it is usually practical to perform flow mapping in two-dimensional planes only. This is why software Version 3 provides calculations for 2D flow mapping only.

For 2D flow mapping, it is necessary to measure two velocity components at one spatial point in order to form a vector. Two velocity components are known at any intersection of measuring lines of any two transducers.

A vector can be obtained from any two non-parallel components, however, it should be noted that a small crossing angle causes large inaccuracy in direction estimation. Best measuring results can be achieved with orthogonal (or nearly orthogonal) measuring lines.

Warning:	***It should be noted that measured vector component is an orthogonal projection of a true vector into a measuring line. Reverse forming of a true vector from two measured projections is therefore made by drawing two lines in end points of measured projections, which are normal to each corresponding component measuring line. The resulting vector end-point is formed by an intersection of these normal lines, see Figure 80. Do not simply make a parallelogram of measured vector components!***

The situation of vector orthogonal decomposition is depicted on Figure 80.

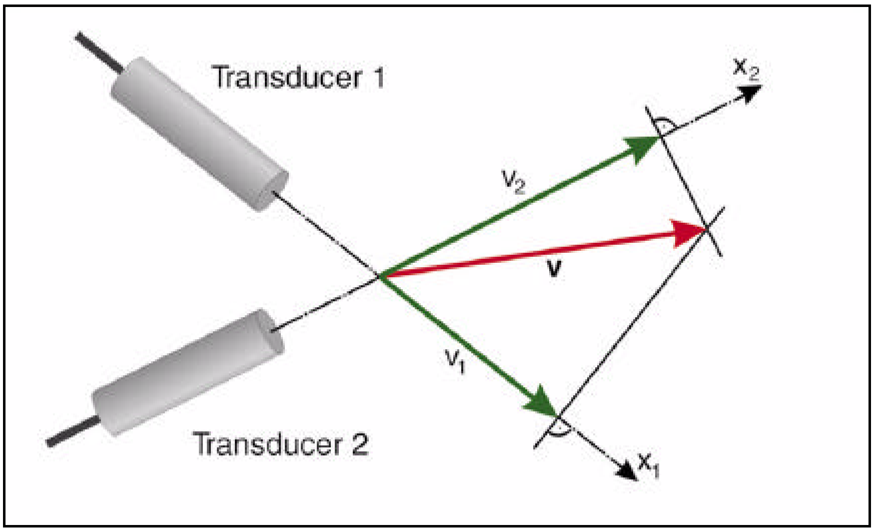
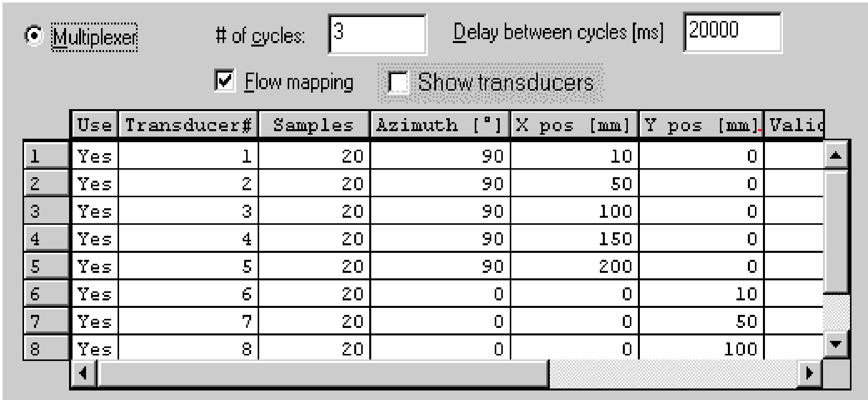


Figure 80 – Vector orthogonal decomposition

5.6.2 Setting up transducer grid table

In flow mapping, transducer position and timing are edited from the same Data Acquisition dialog as normal multiplexer table.



	Use	Transducer#	Samples	Azimuth [°]	X pos [mm]	Y pos [mm]	Valid
1	Yes	1	20	90	10	0	
2	Yes	2	20	90	50	0	
3	Yes	3	20	90	100	0	
4	Yes	4	20	90	150	0	
5	Yes	5	20	90	200	0	
6	Yes	6	20	0	0	10	
7	Yes	7	20	0	0	50	
8	Yes	8	20	0	0	100	

Figure 81 – Flow mapping grid table

Once '*Flow mapping'* check box is checked (see Figure 81), for each transducer the following data have to be filled in:

- *Use [Yes – No]* describes if a transducer will be used for data acquisition or skipped. Toggle Yes/No by double-clicking by mouse.
- *Transducer #* is a number of transducer, which is the same as transducer connector number on multiplexer output.
- *Samples* means number of profiles acquired by UVP during each sweep through multiplexer table.
- *Azimuth [°].* Describes direction of US beam transmission, in standard 'mathematical' way (0° azimuth = 3 o'clock, positive azimuth increases anticlockwise, negative azimuth increases clockwise. The software accepts both positive and negative values of azimuth, up to +/- 360°, so users can use any positive or negative value which is convenient to them.).
- *X position [mm].* Transducer front face in Carthesian co-ordinates.
- *Y position [mm].* Transducer front face in Carthesian co-ordinates.
- *Valid from [mm].* US beam is considered for crossing only in selected 'valid' length from–to certain limit. This is the beginning of 'valid' length.
- *Valid to [mm].* US beam is considered for crossing only in selected 'valid' length from–to certain limit. This is the end of 'valid' length.
- *Delay[ms]* is time delay (waiting time) between end of data acquisition from the current transducer, and start of data acquisition from the next transducer.
- *# of cycles* defines how many times will software repeat its sweep through entire transducer table. Each cycle produces a separate flow map.
- *Delay between cycles [ms]* defines delay (waiting time) between acquisition cycles.

The transducer grid can be plotted on-line during editation, when a check-box *Show transducers* is checked. Checking the box opens a graphical window with transducer map. This map changes dynamically, as soon as changes in multiplexer table are made. This greatly simplifies setting up of flow mapping table.

The *Transducer* grid map can only be displayed, when *Flow mapping* check box is selected.

As with Multiplexer table, Flow mapping table is saved with data file.

After Flow mapping table is set up, measurement can be initiated by clicking the <OK> button on Measurement parameters dialog.

Graphical Flow mapping table design can be viewed in Flow mapping window.

5.6.3 Flow map window

Flow mapping data are displayed in the Flow mapping window. To open *Flow map* window from main menu, click *Analysis | Flow Map.* From *Toolbar*, click the *Flow map* icon  . *Flow map* window opens, see Figure 82.

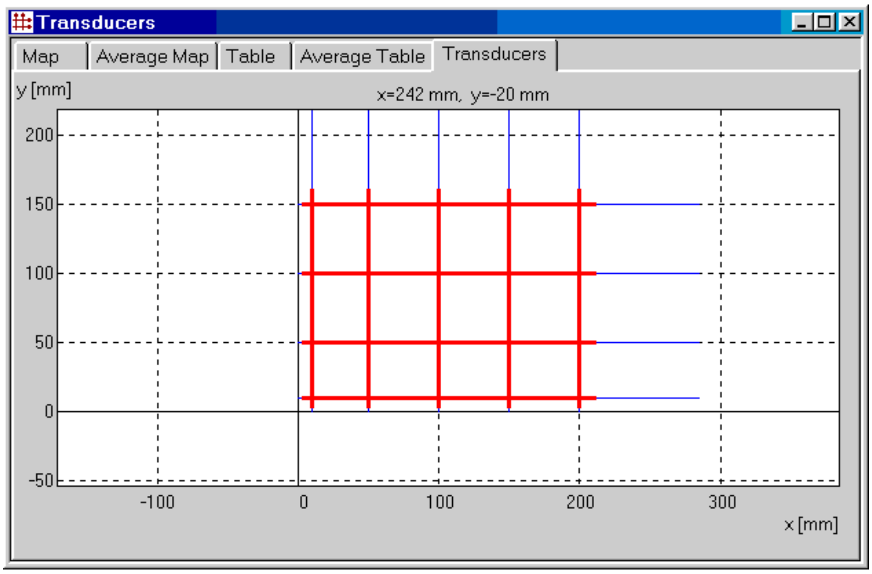
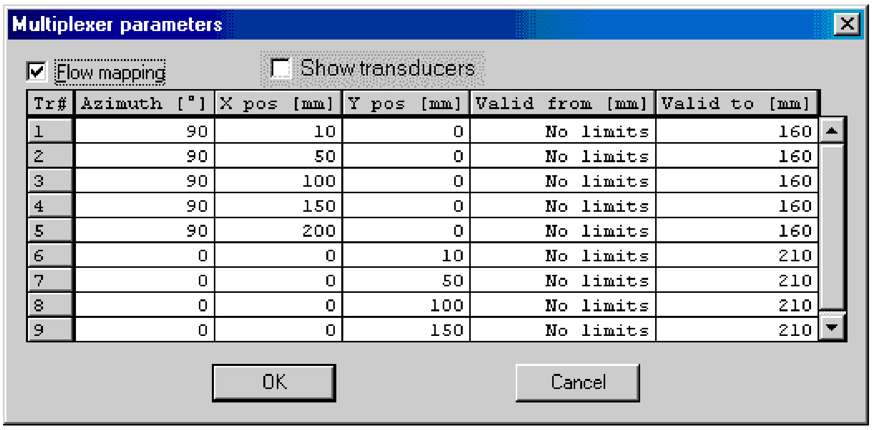


Figure 82 – Flow map window – Transducers tab

The **Transducer tab** shows graphical layout of transducer grid (thin blue lines) and its active measurement zones (thick red lines). In our example, there are 9 transducers forming the grid, five of them measuring 'vertically' from bottom to top (Azimuth = 90 deg), and four transducers measuring 'horizontally' from left to right (Azimuth = 0 deg). Thick red lines mark active measurement zones of transducers (see 'Valid from' to 'Valid to'). Thin blue lines also mark transducer's 'Maximum depth', i.e. the most distant place where transducer can measure.

The Flow map window can be also zoomed into by mouse, as other windows.

Multiplexer parameters can also be seen and edited from *Edit | Edit Multiplexer Parameters…* dialog. The multiplexer table corresponding to the flow-mapping grid depicted on Figure 82 can be seen on Figure 83.



Tr#	Azimuth [°]	X pos [mm]	Y pos [mm]	Valid from [mm]	Valid to [mm]
1	90	10	0	No limits	160
2	90	50	0	No limits	160
3	90	100	0	No limits	160
4	90	150	0	No limits	160
5	90	200	0	No limits	160
6	0	0	10	No limits	210
7	0	0	50	No limits	210
8	0	0	100	No limits	210
9	0	0	150	No limits	210

Figure 83 – Edit Multiplexer Parameters table

We suggest that you compare data from table on Figure 83 with graphical representation of the same data on Figure 82 to get a better grasp of transducer grid editing.

It is also possible to display *Transducer* grid map from *Multiplexer parameters* table by checking the *Show transducers* check box.

The Flow map window has only standard Copy/ Print pop-up menu with reference to Options.

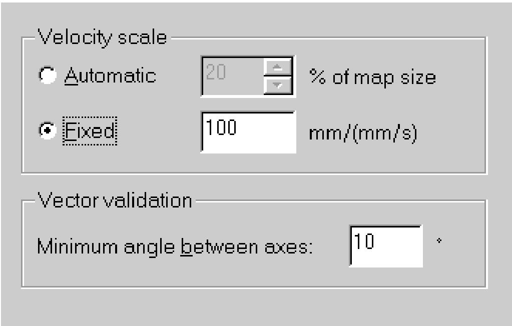


Figure 84 – Flow map options

Options of Flow map include the following parameters:

- *Velocity scale.* In *Automatic* scaling mode, the longest depicted vector can reach a pre-set fraction of map size (20% as default value). In *Fixed scale* mode, user can edit and calibrate his or her vector scale.
- *Vector validation.* Most precise spatial resolution results when two transducer axes are crossing under 90° angle. Two parallel transducer axes do not offer any crossing point whatsoever. When axes cross under very small angle, the resulting vector can have large uncertainty. This is why user can suggest the smallest crossing angle acceptable for vector calculation. All crossing points resulting from smaller-angle crossings will be ignored in calculation and graphics.

Warning	*For successful flow mapping it is necessary that transducers have well-aligned mechanical axis and US axis. Original Met-Flow transducers are of controlled high quality, and are suitable for flow mapping. Cheaper 'no-name' transducers do not always comply with quality conditions necessary for flow mapping. This is why we strongly suggest to use original Met-Flow transducers.*

The **Flow map** tabs show vector flow maps of a flow field. An example of flow map is on Figure 85.

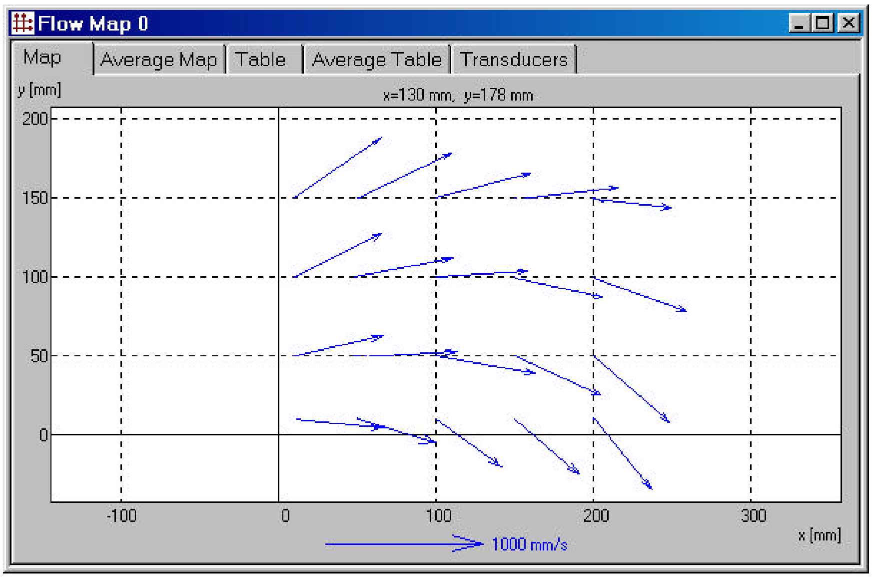


Figure 85 – Flow map window – flow field map tab

Each crossing of two US transducer axes has generated one 'arrow' representing flow velocity in axes crossing point. Orientation of arrow shows velocity vector direction, length of arrow represents flow velocity.

Please note that there are as many separate flow maps as there were '*# of cycles*' in the Flow map table. This means that each 'sweep' through all active transducers produces a separate flow field map. This allows for measurement and recording of changing flow fields.

Flow maps are selected by a selection box in Tool bar.

Figure 86 – Map selection box

Average flow map is calculated from all available flow maps in a data file.

It is also useful to know measured data in numerical form. These data are shown in additional tabs in tabular form.

An example of flow map **Table** is shown on Figure 87. (The Table gives crossing points matching to the Example above, but velocity values are simulated.

Flow Map 0

Map | Average Map | Table | Average Table | Transducers

	X pos [mm]	Y pos [mm]	X velocity [mm/s]	Y velocity [mm/s]	X RMS [mm/s]	Y RMS [mm/s]	Tran.	Distance A [mm]	Tran.	Distance B [mm]	sin
1	10	10	403.2	161.0	18.9	34.0	1	10.00	6	10.00	1.000
2	10	50	297.7	466.2	28.2	2.4	1	50.00	7	10.00	1.000
3	10	100	156.2	-19.6	33.9	36.1	1	100.00	8	10.00	1.000
4	10	150	-2.3	-466.2	35.2	2.5	1	150.00	9	10.00	1.000
5	50	10	-98.5	301.5	36.0	27.4	2	10.00	6	50.00	1.000
6	50	50	-248.9	432.1	30.8	14.5	2	50.00	7	50.00	1.000
7	50	100	-369.3	-177.3	22.2	34.7	2	100.00	8	50.00	1.000
8	50	150	-444.9	-431.9	11.3	15.0	2	150.00	9	50.00	1.000
9	100	10	-456.2	405.7	7.8	17.8	3	10.00	6	100.00	1.000
10	100	50	-394.6	344.6	19.9	25.1	3	50.00	7	100.00	1.000
11	100	100	-284.4	-314.4	29.6	28.0	3	100.00	8	100.00	1.000
12	100	150	-140.2	-344.2	35.3	26.1	3	150.00	9	100.00	1.000
13	150	10	99.0	460.3	37.4	5.8	4	10.00	6	150.00	1.000
14	150	50	249.8	215.3	31.7	32.8	4	50.00	7	150.00	1.000
15	150	100	369.6	-413.5	22.8	17.7	4	100.00	8	150.00	1.000
16	150	150	444.7	-214.8	11.6	34.1	4	150.00	9	150.00	1.000
17	200	10	455.8	459.4	7.6	7.0	5	10.00	6	200.00	1.000
18	200	50	394.2	61.1	19.1	36.2	5	50.00	7	200.00	1.000
19	200	100	284.1	-462.8	28.5	5.3	5	100.00	8	200.00	1.000
20	200	150	139.8	-60.4	34.7	37.4	5	150.00	9	200.00	1.000

Figure 87 – Flow map window – flow field table

Table has as many lines as there are valid crossing points.

Table gives the following values:

- *X position [mm].* Position of a crossing point in Cartesian co-ordinates
- *Y position [mm].* Position of a crossing point in Cartesian co-ordinates
- *X velocity [mm/s].* Calculated x–component of velocity vector
- *Y velocity [mm/s].* Calculated y–component of velocity vector
- *X RMS [mm/s].* Calculated RMS of x–component of velocity vector
- *Y RMS [mm/s].* Calculated RMS of y–component of velocity vector
- *Transducer A.* Number of the first transducer which forms a crossing point
- *Distance A [mm].* Distance from face of transducer A to a crossing point.
- *Transducer B.* Number of the second transducer which forms a crossing point
- *Distance B [mm].* Distance from face of transducer B to a crossing point.
- *Sin [1]* . Sinus of angle between both transducer axes, crossing in a given point. It can be used for estimating vector calculation reliability. The higher the sinus in a given point, the better vector calculation reliability.

Please note that there are as many separate flow map tables available as there were number of flow maps, i.e. as there were *'# of cycles'* in the Flow map set up table.

Tables are selected in the same way as Maps, by the Map selection box on Toolbar.

Average flow map table is calculated from all available flow map tables in a data file.

5.6.4 Flow map export

Flow map data can be exported in several formats, similarly as other data. In Flow map window, click the tab with table, which you intend to export. Then from main menu open the File | Export | Flow Map… menu item. Standard dialog appears.

Keep in mind that export format can be selected from 'tab-separated text' (txt format), and 'comma-separated text' (csv format).

Clik the <Export> button to finalize the export.

Data from any Flow map table can also be exported through Clipboard. Highlight by mouse dragging the part of table that you want to copy, and click <Ctrl+C>.

Data from Clipboard can be pasted into Word, Excel, and other software.

5.6.5 Flow map comments

During flow mapping, user will experience certain peculiarities which can be confusing at first sight, but which are perfectly logical.

One of them is a 'strange' look of many windows.

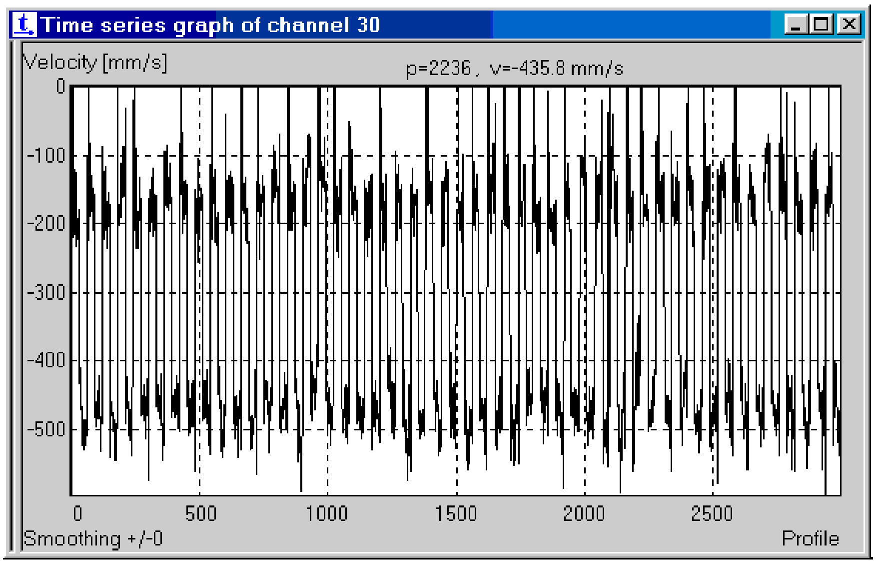


Figure 88 – Time series looks in Flow mapping

Time series window looks 'garbled'. This is logical, since time series window shows all as they are measured and saved to file – including switching between transducers. Since different transducers indicate different speed, time series are then – after some smoothing and zooming in – rather step-like function.

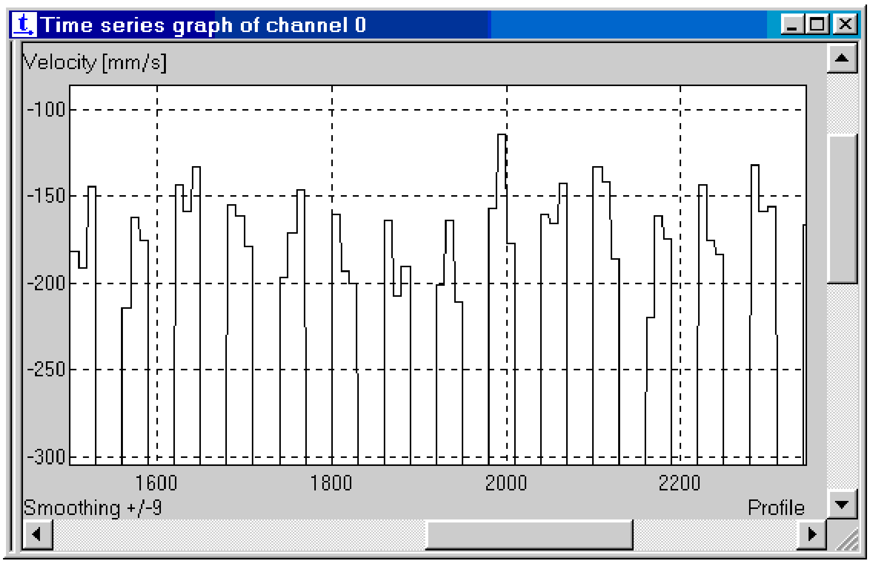


Figure 89 – Step-like look of time series in Flow mapping

Each step represents one transducer data block.

Similar effect also applies to Color graph.

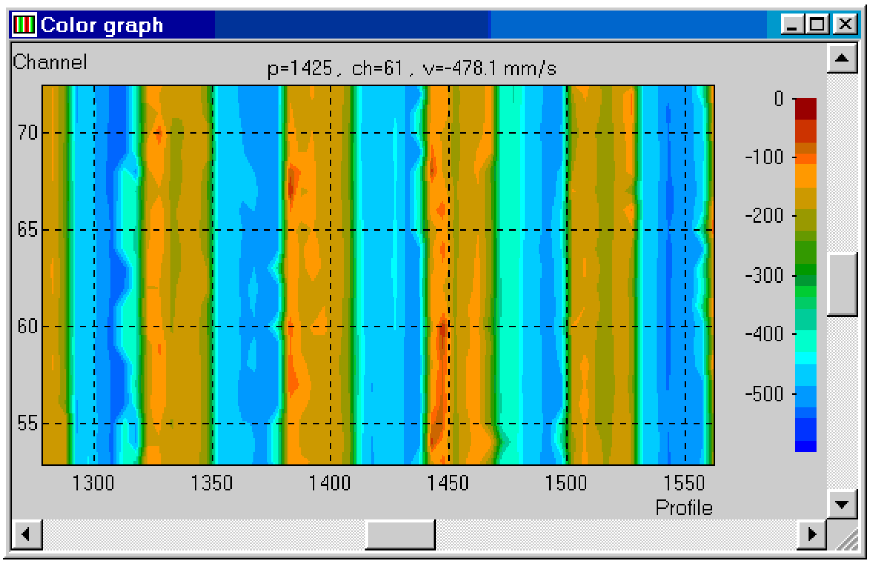


Figure 90 – Flow mapping in Color graph

As soon as you see vertical bars like these in Color graph, the depicted file is a Flow map file.

Multi-transducer measurements have a look similar to Flow map measurements.

6. Practical measurement considerations

6.1 Velocity vector considerations

When interpreting UVP measurement results, please bear in mind that the velocity value obtained by UVP measurement is a component of true velocity vector projected onto the measurement line (read US beam axis, which is strictly identical with transducer axis when using Met-Flow transducers). The maximum velocity indicated by the UVP is space-averaged and time-averaged value. It is a safe bet that peak values of real velocities can be significantly larger than averaged values.

It should also be noted that the velocity profile is usually one- or two-dimensional, and that real flow fluctuations are usually three-dimensional, while its true direction is unknown.

It is also well known that measured time-averaged velocity profile can be rather different from solutions of basic stationary equations for the same situation. This is especially the case where flow involves oscillating behaviour.

6.2 Transducer positioning

A good and stable positioning of a transducer is essential for the successful measurement. Precision of measurement cannot be better than precision of transducer positioning. This especially concerns the angle of transducer. Do not hesitate to design and manufacture a dedicated fixture for the stable and repeatable positioning of the transducer. Do not try to save time by shabby fixing of transducer. This especially applies for flow mapping with several transducers involved.

It is implicitly expected that the axis of the US beam is identical with the transducer mechanical axis. Any deviation of US axis from mechanical axis causes measurement position uncertainty. This is why Met-Flow transducers are custom–manufactured for highest precision, and why they are a little more expensive than off-the-shelf serial stock transducers.

You can easily check the position of the real US beam axis by traversing a wire across the US beam, while simultaneously observing the echo from the wire on an oscilloscope. Since the maximum amplitude of US beam is on its axis, it is easy to find the real beam axis. Do the experiment with wire position in two directions perpendicular to the US beam axis, and you will be able to precisely establish the US beam axis position. This can be especially important in situations where US beam passes through wedge-shaped vessel walls.

6.3 Reflecting particles

Always bear in mind that the UVP method only measures echo from reflecting particles suspended in the fluid, not the velocity of the fluid itself. Where there are no reflecting particles, there is no signal and no measurement. Most of the fluids contain sufficient number of reflecting particles, but sometimes it is desirable to increase SNR (signal-to-noise ratio) by adding particles.

Theory of ultrasound reflection on particles suggests that reflecting particles should have larger diameter than $\lambda/4$, where λ is the wavelength of the emitted ultrasound burst:

$$d > \frac{l}{4}$$

For the different available frequencies different minimum particle diameters result, as follow, in water (c = 1,480 m/s):

f_0 [MHz]	l [mm]	d_{min} [microns]
0.5	2.96	740
1	1.48	370
2	0.74	185
4	0.37	93
8	0.19	46

Ideal particles should have specific weight similar to that of the fluid they flow in, but should have different acoustic impedance to form strong reflections. For water, very good particles are e.g. polystyrene (specific density r = 1.05) and similar materials.

Some commercially available particles are listed in the table below.

Manufacturer	Name	Material	Average size [microns]	Density r [$kg.m^{-3}.10^{-3}$]
3M	B38/4000	Glass bubbles	100	0.38
	S60/1000	Glass bubbles	105	0.60
	K46	Glass bubbles	149	0.46
Liquid Gas	MSF-300M	SiO_2	30	1.35
	MSF-500M	SiO_2	50	1.35
	MSF-750M	SiO_2	75	1.35
	MSF-1000M	SiO_2	100	1.35
HULS	WP200S	Nylon 12	80	1.02
	L1640P	Nylon 12	350	1.02
Sumimoto	CL-2507	Polystyrene	150	0.92
Sekisui	SB-100	Polystyrene	100	1.17
	SB-200	Polystyrene	200	1.17
	MBX-50	Polymetacrylate	50	1.17
	MBX-80	Polymetacrylate	80	1.17
	MBX-100	Polymetacrylate	100	1.05
	MBX-200	Polymetacrylate	200	1.05

Very good US reflecting particles can be also cheaply purchased from NORTEK AS. For details, see **www.nortek-as.com**. One-litre bottle costs approximately USD 40 and lasts for a long time.

6.4 Measurement optimisation

We feel necessary to repeat here again**: Always Raw echo amplitude in Profile graph, to monitor the echo signal from the transducer**. It is the best indicator of SNR, and it reliably monitors unwanted reflections from walls.

Start operation with smaller Pulse Repetition Frequency PRF (i.e. larger P_{max}), to observe that strong reflections from walls and other solid structures are out of the region to be measured. Usually these reflections give stationary signal, which can be easily recognised among reflections from moving particles. Moving particles have transient character.

Reflections can also be recognised on the computer display since they are stationary, while liquid changes its instantaneous velocity due to turbulence.

After identifying (and possibly removing) static reflections, reduce P_{max} to adjust the maximum velocity range to your flow, and then adjust Channel distance and thus a window width to cover the measured region.

Observe if there is sufficient quantity of reflecting particles in the flow. Try to set up the signal with as few dropouts as possible.

If the measured flow is sufficiently stationary, and if time resolution is not a critical parameter for your application, it is helpful to increase number of repetitions N_{rep} for computation averaging.

In case that Channel distance is relatively large, it is also possible to increase the number of cycles per pulse as long as the decreased spatial resolution does not affect the measured results.

If the measurement signal is still weak, first think of improving reflecting particles contents. This is the safest way of improving SNR.

In case concentration or quality of reflecting particles cannot be increased, try first to increase the emission voltage, and only if this does not help, increase the RF Gain. Use RF Gain with prudence. Too high amplification also amplifies the electronic noise, and the resulting SNR might be lower, than if emission voltage is higher and input amplifier gain stays lower.

Observe whether the far side of the profile has a lower measurement success rate than the near side. This indicates that the echo is not sufficiently strong from the far side. In such case, adjust the RF Gain (higher gain at the far side).

If all described tips did not help, think of using a different US frequency, or possibly a larger transducer.

7. Transducers and their properties

7.1 Definition of a transducer

An ultrasonic transducer is a device capable of transforming a high-frequency electrical signal into high-frequency mechanical vibrations. The latter generate sound waves, which are transmitted through the medium surrounding the active face of the transducer, thanks to its elasticity. The latter transport medium can be either liquid or solid. By this way, a transducer works as a generator of ultrasonic waves.

On the other hand, a transducer can also work in reverse as an ultrasonic waves receiver (sensor). When an ultrasound burst reaches the transducer, the latter generates an electrical signal proportional to ultrasound mechanical excitation.

An ultrasonic transducer is made of three main components: the active element, the backing, and the wear plate. As a generated ultrasonic burst has to go through each of these elements before travelling to the outer environment an utmost attention is given to their respective acoustic impedance coupling. An impedance mismatch between each element or with the outer medium means loss of beam transmitted energy and increased beam angle divergence.

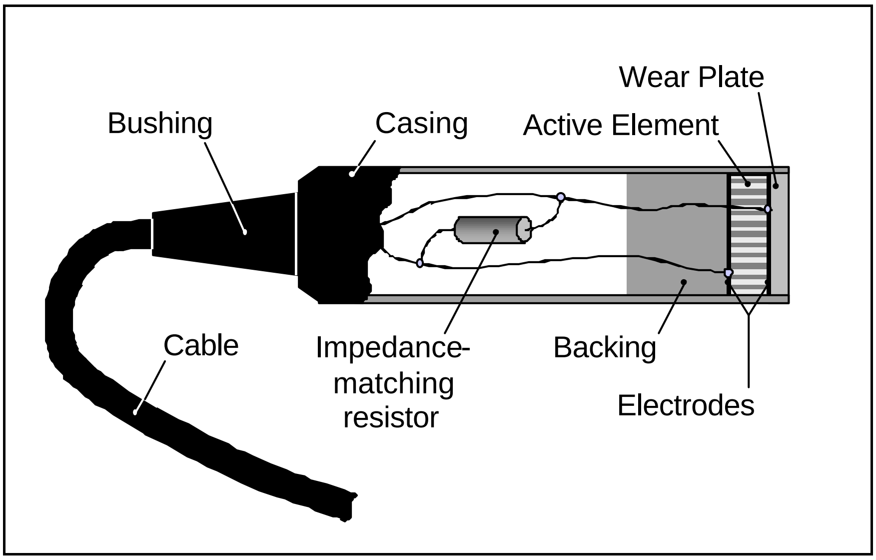


Figure 91 - Cross-section of an ultrasonic transducer

7.1.1 Transducer active element

The active element made of piezoelectric or ferroelectric material, converts electrical energy into ultrasonic energy. The most commonly used material is polarised ceramics, which vibrates at high frequency when excited electrically.

Met-Flow's transducer manufacturer has developed a special piezo-composite active element having a "1-3" mechanical structure, composed of thin ceramic rods (mechanical continuity in one single direction) embedded into a polymer matrix (mechanical continuity in the three spatial directions) to generate a perfect onedimensional longitudinal sound wave. The microstructure of this material is designed so that all the waves subject to excitation have a larger wavelength than the rod's own size. This is a necessary condition for the composite material to behave as homogeneous material.

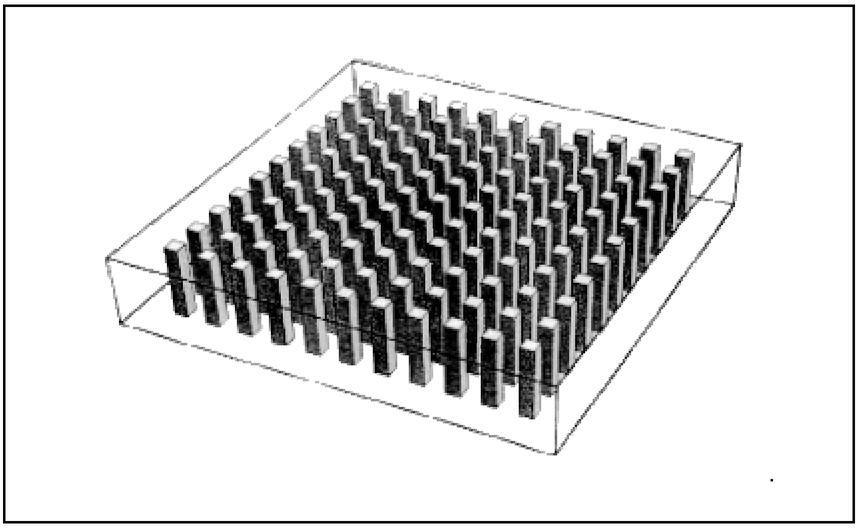


Figure 92 - Active matrix element of an ultrasonic transducer, composed of thin piezoelectric rods

7.1.2 Transducer backing

The purpose of transducer backing is to absorb the acoustic energy radiating from the back face of the active element. A highly attenuating and high-density material is generally used for backing.

Depending on the transducer purpose, the acoustic impedance of the backing can be set in two ways:

If backing has acoustic impedance well matched with the high impedance of the active element, it will absorb acoustic energy and thus the transducer will feature a good temporal resolution (short transients). In return, the ultrasonic output signal amplitude will be lower because of the loss of ultrasonic energy absorbed in the backing.

On the other hand, if acoustic an impedance mismatch between active element and backing exists, more ultrasound energy will be reflected back into the active element and forwarded into the tested medium. This results in a transducer having a lower temporal resolution due to longer transients (less absorption makes the active element 'vibrate' longer after its electrical excitation has been switched off). On the other hand, impedance-mismatched backing yields higher acoustic output signal amplitude.

UVP measurement needs very agile transducers, which can transmit only several waves of ultrasound and then switch to receiving of very weak echo signals. Long transients would thus be fatal for the transducer ability to switch between different working modes. This is why UVP uses impedance-matched backing for good dynamic characteristics of transducer.

7.1.3 Transducer wear plate

Beyond its basic purpose of protecting the inner elements against the external environment, the wear plate plays the role of acoustic impedance adapter, which is of high importance for immersion transducers such as UVP types.

This part is then used as a matching layer connecting the high acoustic impedance of the active element with the tested liquid one, which is generally ten times smaller. Practically the wear plate impedance is set close to the test liquid value, and its thickness is adjusted to a quarter of the ultrasound wavelength while the active element one is set to one half of the ultrasound wavelength. By this mean two waves generated simultaneously by each face of the active element are in phase when leaving the transducer front face, increasing the overall ultrasound energy output. This phenomenon is illustrated as following.

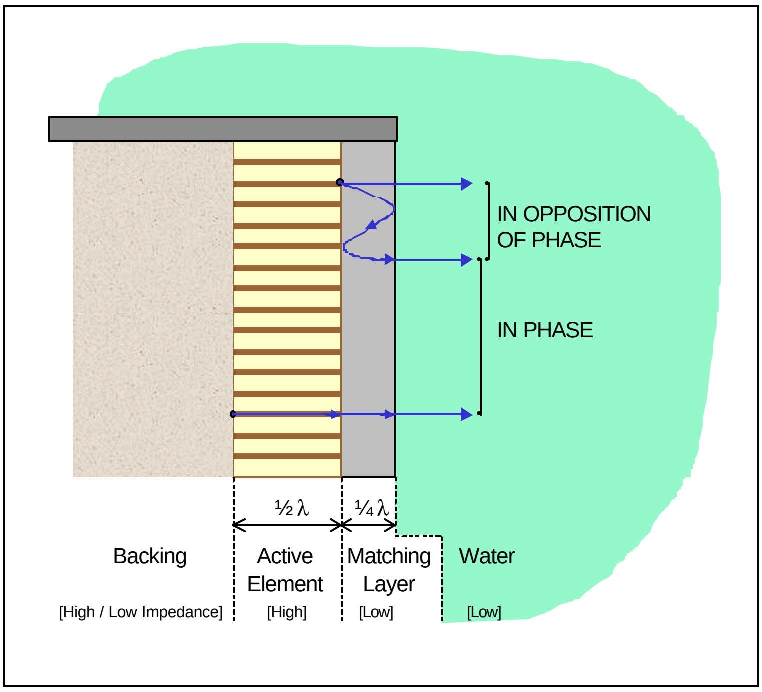


Figure 93 - Phase relations at the output of a transducer

7.1.4 Transducer designs

Mainly two types of transducers with associated methods can be mentioned: Contact transducers and immersion transducers.

Contact transducers are used directly on contact with a solid medium. This requires a very accurate fit of both surfaces. This technique, which is mainly used in the field of material non-destructive testing (NDT), provides the highest coupling efficiency of ultrasound from the transducer into the test piece, since both transducer and tested piece have nearly the same acoustic impedance. Contact transducers can be used in straight beam configuration to introduce longitudinal waves into the test material, or as an angle beam transducer with adjunction of a special wedge element to generate shear wave or a combination of both wave modes.

Immersion transducers are operated (at least partially) submerged in liquid, usually in water. This liquid can be either the testing medium, or a coupling material (gel, submerged test piece in NDT application…). This method, which is commonly used for UVP method and medical applications, provides uniform coupling and reduces sensitivity variations. Moreover, due to its easier fit compared to contact technique it offers more application flexibility, for example, it can be integrated in an on-line control process for NDT. However, its most interesting characteristic remains the ability to focus and concentrate the beam energy in a specific region to increase sensitivity to small reflectors.

The following configurations are worth of noting:

Focusing transducers with spherical transducer: When the front of the active element is not flat but spherically concave in shape, it does not transmit a plane wave but a spherical wave, and focusing of the output beam takes place. US beam is then concentrated into smaller focus region with higher intensity. In UVP use, this can significantly increase lateral spatial resolution and signal-to-noise ratio.

A similar effect can also be achieved with an ultrasonic lens placed in front of the transducer. Drawback of such configuration is that part of acoustic energy is lost on the lens element.

Dual-element transducers utilise separate transmitting and receiving elements, which improves near-field resolution and transducer sensitivity. Dual-element transducers have a pseudo-focus due to their cross-beam design. They are generally not used for precision gauging, because they are affected by zero drift and timing error due to V-path correction.

High temperature transducers (higher than 60°C) use special casing and special inner elements providing good thermal isolation and homogeneous thermal expansion characteristics. For temperature above 100°C, special coupling placed in front of the transducer is recommended.

7.2 Sound field generated by transducer

The following equation expresses relative pressure distribution along the axis of a transducer, and is often used to express characteristics of an ultrasonic beam:

$$p = p_0 .2.\sin\left\{ \frac{p}{l} \left[\sqrt{\left(\frac{D}{2}\right)^2 + z^2} - z \right] \right\}$$

where	p	acoustic pressure
	p_0	reference acoustic pressure on transducer
	l	US wavelength
	D	active diameter of the transducer
	z	on-axis co-ordinate of US beam

The generated sound field can be divided in two main regions called the "near field" and the "far field".

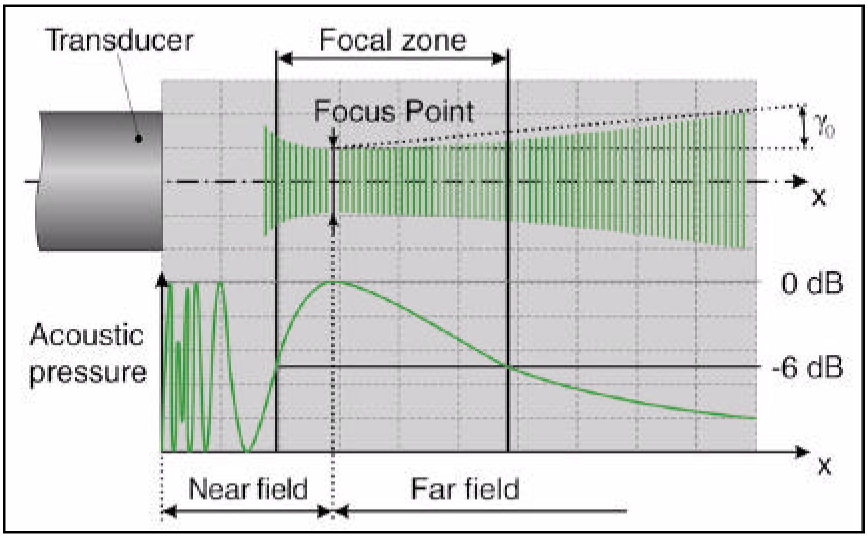


Figure 94- Sound field generated by a transducer.

In the near field, the sound field pressure amplitude goes through a series of maxima and minima, and interacts inside the beam as it propagates. This zone starts at the transducer front and extends to the location of the last maximum of this series at a distance *N*. The distance *N* is called 'near-field distance', and it presents the natural focus of a transducer. It can be estimated by the equation:

$$N = \frac{D^2 f_0}{4c}$$

where	N	near-field distance [m]
	D	active element diameter [m]
	f_0	basic ultrasound frequency [Hz]
	c	sound velocity in test medium [m/s]

In the far field, and with correctly-moding transducer, the highest pressure is usually situated on the beam axis. In this region starting from the focus point N of the transducer, the sound beam is diverging at a constant angle for a given pressure amplitude drop. By defining the beam divergence half-angle γ_0 as the half-width (- 6 dB) of the sound pressure (the point where sound pressure decreases to one half), γ_0 can be expressed as a function of wavelength and transducer diameter (respectively as a function of the λ/D parameter). In the case of a circular beam we have:

$$\gamma_0 = \sin^{-1}\left(0.51\frac{\lambda}{D}\right)$$

where	γ_0	beam divergence half-angle (for -6 dB drop)
	λ	US wavelength
	D	transducer active diameter

Note: ***Please note that all equations above expressing divergence and pressure on-axis distribution apply for the assumption of plain acoustic wave generated by the transducer. This is fulfilled for all 'normal' transducers, but is not true for special 'focused' transducers, which do not generate plane wave, and thus have different pressure distribution and divergence.***

From the equation above, it is seen that, for the same frequency, larger diameter transducers have smaller beam divergence and vice versa.

Alternatively, for a certain transducer transmitting size, the higher the basic frequency of ultrasonic wave, the better its directional propagation (the smaller the beam divergence). The divergence is governed by a parameter l/D, where D is the diameter of the active transmitting area of a transducer. US wavelengths are generally very “long” in comparison to light waves. For a typical UVP transducer with D = 5 mm and l = 0.35 mm (water, 4 MHz), there are only 14 wavelengths across the transmitting area (because 5 / 0.35 = 14), and diffraction effects show strongly.

The higher the US beam divergence, the sooner the beam looses its intensity, and the poorer is the spatial resolution of the UVP measurement.

To demonstrate the practical values of near-field length and divergence half-angle, the following tables show all practically used combinations of frequencies and transducer diameters.

The tables do not apply for focused transducers.

From practical measurement point-of-view, weak echo problems might sometimes occur while doing measurement inside a Near Field zone.

Near Field length N [mm] in water (c = 1 480 m/s)					
Transducer diameter D [mm]	**f = 0.5 MHz** λ = 2.96 mm	**f = 1 MHz** λ = 1.48 mm	**f = 2 MHz** λ = 0.74 mm	**f = 4 MHz** λ = 0.37 mm	**f = 8 MHz** λ = 0.19 mm
1	0.09	0.17	0.35	0.7	1.4
2	0.35	0.7	1.4	2.7	5.4
2.5	0.53	1.1	2.1	4.3	8.4
3	0.75	1.5	3.0	6.1	12.2
4	1.35	2.7	5.4	10.8	21.6
5	2.1	4.2	8.4	**16.9**	33.8
8	5.4	10.8	21.6	43.2	86.5
10	8.4	16.9	33.8	67.6	135.1
20	33.8	67.6	135.1	270.3	540.5

Table showing Near Field length as parameter of transducer diameter D and working frequency f. Since wavelength l is dependent on sound velocity c, values of N would differ for different media. In UVP, the most commonly used transducer is f = 4 MHz, D = 5 mm, and this is why the resulting value of D = 16.9 mm is highlighted.

	Far Field beam divergence γ [°] in water (c = 1 480 m/s, for -6 dB intensity drop)				
Transducer diameter D [mm]	**f = 0.5 MHz** λ = 2.96 mm	**f = 1 MHz** λ = 1.48 mm	**f = 2 MHz** λ = 0.74 mm	**f = 4 MHz** λ = 0.37 mm	**f = 8 MHz** λ = 0.19 mm
1	—	49.0	22.2	10.9	5.4
2	—	22.2	10.9	5.4	2.7
2.5	—	17.6	8.7	4.3	2.2
3	—	14.4	7.2	3.6	1.8
4	22.2	10.9	5.4	2.7	1.4
5	17.6	8.7	4.3	**2.[illegible]**	1.08
8	10.9	5.4	2.7	1.4	0.68
10	8.7	4.3	2.2	1.08	0.54
20	4.3	2.2	1.1	0.54	0.27

Table showing Far Field divergence as parameter of transducer diameter and working frequency f. Since wavelength λ is dependent on sound velocity c, values of N will differ from media to media. Again, the most commonly used transducer f = 4 MHz, D = 5 mm result is highlighted (γ = 2.2°).

The very high values of divergence (small diameter, long wavelength) are added for illustration only, and are not suitable for practical UVP measurement. Decent divergence values result from transducers having at least 10 US wavelengths across their active diameter.

The following picture shows real US field emitted by a transducer working in continuous mode. The US field has been visualised by means of Raman spectroscopy.

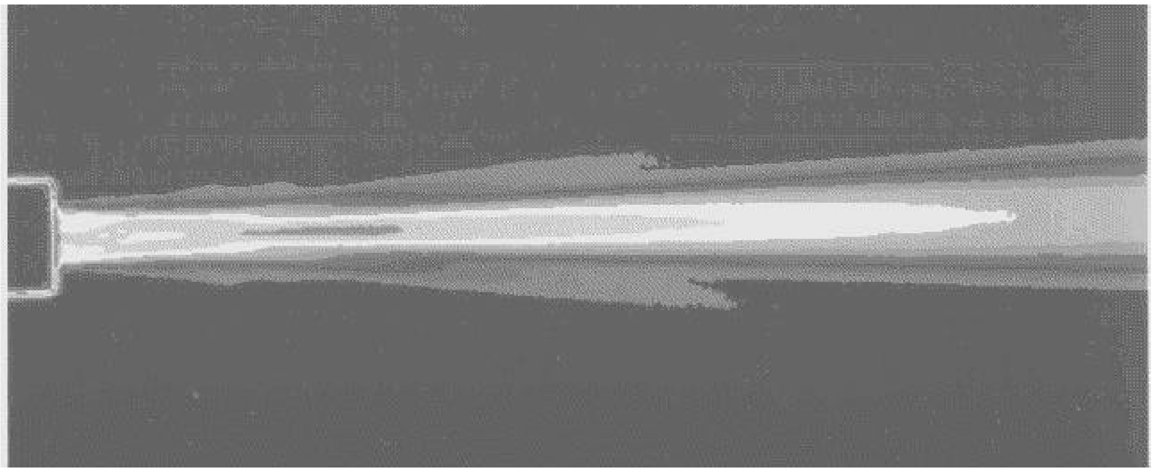


Figure 95 - Picture of an ultrasonic field generated by the transducer working in continuous mode. The transducer was standard type 5 mm/ 4 MHz. Note the visible focus (dark spot on the axis) which centre marks the end of the near-field zone. Two small side lobes (-18 dB) show at the central part of the beam.

7.3 Met-Flow transducers

Met-Flow's transducers are custom-designed and manufactured by a leading specialised third-party manufacturer. Immersion-type transducers were chosen particularly because they are designed for liquid applications, moreover they offer more flexibility for geometrical fit and acoustic coupling, plus focusing beam option. Here is a description of their main features.

Met-Flow transducers are connected to the UVP Monitor by a standard BNC connector. Maximum operational peak-to-peak voltage is 200 V, maximum applicable DC voltage is 500 V. Electrical input impedance of all transducers is close to 50 Ohm.

Default cable length is 4 m, but can be specified longer (up to 10 m) or shorter when ordering transducer. For longer cables, small surcharge can apply. The cable is firmly fixed to the transducer and cannot be extended. Warranted-operation cable length is 4 meters.

Transducer electric-to-acoustic efficiency is approximately 40-50 %. The losses are mainly due to absorption in the backing necessary to generate short ultrasound pulse required by UVP technique (see paragraph Transducer backing).

Transducer casing material is Delrin, a plastic material resistant to most of common chemicals. Nevertheless, Met-Flow only guarantees transducer resistance to water and mercury. In case of other chemicals, please consult Met-Flow.

The following transducer centre working frequencies are available:
0.5, 1, 2, 4, 8 MHz.

Generally, lower frequencies are used in large-scale applications for their good propagation abilities (attenuation is proportional to the square of frequency). These applications include measurements in large-scale tanks, rivers, wave basins and such. Low frequencies are also used for high-velocity flows.

Higher frequencies are used for small-scale flows for which they offer good spatial resolution due to their short wavelength. These applications include small-diameter pipes, small hydraulic models, artificial heart models and such.

Figure 96 - Photograph of a typical UVP transducer for 4 MHz frequency.

Standard Met-Flow transducers are plane-wave type, with a flat active element. These transducers for 'normal' temperature range up to 60°C temperature (in the immediate vicinity of the transducer) are named by letters 'TN'.

Two lines of similar transducers for two ranges of extended temperatures up to 150°C or 250°C are available. They are named by the letters 'TH' and 'TV' respectively. These transducers have special casing for good thermal isolation and special inner elements to resist thermal constraint.

Spherical focusing transducers ('TF' denomination) are custom-made on request. The focusing effect is given by a spherical active element. This yields a good US efficiency, since no energy is wasted on a commonly used focusing lens on the front surface.

The casing diameter is derived from the active element diameter. The default casing length is 60 mm, but other lengths (minimum 36.5 mm) can be manufactured on request with a small surcharge.

Any other specific development can be considered, please feel free to contact us for further information.

7.4 Met-Flow transducer cables

Met-Flow transducer cable can be considered as a standard 50 Ohm coaxial cable (type KX 15 for normal temperature or KX18 for extended), with an attenuation of under 0.1 dB/m for a 8 MHz signal. The attenuation decreases with frequency.

A reasonable extension of transducer cable using an additional standard 50 Ohm coaxial extension cable with BNC connectors should not be critical from attenuation point of view.

Warning	***Use of any other cable and connector type can cause impedance mismatch, and signal can be distorted in addition to loss of sensitivity, due mainly to parasitic reflections at cable junctions.***

Obviously, in strong electromagnetic interference (EMI) environment overall cable length has to be minimised. This is why Met-Flow is assuring reliable functioning of its transducers up to 4 meters cable length only.

7.5 Standard Met-Flow transducer overview

Symbols used in transducer denominations:

TN	transducer for temperatures up to 60°C
TH	transducer for high temperatures (up to 150°C)
TV	transducer for very high temperatures (up to 250°C)
TF	focused (spherical) transducers
1st digit	frequency
2nd digit	active diameter in mm
3rd digit	exterior diameter in mm

Default casing length for all transducers is 60 mm. Other lengths can be manufactured upon request (minimum length is 36.5 mm).

Default cable length for all transducers is 4 m. Length can be adjusted from 1m up to 10 m upon request to suit customer's needs

Plain-wave transducers						
Transducer type	Centre frequency [MHz]	Active diameter [mm]	Overall diameter [mm]	Overall length [mm]	Near-field distance N [mm]	Divergence half-angle γ [deg]
Normal temperature range (up to 60° C), water and mercury resistant						
TN05-19-23	0.5	19	23	60	30.5	4.6
TN1-13-16	1	13	16	60	28.5	3.4
TN2-10-13	2	10	13	60	33.7	2.2
TN4-5-8	4	5	8	60	16.9	2.2
TN8-2.5-8	8	2.5	8	60	8.43	2.2
High temperature range (up to 150° C), water and mercury resistant						
TH4-5-8	4	5	8	60	16.9	2.2
Very high temperature range (up to 250° C), water and mercury resistant						
TV4-5-8	4	5	8	60	19.9	2.2

Focused transducers							
	Centre	Active	Overall	Overall	Active element	Real focus	Natural

Transducer type	frequency [MHz]	diameter [mm]	diameter [mm]	length [mm]	minimum curvature radius [mm]	point minimum [mm]	focus point N [mm]
TF05-19-23	0.5	19	23	60	>110	>26.0	30.5
TF1-13-16	1	13	16	60	>80	>23.4	28.5
TF2-10-13	2	10	13	60	>60	>24.9	33.7
TF4-5-8	4	5	8	60	>40	>13.3	16.8

Note: Focused transducers can be ordered with focus point from listed minimum length up.
Active element curvature point varies according to selected focus point.

8. Turbulent statistics basics

UVP measures (almost) instant values of velocity, and produces many realisations of measurement. This offers statistical processing of measured data.

In software Version 3, several statistical calculations are included: histograms, statistical moments, correlation, auto-correlation, and frequency analysis. Here the very basics of these calculations and their physical interpretation is given.

Basic data for all calculations is time series of velocity values in a single spatial point.

Reader can find more detailed information in any statistics or signal processing textbook.

8.1 Histogram, PDF

Histogram is created by sorting measured velocity realisations into intervals (bins) of equal width Δv . Its y–co-ordinate is proportional to number of measurement in a given velocity interval.

This is exactly what is calculated and displayed in the 'Velocity histogram' window.

The more measurements are available, the 'nicer' histogram looks. If data file does not have very long length, it is better to increase width of intervals (and thus decrease number of intervals).

Software Version 3 allows for changing number of sorting intervals (see Options).

If histogram has many intervals and is normalised in such way that the length of all bars equals to 1, then it approximates '*probability density function*' or PDF (also called 'frequency function' in statistics).

PDF has the following features: it is never negative, and area under the PDF equals to 1.

8.2 Statistical (central) moments

When a set of values has a sufficiently strong central tendency, that is, a tendency to cluster around some particular value, then it may be useful to characterize the set (and its PDF shape) by a few numbers that are related to its moments, the sums of integer powers of the values.

These numbers are called statistical moments.

General definition of m–th moment $\overline{v_k^m}$ for all measured values *k* from 1 to K is

$$\overline{v^m} = \frac{1}{N}\sum_{k=1}^{N} v_k^m$$

The most important statistical moment is First moment (average, mean). Higher moments are more practically expressed as 'central' moments. Central statistical moment is statistical moment of differences from average value:

$$\overline{v^m} = \frac{1}{N}\sum_{k=1}^{N}\left(v_k - \overline{v_k}\right)^m$$

Infinite number of moments would be needed to fully characterise the PDF, nevertheless it is sufficient to know only a few lowest moments to estimate its basic properties. These lowest moments have their names and physical interpretation.

8.2.1 First moment – mean velocity, arithmetic average

Mean estimates the value around which central clustering occurs.

This is simply an arithmetic average of measured values.

$$\overline{v^1} = \overline{v} = \frac{1}{N}\sum_{k=1}^{N} v_k$$

8.2.2 Second central moment – variance, RMS

Variance is a measure of distribution 'width'. The higher the variance, the wider the PDF is.

$$\overline{v^2} = s^2 = \frac{1}{N}\sum_{k=1}^{N}\left(v_k - \overline{v_k}\right)^2$$

The usual description of Second central moment is s^2. Square root of s^2 is called 'Root mean square', or RMS.

In many areas, it is customary to express distribution width in terms of RMS, because RMS complies with definition of 'turbulence' in fluid mechanics. This is why Version 3 calculates both RMS and variance.

8.2.3 Third central moment – skewness

Third central moment normalised by s^3 is called 'skewness':

$$S = \frac{\overline{v^3}}{s^3} = \frac{\frac{1}{N}\sum_{k=1}^{N}\left(v_k - \overline{v_k}\right)^3}{s^3}$$

Skewness is a measure of asymmetry of distribution. Since variables are in the third power, skewness can reach both positive and negative values.

If S=0, distribution is symmetrical.

For S<0, velocity distribution is 'skewed' to the left (the larger tail of a distribution is on the left), to lower velocity values.

For S>0, velocity distribution is 'skewed' to the right (the larger tail of a distribution is on the right), to higher velocity values.

8.2.4 Fourth central moment – Kurtosis (flatness)

Fourth central moment normalised by s^4 is called 'kurtosis':

$$K = \frac{\overline{v^4}}{s^4} = \frac{\frac{1}{N}\sum_{k=1}^{N}\left(v_k - \overline{v_k}\right)^4}{s^4}$$

Kurtosis is always positive (variables are in fourth power). Kurtosis shows if distribution is flatter on top of distribution (as e.g. top-hat distribution), or if it has narrower peak.

Comparable Gaussian (Normal) distribution has kurtosis (flatness) value K=3. 'Top-hat' distribution has kurtosis < 3. 'Triangular' distribution has kurtosis > 3.

8.2.5 Higher moments

Higher moments also exist but do not have direct physical interpretation, and software Version 3 does not compute them.

However, if interest in these moments arises, it is possible to export velocity series data into Excel and compute higher moments there.

8.3 Correlation

Correlation – as its name suggests – shows if any relation between different time series exists.

8.3.1 Auto-correlation

Auto-correlation finds relations between different parts of the same time series. Practically this means finding periodicity in certain time series.

Auto-correlation function of a discrete time series (for a single channel)

$$\{ x_i \}, \; i = 1, 2, \ldots, N$$

is defined by:

$$R_{xx}(t) = \frac{1}{N} \sum_{i=1}^{N} x_i x_{i+j}$$

where $t = j\,\Delta t$, and Δt is sampling interval.

Auto-correlation function is usually normalised by dividing by $R_{xx}(0)$.

Such normalised auto-correlation function has several features:

- for $t = 0, \; R_{xx}(0) = 1$
- auto-correlation function is an even function: $R_{xx}(t) = R_{xx}(-t)$
- for periodic time series, auto-correlation function is periodic function with the same period.

The first feature directly derives from normalisation condition.

The second feature means that it is necessary to calculate auto-correlation function for positive values of time delay only.

The third feature allows for easy finding of periodic functions hidden in the noise.

When practically calculating auto-correlation function, the longest time delay should not be longer than about half of the overall record.

8.3.2 Cross-correlation

Cross-correlation finds relations between two different time series, in our case between two channels of measured data.

Cross-correlation function between discrete time series

$$\{ x_i \}, \; i = 1, 2, \ldots, N \text{, and } \{ y_i \}, \; i = 1, 2, \ldots, N$$

is defined by cross-correlation function:

$$R_{xy}(t) = \frac{1}{N}\sum_{i=1}^{N} x_i y_{i+j}$$

where $t = j\,\Delta t$, and Δt is sampling interval.

Cross-correlation function has several features:

- Generally, it applies that $R_{xy}(t) \neq R_{yx}(t)$
- Cross-correlation function not even function, but applies: $R_{xy}(-t) = R_{yx}(t)$
- Relation to auto-correlation functions of both respective functions exists:
  $\left|R_{xy}(t)\right|^2 \leq R_{xx}(0)\ R_{yy}(0)$
- For periodic time series, cross-correlation function is periodic function with the same period.

The third feature allows for normalisation of auto-correlation function by dividing by $\sqrt{R_{xx}(0)\ R_{yy}(0)}$.

The fourth feature allows for easy finding of periodic relations between functions, hidden in the noise.

When practically calculating the cross-correlation function, the longest time delay should not be longer than +/- half of the overall record.

Software Version 3 uses velocity series of 'pivot' channel as $\{\ x_i\}$, and calculates cross-correlation function with another channel $\{\ y_i\}$.

8.4 Power spectra

Power spectra show distribution of liquid fluctuation energy of one channel as a function of frequency.

For Power spectra calculation, complex velocity *V(f)* as function of frequency is first calculated by Fast Fourier Transform (FFT) of velocity time series *v(t)* :

$$V(f) = FFT\{\ v(t) \cdot w(t)\}$$

where *w(t)* is windowing function.

From complex velocity image in frequency domain, the Power frequency spectra is then calculated:

$$P(f) = \left|V(f)\right|^2$$

In energy calculations, software Version 3 discounts for energy of mean flow translation, and calculates only fluctuation energy.

Software Version 3 uses the following windowing options:

- No window $w(t) = 1$
- Hanning window $w(t) = 0.5 - 0.5\cos(2p \cdot t/T)$
- Hamming window $w(t) = 0.54 - 0.46\cos(2p \cdot t/T)$
- Gaussian window $w(t) = \exp\left(-1/2 \cdot \left(\frac{t/T - 0.5}{3}\right)^2\right)$

- Triangular window $w(t) = 1 - |2t/T - 1|$

Since FFT algorithm requires the number of calculated time series points to be 2^n, it only takes the largest possible *n*, which still can fit into number of profiles, and it discards the rest of the points. It is therefore advantageous to measure such number of profiles, which fits to 2^n value, i.e. 512, 1024, 2048 etc. Calculation of Power spectra from very small number of profiles can give rather unsatisfactory results.

9. Application examples

9.1 Single-transducer UVP measurement in a pipe

The following example shows single-transducer measurement in a circular pipe partially filled with flowing water. The paper shows how relatively simple UVP measurement can give very valuable insight view into the flow, when correctly evaluated. The Example is a complete Conference paper with original pictures, which has been reformatted for the purpose of this User's Guide.

The paper has been presented at 'Fourth bi-annual Conference Wastewater 2001', in Mlada Boleslav, Czech Republic, on 15-17 May 2001, ISBN 80-238-6917-5, Proceedings page 365-368. It has won the price of Association of Wastewater Cleaning Experts of Czech Republic.

Title, authors and affiliation

UVP analysis of velocity field in circular pipe

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Abstract

Average velocity profiles were measured by UVP method (Ultrasonic Velocity Profiling) in the axis plane of a circular pipe. The flow was stationary, uniform, and hydraulically smooth with free surface. Experiment has been carried out on glass pipe DN 150, and plastic pipe DN 290 respectively, with maximum water level H/D = 0.5. Distribution of velocities in inner region of turbulent layer corresponds to logarithmic distribution law. The value of integration constant B was found to be in the range between 4 and 6. For outer region of turbulent layer, where velocity distribution is formed according to Coles (1956), the value of Coles parameter has been found to be P=0,3. Velocity distribution along the height of pipe in pipe plane of symmetry shows the same parameters as flow in open channels. Bottom shear stress t0 and shear velocity u has been calculated both (1) from UVP-measured profiles in the inside region of turbulent layer in pipe plane of symmetry, and (2) from hydraulic radius R and pipe longitudinal slope i0. The ratio between the values found from (1) and (2) was in the range of 1.1 to 1.3. This ratio is in good agreement with results presented lately by Knight (2000).*

Introduction

Wastewater flow in drainage systems is governed by many specific factors. Water includes many non-soluble particles, and both cross-section and material of drainage pipe is very often varying. In dry weather period, stationary flow with free surface prevails, while during rain events flow changes to transient and can even develop into pressure-mode flow.

The goal of an experiment was to analyse velocity distribution in circular pipe with stationary free surface flow. UVP Monitor has been used for measurement, since it records both temporal and spatial representation of the flow. The main UVP advantage is its ability to measure instantaneous velocity profiles in flowing liquid. This provides the means for wall roughness analysis and shows ability of liquids to transport insoluble particles.

Keulegan (1938), Coles (1956), Nezu and Rodi (1986), Cardoso et al. (1989), Kirkgoz (1989), and other have described velocity distribution in turbulent boundary layer of flow with free surface. For evaluation of sediment transport in drainage systems and for design of bottom slope of drainage pipes a criterion of critical bottom shear stress is most often used. According to Czech standard CSN 75 6101 its value should be t0 = rgRi0 = 4 Pa. This value should be reached at least five times per year. The validity of this relation has been proven by many authors and methods above and applies both for free-surface flow in rectangular channels and for pressure flow in circular pipes.

Experiments should then describe influence of pipe geometry on real t0 near pipe bottom during free-surface flow conditions.

Experiments

Experiments were carried out in two circular pipes. The first pipe was made of glass, with diameter DN 150 mm, length 17 m, and bottom longitudinal slope 0.1 %. The second pipe was made of Plexiglas, with diameter DN 290 mm, length 17 m and bottom longitudinal slope 0.175 %.

Measurement of discharge was made on inlet pipe by a flow meter KROHNE DN 50 or DN 150 respectively, and by a triangular measuring weir. Water level in pipes has been measured by pressure inductance transducers Hottinger Baldwin, and by digital point gauge. Maximum water level in both pipes was half of the pipe diameter, i.e. H/D < 0,5. Measured discharge in DN 150 pipe was from 0.75 to 7 litres per second, and in DN 290 pipe from 4 to 11 litres per second.

Velocity measurement

Velocity information has been obtained by UVP Monitor (Ultrasonic Velocity Profile Monitor) from Met-Flow, Switzerland. Its main advantage is non-contact measurement of spatial and temporal fluid velocity information by means of ultrasonic pulses, transmitted into flowing water – see Figure 97.

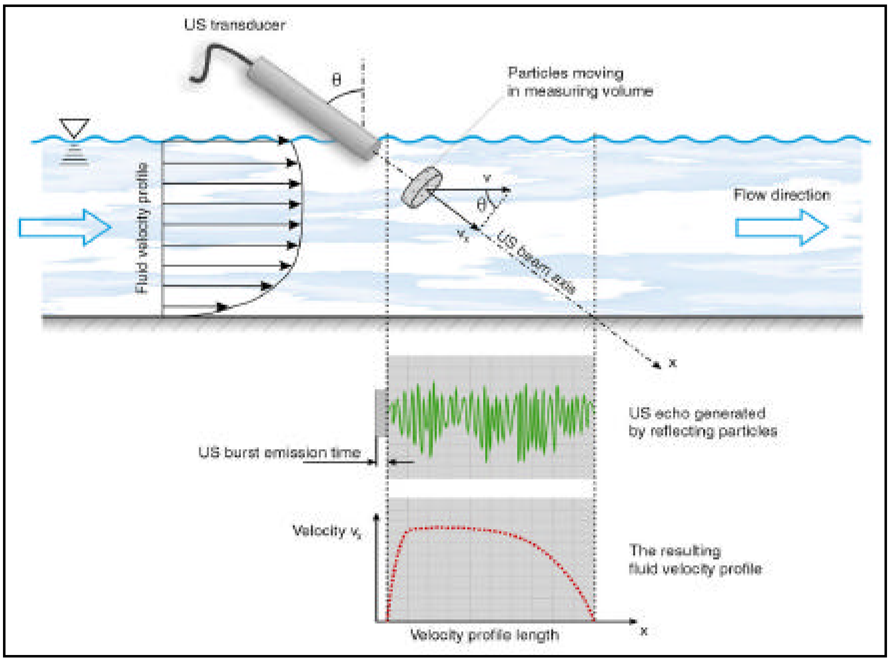

Figure 97 -Principles of UVP Monitor

Each ultrasonic transducer transmits short ultrasonic (US) pulses along transducer axis. Part of the US energy is reflected from minuscule particles scattered in flowing water and returned back to the transducer, which also acts as US receiver. The reflected signal is Doppler-shifted, and comes back to transducer with certain delay. Doppler shift frequency is proportional to particle (and liquid) velocity, and the delay is proportional to particle position in the time of pulse reflection. By space separation of many measurement points UVP Monitor is capable of evaluation of a complete velocity profile in the flowing liquid.

Ultrasonic transducers with working frequency 4 MHz, external diameter 8 mm, and transducer active diameter 5 mm were used for the measurement.

Two basic geometrical configurations were used for transducer positioning. For measurement of velocity profile in the inner region of turbulent boundary layer, the transducer has been entered into liquid through a hole drilled in the pipe bottom at its plane of symmetry. Transducer axis was at an angle of 60 deg to pipe bottom, pinging against flow direction (see Figure 98).

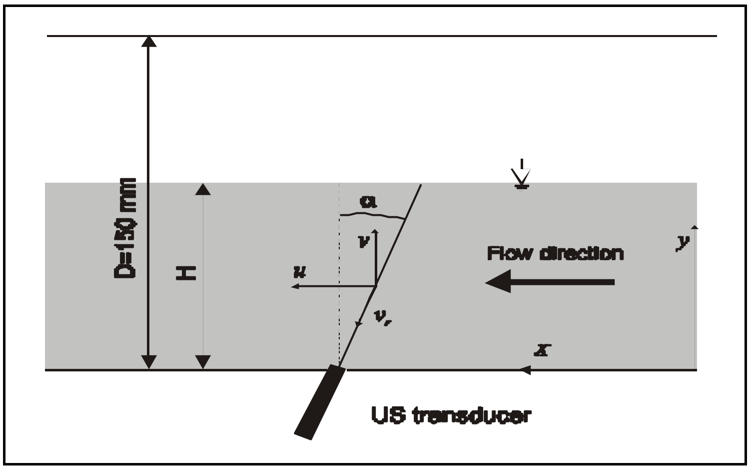

Figure 98 - Transducer position at the bottom

For measurement of profiles in the outer region of turbulent boundary layer, the transducer has been placed near water surface and the axis of probe was at an angle of 60 deg to pipe bottom, pinging down the flow direction (see Figure 99).

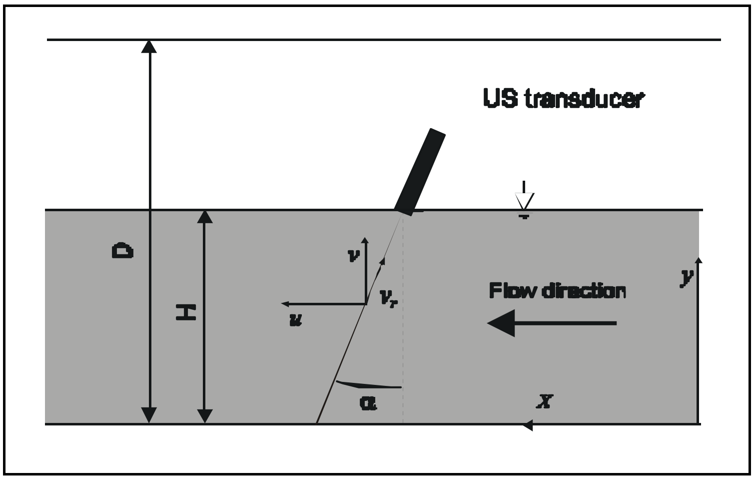

Figure 99 - Transducer position at the surface

The distance between individual measurement points on measured profile line was 0.74 mm or 1.48 mm respectively. With fixed number of 128 measurement points in a profile, the profile measurement length was 99.7 mm or 198.4 mm respectively. The measurement length has been changed according to pipe water level.

Values of longitudinal velocity components were evaluated on base of the following presumption:

$$|u \sin a| >> |v \cos a|$$

For longitudinal velocity component in pipe then applies:

$$|u| \approx \left|\frac{v_R}{\sin a}\right|$$

Analysis and results

Inner region of turbulent layer

For description of velocity profiles in fully developed turbulent flow with free surface, generally valid semi-empirical models are generally used.

Inside inner region of turbulent layer the velocity distribution as a function of height is described by a relation derived by von Kármán (1930) and Prandtl (1932), which is called logarithmic velocity distribution law. This is expressed as:

$$\frac{u}{u_*} = \frac{1}{k} \ln \frac{u_* y}{u} + B$$

where	k	von Kármán constant
	B	constant
	u*	friction velocity.

Value of B depends on pipe wall surface. On the other hand, ratio 1/k does not depend on pipe wall surface, as noted by Schlichting (1968).

Nikuradse (1932) on base of his experiments has found values of 1/k and B to be 1/k = 2.5 and B = 5.5 for hydraulically smooth pressure flow in circular pipe. Keulegan (1938) has confirmed the same values for flow with free surface as well.

Nevertheless, different values of 1/k and B were found by other authors, value of 1/k in the range between 2.43 (Nezu and Rodi, 1986) and 2.5 (Steffer et al. 1985), and value of B in the range between 4,9 (Klebanoff, 1954) and 7 (Townsend, 1956).

Figure 100 shows evaluated velocity profiles for different water level heights in plastic pipe DN 290. Velocity profiles in pipe plane of symmetry were evaluated for water levels 0.2 – 0.5 H/D.

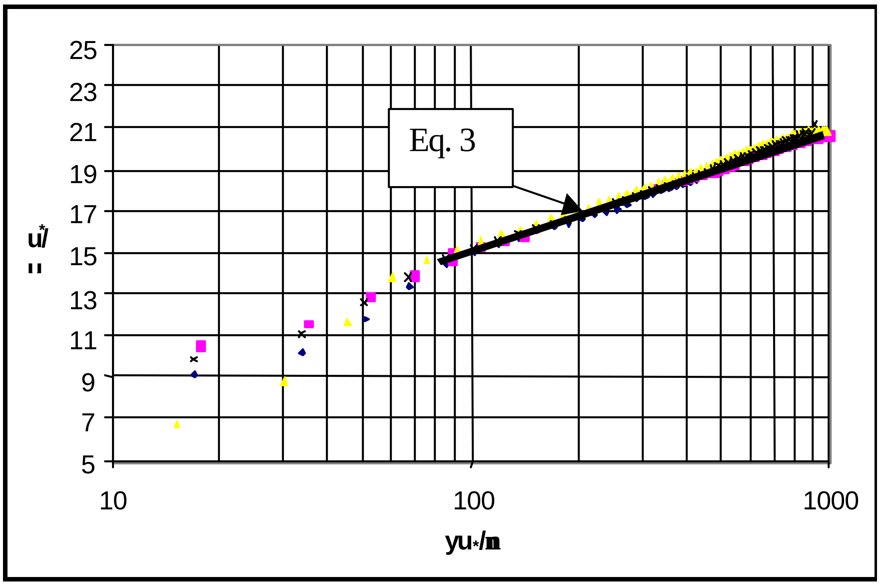

Figure 100 - Velocity profile in the inner region of turbulent layer for different water levels, with regression line depicted

Regression analysis has been used to establish u* and B values. Value of B has been found to be in the range from 4 to 6 for different water levels.

Outer region of turbulent layer

Coles (1956) has introduced a modified logarithmic “law of wake”, which describes shape of velocity profile in the outer region of turbulent layer for hydraulically smooth mode of flow, in a form:

$$\frac{u}{u_*} = \frac{1}{k} \ln \frac{u_* y}{u} + B + 2 \sin^2 \left(\frac{pz}{2d} \right)$$

Coles (1956) has also shown that values for k = 0.4, B = 5.1, and P = 0.55 are in agreement with experimental measurements.

Different value of Coles parameter P = 0.2 were assessed by Nezu and Rodim (1986), and Krikgoz (1989) gives value P = 0.1. These are significantly smaller values than that of P = 0.55 given by Coles.

Our evaluation has been done for velocity profiles obtained by measurement from bottom to surface, see Figure 101. Evaluation has been made for all velocity profiles together, while each profile has been normalised to unity depth H = 1, and unity velocity $\bar{u} = 1$, see Figure 102. Values of Coles parameter P = 0.3 and constant B = 4.7 were found by regression analysis.

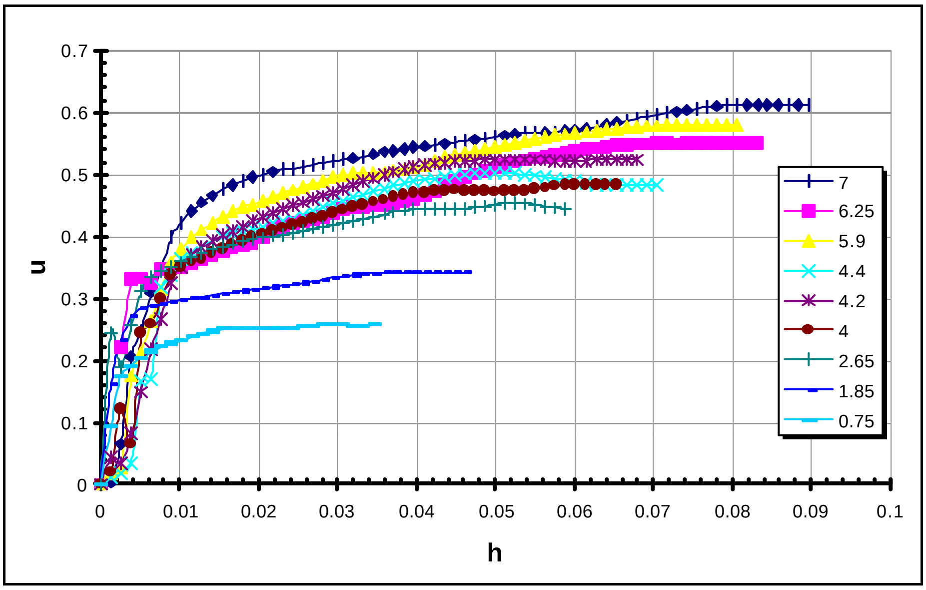

Figure 101 - Measured data for different discharges

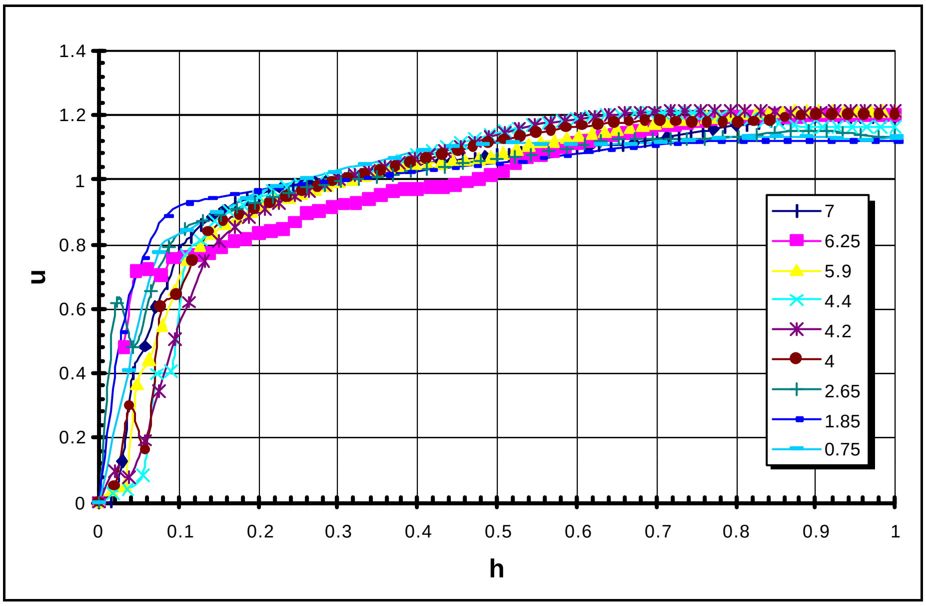

Figure 102 - Comparison of data normalised to unity depth and velocity

Assessment of shear stress and friction velocity

Direct assessment of shear stress near the wall is difficult. Therefore, friction velocity is being evaluated by different indirect methods. Keulegan (1938), Kamphuis (1974), Blumberg (1992) and many other use expression:

$$u_* = \sqrt{ghi_0}$$

or

$$u_* = \sqrt{gRi_0}$$

respectively, where h depth
R hydraulic radius
io bottom slope

Graf (1983), Cardoso et al. (1989), Song et al. (1994), Gyr (1997), Boillat et al. (1999) assess friction velocity u* according to Clauser (1956) by application of logarithmic regression curve on data in the inner region of turbulent layer. Kirkgoz (1997) and Knight (2000) use for the same purpose data from laminar sub-layer in combination with Newton law of viscosity:

$$u_* = \sqrt{\nu \frac{u}{y}}$$

Many of the referenced authors compare experimentally established values of friction velocity, obtained by different methods. Experimental results are in good agreement for rectangular channels only.

Knight (2000) described distribution of local shear stress around wetted cross-section of flow in circular pipe with free surface, for different water levels. Local shear stress was measured by Preston tube, and compared with average value, see Equation 6, which gives average value of friction velocity along the wetted perimeter. The maximum ratio of these values is 1.1 – 1.2 and its location is at the pipe axis.

From shape of velocity profile, local values of friction velocity resp. shear stress at the pipe axis were assessed by Clauser method for different water levels.

The part of velocity profile fulfilling the following condition has been selected:

$$0,01 \leq \frac{y}{d} \leq 0,2$$

Through these points a logarithmic regression curve has been interpolated in the following form:

$$u^+ = A_1 \ln y^+ + A_2$$

where u+=u/u* and y+=u*y/n. From parameter A1 the friction velocity u* can be found:

$$u_* = k \,.\, A_1$$

The following condition should be fulfilled:

$$60 \leq \frac{y_{max} \,.\, u_*}{n} \leq 500$$

These local shear stress values were compared with global shear stress values calculated from Equation 6, and its respective ratio plotted into a graph on Figure 103. The ratio of these values fluctuated between 1.1 and 1.3.

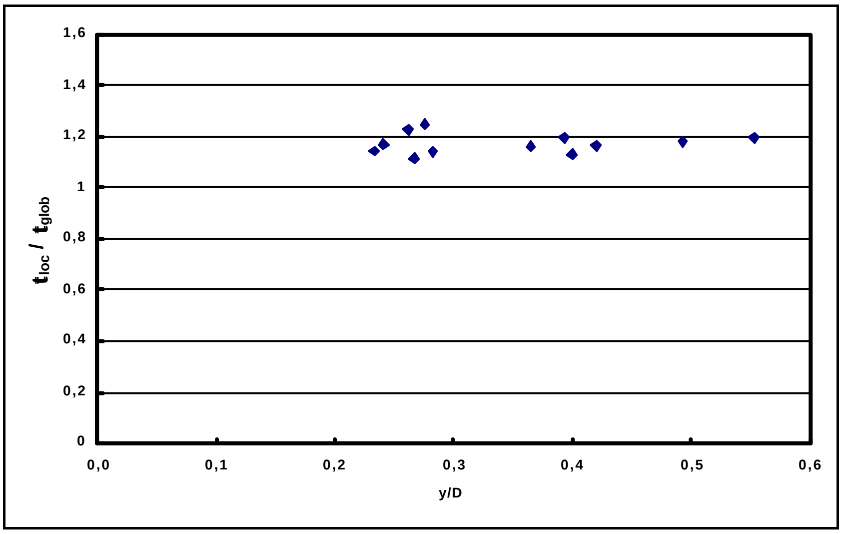

Figure 103 – Ratio between local bottom shear stress value on pipe axis (t_{loc}) and global bottom shear stress (t_{glob}) calculated from Equation 6 for different water levels

Conclusions

Velocity profile has been measured by means of UVP method (Ultrasonic Velocity profiling) in a hydraulically smooth circular pipe with free surface and turbulent flow.

Detailed analysis of averaged velocity profiles in a pipe plane of symmetry has been made and parameters of velocity distribution have been compared with values found in literature.

Further, shear stress has been assessed by the bottom at pipe plane of symmetry, and compared with values calculated according to accepted equations (Equation 6).

From completed experiments the following conclusions result:

The shape of velocity profile in the inside region of turbulent flow has been evaluated. The value of parameter B has been found to be in the region from 4 to 6.

The value of Coles parameter P for outer region of turbulent layer has been established as P = 0.3.

The ratio has been found between local bottom shear stress at pipe plane of symmetry, and between average values calculated on base of hydraulic radius R and longitudinal pipe bottom slope i.

A good applicability of UVP method for analysis of turbulent flow has been proven.

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List of symbols

u	Average longitudinal point velocity
Π	Coles parameter
t_0	Bottom shear stress
B	Integration constant
b	Width on surface
H	Overall depth
Q	Discharge
S	Cross section
$\overline{u}$	Average sectional velocity
u_*	Friction velocity
x,y	Cartesian co-ordinates
δ	Maximum longitudinal point velocity depth
κ	Von Karman constant
ν	Kinematic viscosity
i_0	Longitudinal pipe bottom slope
R	Hydraulic radius
a	Angle of transducer with vertical
v_R	Measured velocity vector
v	Average vertical point velocity

Acknowledgement

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9.2 Flow field mapping example

The following example is a very nice demonstration of skilfully used UVP technique, where multiple profile measurement and flow mapping is used. The example uses a very valuable measurement feature of UVP, which is the ability to measure flow velocities in both clear water and mud. The Example is a complete Paper with original pictures, which has been reformatted for the purpose of this User's Guide.

Title, authors and affiliation

Turbidity current monitoring in a physical model flume using ultrasonic Doppler method

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Summary

In order to clarify the flow mechanism of river-induced turbidity currents in artificial lakes, physical modelling of turbidity currents was carried out in a laboratory flume. Parallel to the laboratory study, performed at the Laboratory of Hydraulic Constructions at the EPF-Lausanne, field observations have been made in an Alpine reservoir and its main inflow river. The reproduced turbidity currents in the laboratory have been monitored using ultrasound probes functioning with the Doppler Method. Measurements were made in the flume with three different configurations of the ultrasound transducers. The flow in the laboratory flume has been simulated numerically. The results of the laboratory experiments and the numerical calculations were compared in order to check the accuracy of the numerical two-phase flow code. Comparisons were made with vertical and axial velocity profiles. The complete 3D flow field has been computed and compared with the measured 2D velocity distribution near the bottom of the flume. The so tested numerical two-phase flow code has then been applied to simulate river-induced turbidity currents directly in an artificial reservoir.

Introduction

Sediment deposition in reservoirs causes mainly loss of water storage capacity (Graf 1994, Fan and Morris 1992), the risk of blockage of intakes structures as well as sediment entrainment in hydropower schemes (Boillat et al. 1994, Schleiss et al. 1996, De Cesare 1998). Finally, the sediment ends to some extent in the downstream river during flushing (Rambaud et al. 1988). The planning and design of a reservoir require the accurate prediction of sediment transport, erosion and deposition in the reservoir. For existing artificial lakes, more and wider knowledge is still needed to better understand and solve the sedimentation problem, and hence improve reservoir operation.

Turbidity currents are often the governing process in reservoir sedimentation by transporting fine materials over long distances through the impoundment to the vicinity of the dam. They are flows driven by density differences caused by suspended fine solid material. They belong to the family of sediment gravity currents. These are flows of water, laden with sediment, that move down slope in otherwise still waters like oceans, lakes and reservoirs. Their driving force is gained from the suspended matter, which renders the flowing turbid water heavier than the clear water above. Turbidity currents are encountered in fluvial hydraulics, most prominently if a sediment-laden discharge enters a reservoir, where, during the passage, it may unload or even resuspend granular material.

This paper presents some aspects of physical modelling and numerical simulation of turbidity currents. Special attention is drawn on the measuring technique in the laboratory using ultrasonic Doppler velocimetry.

Experimental set-up

The next Figure shows the general schematic view of the flume, two adjacent mixing and storing tanks and the measuring equipment. The flume used in this investigation is 8.4 m long, 1.5 m wide and 65 cm deep. It is made of steel but has a glass wall on one side. On the bottom, a 6 m PVC plate is laid which varies a slope from 0 to 6%. Water-sediment mixture is takes place in a separate tank (2 m^3) with a propeller-type mixer. This tank is connected to an upstream tank by a re-circulation pump. The turbid water returns to the mixing tank over a free surface weir, which controls the water level in the upstream tank. A gate with variable width and opening allows the controlled release of the turbidity current into the flume.

Measurements were made in the flume with three different configurations of the UVP transducers. Because the UVP instrument allows only one transducer to be connected at a time, the eight transducers used in the experimental set-up were connected to the UVP via a multiplexing unit.

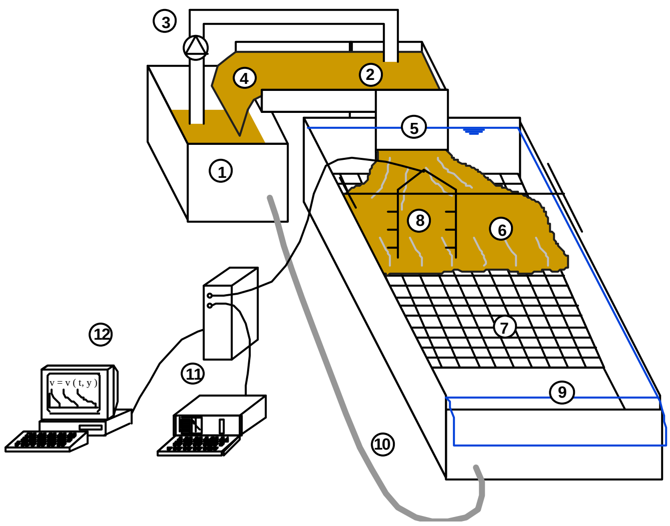
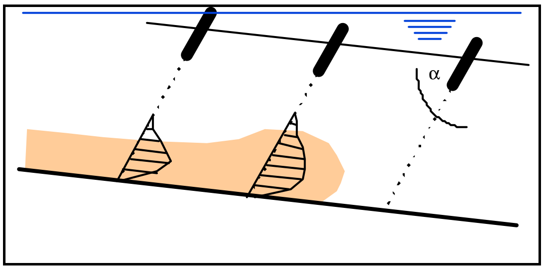
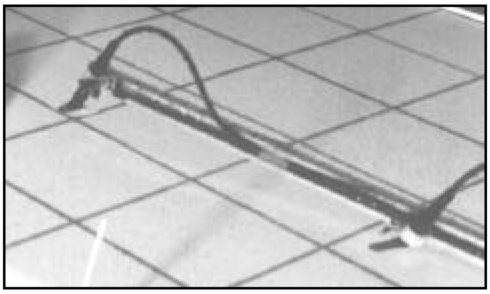


Figure 104 - Schematic drawing of the experimental installation, (1) mixing tank (2) upstream tank (3) recirculation pump (4) free surface weir (5) inflow gate (6) turbidity current (7) experimental flume (8) ultrasonic probes (9) sharp crested weir (10) flexible duct (11) UVP-X3-PS instrument (12) controlling computer

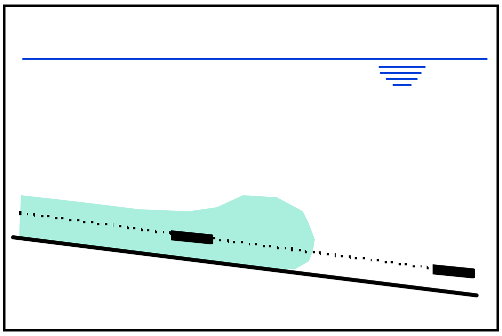
The beam directions and the penetration length were chosen in order to cover the interior of the advancing turbidity current. As the model is symmetric, the profiles were taken on the axis of symmetry and the flow -mapping region was situated on one side of the flume only. The arrangement of the transducers are described as follows:

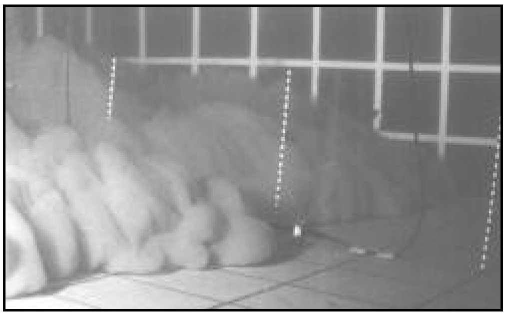
- Vertical arrangement with 8 transducers looking with an angle of 60° against the main flow. The measurements give the projected vertical velocity profiles over 2 m flow length from the gate, the distance between the transducers was 25 cm.



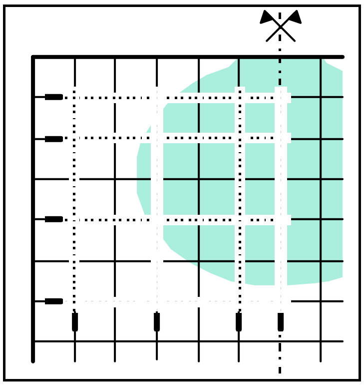


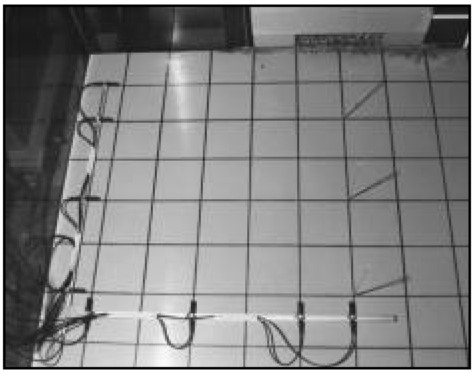
- Axial disposition with 8 transducers looking straight against the main flow. Measurements give the horizontal velocity profiles over the whole 3 m flow length from the gate, the distance between the transducers was 50 cm. The probes were installed 12 mm above the bottom and were slightly set off laterally in order to reduce interference by reflection of US from different transducers.





- Square grouping with 4 transducers on each side looking straight at and perpendicular to the main flow in the spreading part just after the inflow gate. The side of the square plane where the flow mapping took place was 62.5 cm long, the distance between transducers was 12.5 cm close to the inflow gate, and 25 cm elsewhere. The transducers were installed with plastic clamps 12 mm above the bottom on an aluminium frame.





The echo of the flowing turbidity current was strong enough to allow rapid measurements, only 4 successive profiles were taken with each transducer, and the averaged profile is used as velocity profile at one location. The temporal resolution was therefore less than ½ second per profile. The duration to sweep all transducers was around 3 seconds and the cycle was repeated every 5 seconds, thus giving a quasi-instantaneous velocity information every 5 seconds. The vertical profiles were obtained with 8 measurements per profile, thus doubling cycle time, repetitions were made every 10 seconds.

Met-Flow note:

The given measurement times apply for older discontinued Model UVP-X. For contemporary Model UVP-DUO measurement times are nearly four times faster. While UVP-X took 440 ms to collect a profile, modern UVP-DUO takes only 120 ms. While – in the described measurement situation – it took UVP-X 3,680 ms, it takes UVP-DUO only 960 ms. It pays back to upgrade older UVP-X models to UVP-DUO.

Simulated turbidity current

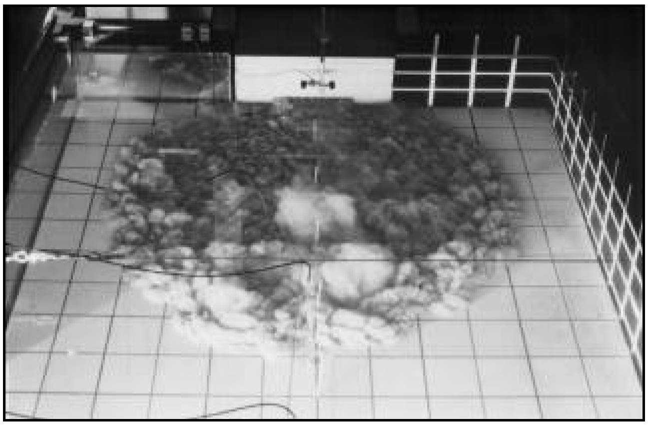


Figure 105 - Photograph of the expanding turbidity current in the experimental flume 25 s after opening of the gate, the current spreads out almost radial, 125mm x 125mm grid on PVC bottom

All the experiments were conducted with fine homogenous clay as suspended matter. The density of the sediments is ρ_s = 2'740 kg/m^3. The particle size distribution ranges from d_{10} = 0.002 mm to d_{90} = 0.1 mm, with a mean particle diameter of d_{50} = 0.02 mm. The corresponding settling velocity calculated using Stokes law is $v_{ss} \approx$ 0.4 mm/s for the representative particle size in calm water. In all experiments, clear water from the main reservoir of the hydraulic laboratory was used as the ambient fluid. The water-sediment mixtures were prepared in the mixing tank by adding the dry clay to the clear water. The density of the water-sediment mixture, ρ_m varied between 1'002 and 1'005 kg/m^3, and the mixture was considered a Newtonian Fluid.

The Figure above shows a photograph of the spreading turbidity current 25 seconds following its initial release. After its spreading to the total flume with, the current adjusted itself rapidly to a uniform flow advancing steadily within the tank. When the current reached the downstream end of the flume, the turbid water was evacuated by opening the bottom gate. During the total duration of the experiment, the same turbid water flux was fed from the inflow gate.

Experimental results

The measured velocity profiles were compared with a theoretical distribution, the result agrees well as shown in. At bottom surface layer region, velocity distribution is logarithmic. At jet region, velocity has half Normal (Gaussian) distribution.

The Figure below shows the velocity distribution in the turbidity current expansion. Both calculated and measured values are plotted on the same graph. The results of the numerical modelling are presented by a surface of equal concentration where the maximum concentration gradient can be found.

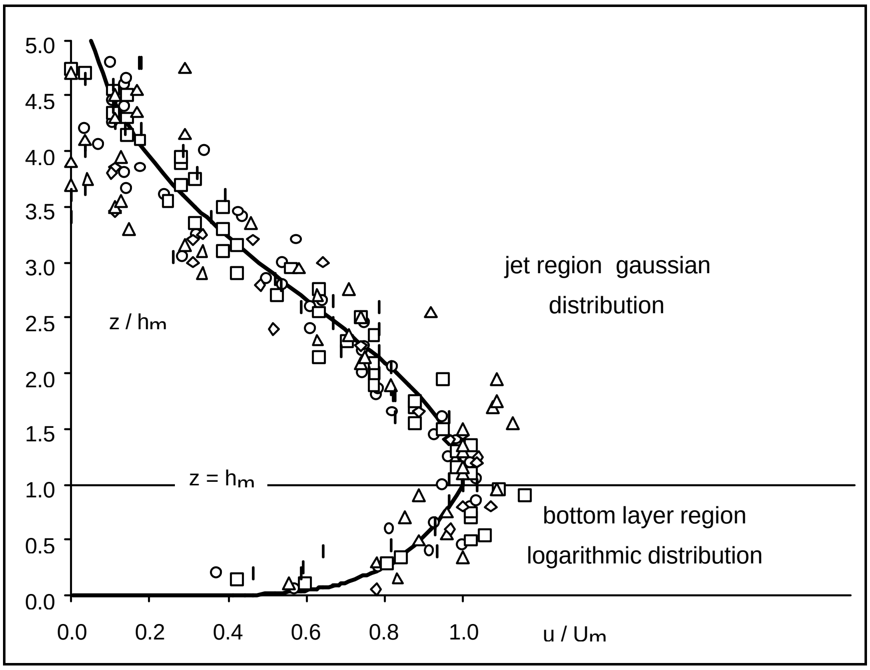


Figure 106 - Measured velocity values compared to theoretical vertical velocity distribution. Values from run n° 2, 80 ms between two succeeding measurements

This surface fits well to the position of the interface between the turbidity current and the surrounding water. The velocity vectors are given on a fine grid in a plane parallel to the bottom. This plane is situated at 12 mm from the bottom, the same level as the one where the transducers were installed.

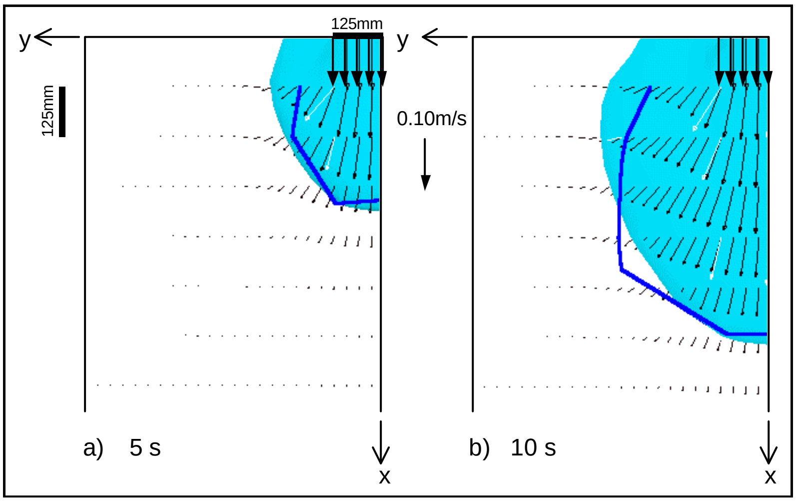


Figure 107 - Computed and measured 2D flow field 12 mm from the flume bottom and limits of the spreading turbidity current a) 5 and b) 10 s after the opening of the gate; numerical simulation: black velocity vectors, turbidity current as a grey surface; physical model: white velocity vectors, limits of the turbidity current as a bold line.

Conclusions

Good experience with the UVP technique for flow measurement in the laboratory has been acquired. The characteristics of the UVP instrument make it well adapted to operate in physical scale models with turbidity currents. The small ultrasonic transducers allow easy handling and undisturbed flow monitoring. It is possible to capture precise velocity profiles in very short a time.

Computer simulation has been used to predict the advancing 3D-turbidity current in the laboratory and validated with experimental results. Based on the numerical simulation, not only general conclusions can be drawn, but also the precise behaviour of turbidity currents can be predicted.

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10. Frequently Asked Questions (FAQ)

(All numbers are for water and 4MHz ultrasound basic frequency unless otherwise noted.)

10.1 Commercial features

Why is UVP-DUO Monitor delivered with 5 working frequencies?

Low working frequencies enable measuring of higher values of on-axis velocity component on greater distance, but at the same time decrease spatial resolution of measurement. High working frequencies enable measuring of small details on shorter distance, but enable measuring of smaller on-axis velocity component. With five available measuring frequencies, it is therefore possible to optimise measurement conditions for a given task.

Is simultaneous measurement of UVP Monitor and PIV or LDA viable?

UVP Monitor uses ultrasound, and PIV (Particle Image Velocimetry) or LDA (Laser-Doppler Anemometry) uses light. Therefore, both methods do not interfere with each other, and can be used simultaneously.

What is the difference between conventional ultrasonic flow meter and UVP?

The typical ultrasonic flow meter uses the principle of transit time of ultrasonic pulse which is carried by the flow. It measures the time difference from the sound speed between transmitter and receiver with some fixed distance. This method measures an average velocity in a measured field like a pipe so that some kind of theoretical assumption is needed to evaluate an integral of the velocity distribution over a flow channel. This requires some strict conditions for the flow to be measured such as an entry length upstream the measured position. On the other hand, UVP measures the velocity profile directly so that the evaluation of integral is direct, requiring no strict measuring conditions. Moreover, the theoretical assumption used for the conventional devices are normally valid for the stationary flow. This eliminates the possibility of measuring a transient flow-rate after pump start or valve operation. UVP can measure the velocity profile instantaneously, and thus the transient measurement is possible and accurate.

Is there any UVP Monitor working near my lab?

Probably it is. Please call to Met-Flow, and we will give you an address of a reference customer near you so you could ask for his experience with UVP Monitor.

10.2 Transducers, US beam characteristics

Is it possible to submerge transducers into a large mixing vessel?

Yes, this is possible. All transducers are watertight, and can be temporarily submerged or installed into vessel as stable measurement installation.

What is maximum applicable RF voltage on transducer?

During operation, the maximum RF voltage on transducer is 150 Vpp, but the transducer can withstand 200 Vpp.

What is maximum transducer cable length?

Transducer cable carries small signals during receiving phase, and it is not advantageous to use superfluous length of cable in environment with strong electromagnetic interference (EMI). Without any specification transducer cable length is 4 m, but the shorter the better. You can get cable length up to 10 m for the asking when ordering, but for lengths above 4 m, Met-Flow cannot guarantee unconditional transducer performance in environments with strong EMI.

Fewer problems are met with low transducer frequencies while one has to be careful with higher frequencies (4 and 8 MHz).

Is it possible to extend or shorten transducer cable?

Cable is integrally molded into transducer, and this is why it is not possible to extend the cable. However, you can shorten the cable from the BNC connector end.

What is ultrasonic beam divergence?

The beam divergence is determined by the ultrasound wavelength and the initial beam size. For most working frequencies and standard transducers, beam divergence is approximately ±2.5°. You can find detailed description of beam divergence elsewhere in this User's Guide.

10.3 Ultrasound, windowing function, resolution

What is the smallest distance of measurement from transducer?

It takes several microseconds to UVP Monitor to switch from transmitting to receiving mode. This time solely due to electronic switching, makes the smallest measurable distance approximately 5mm from transducer face.

Is it possible to measure flow in channels smaller than 90mm?

Yes, without any problems. Measured profile can have practically any length. UVP Monitor with software Version 3 stores any number of profile points from 10 to 2048 in each profile. As the measuring volume length is 0.74 mm for a standard 4 cycles pulse of 4 MHz, the smallest distance between these sampling volume is 0.74mm for a non-overlapping configuration, and thus the smallest measurable profile length is in fact 7.4 mm for 10-point profile.

When measurement on 20 mm channel is made, the number of 'used' points can be only 20:0,74 = 27 points. For practical purposes, this is more than sufficient.

Moreover a minimum of 2 cycles per pulse can be used in case of good echo conditions, or a higher frequency of 8 MHz proposed by Met-Flow implying shorter wavelength (4 cycles per 8MHz pulse is equivalent to 0.37 mm sampling volume) can be selected.

What is measurement resolution and accuracy for low velocity flows?

A data length for the velocity value is 8 bits. This means that the velocity range resolution is 1/256 of the maximum detectable velocity, which can be selected by the UVP. The best accuracy is thus theoretically 0.4%.

When the maximum detectable length is selected as 748 mm for water, the maximum detectable velocity range is 17.5 cm/s which gives the minimum velocity resolution as well as the threshold velocity as 0.7 mm/sec. Adding to this, there is an effect of beam size, particle motion, etc. UVP accuracy has been investigated using a rigid body motion of water in a rotating cylinder, giving overall velocity error better than 5%, and overall axial position error better than 1%.

What typical spatial resolution can be expected from UVP method?

Each single-point measurement of velocity out of the n–points profile is made in a finite cylindrical volume, which depends on the ultrasound beam size. Its longitudinal resolution corresponds to the burst length (0.74mm for 4 cycles of a 4 MHz US wave) while its lateral resolution corresponds to the beam diameter and divergence of a respective transducer.

For high spatial resolution, one should then choose a high US frequency.

What typical time resolution can we expect from UVP method?

Measuring speed of UVP Monitor depends of concrete set-up of measurement parameters. Generally, 30 to 200 full profiles can be measured and saved every second. Obviously, it is possible to slow down data collection to a desired value.

10.4 Data processing

Can measured data be accessed by other programs?

All measurement data are saved on hard disk in binary mfprof file format. This data can be exported in many formats e.g. to Excel or other software for further post-processing.

How many measured profiles can be saved during measurement?

Number of saved data is only limited by available space on computer hard disk. This usually is just theoretical limitation. Number of profiles, which can be saved, is therefore practically unlimited.

Can UVP Monitor calculate turbulence power spectra?

Yes, directly from software Version 3. It can also calculate auto-correlations and cross-correlations within a single channel and/or between two channels.

Is UVP Monitor capable of recording time history of flow?

Yes, it is. Single measurements are recorded with frequency comparable with video recorder rate. Such time ‘movie’ can then be played – in addition to normal computational processing – on computer screen as ‘movie’ of flow.

Moreover, in the data file a time stamp is automatically added to each profile measurement.

10.5 UVP applicability

Can UVP Monitor measure in air?

To measure in air or other gasses is principally impossible with UVP instrument working with high frequency sound fields, as in those media the acoustic impedance is much more smaller than in liquid or solids. Moreover, echo would be generally very weak.

Can UVP Monitor measure in liquids containing bubbles?

As far as bubbles are small in comparison with ultrasound beam diameter, bubbles form very good ultrasound scattering centres. If the concentration of bubbles is too high, there occurs a multiple reflection of ultrasound pulse among these bubbles and obtained profile might not be correct.

What happens when ultrasonic beam hits liquid’s free surface?

In such case, measured profile extends up to the liquid surface, and measurement points above surface are missing. This effect can also be used for surface level measurement. It should be noted however that a reflection from the surface returning to the transducer might destroy, under certain circumstances, the measured profile. Such returning occurs randomly depending on the condition of the free surface.

Can UVP Monitor measure flow-rate?

In case of circular pipe or square channel, it can, through a geometric integration of the velocity profile. If beam incident angle and pipe diameter/ channel width are known, then UVP Monitor can recalculate measured profile directly to through-flow. This is true if the flow is well developed at the measuring position.

Comparative tests have been made with a weight tank calibration system in water, providing error rate from 0.18 % to 0.59 %. Measurement repeatability was also very good.

Is it possible to measure molten chocolate flow?

Yes, this has already been tested, but measuring distance is strongly decreased.

UVP Monitor can also measure in mayonnaise, ketchup, paper pulp, toothpaste, ferromagnetic fluid, glycerol, oil and petrol, and in other liquids and pastes.

What is the thickest suspension measurable by UVP Monitor?

Usually it is 10-15% of solid particles. Sometimes even thicker suspensions can be successfully measured, but experimental testing should be mandatory as the correct answer really depends on material, size, depth to be measured, etc.

How is it possible to measure sound velocity in measured media?

If we do not know sound velocity in measured media, it is easy to calibrate. Use a vessel of known size, and place transducer perpendicular to the wall. In program, iteratively change speed of sound as long as measured reflection from the wall corresponds to the real distance from transducer front face to wall. Then the speed of sound is set up correctly. Using oscilloscope and observing the echo gives better and more accurate results.

Can UVP Monitor measure turbulence of flowing liquid?

Yes, this is being performed automatically. Profile measurements are being done repeatedly, results are calculated by local averaging, and at the same time RMS, variance, flatness and curtosis are calculated as well. Results are available as graph across all channels and as a table.

What is the influence of high temperature of the fluid on measurement?

The temperature has an effect on the sound velocity. If the speed of sound in the fluid has a strong dependence on the temperature, it has to be corrected. From the practical point of view, the temperature of the fluid affects the condition of mounting a transducer. The present ‘standard’ transducers have the maximum operating temperature of 60°C. If the temperature is higher than this at the place where the transducer is mounted, special care has to be taken, or special high-temperature transducers up to 150°C used.

More importantly, in application of UVP to high-temperature flow fields, it is not the temperature level which might form a problem, but temperature gradient in the fluid. The temperature gradient has an influence on propagation of ultrasound. Ultrasound beam can be bent or reflected a little, unless the beam direction is normal to the temperature gradient. Clearly, UVP can measure velocity profile as long as the liquid includes reflectors, but the position of the velocity profile could be distorted a little.

Until now, UVP has been used in water with temperature difference of ca. 30°C per 10 cm, and no significant influence on measurement has been found.

Can the UVP be applied to liquid-gas two-phase flows?

Ultrasound is almost 100% reflected at the interface between liquid and gas, namely gas bubbles. However, the beam size of the ultrasound is relatively large so that if the void fraction of the flow is low and flow regime is nearly dispersed flow where the size of the bubble is smaller than the beam size, the gas bubbles play the role of a reflector and a velocity profile can be well obtained. However, if the void fraction is larger than that for dispersed flow, like chunk flow or annular flow, UVP can only measure the velocity profile for the liquid part (such as liquid film for the annular flow) between the transducer and any large bubbles.

10.6 Test medium, through-the-wall measurement

In what kind of fluids can the UVP be used?

The present model of UVP has been developed for flow in such liquids as:

- Water
- Organic liquids: Freon, Petroleum
- Liquid metals: Mercury, Lead-Bismuth-Eutectic
- Ferromagnetic liquid

- Polymeric fluid
- Food materials: Mayonnaise, Ketchup, Coffee, etc.

How is it possible to measure flow in vessel or pipe through the wall?

Some combinations of wall material and liquid are well suited, some not so well suited. The decisive factor is ‘acoustic impedance’ of wall and liquid. (Acoustic impedance is product of density and sound velocity of material.) If acoustic impedance of wall material and liquid are at least similar, through-the-wall measurement is usually possible without significant problems.

In principle, wall acoustic impedance should not be more than twice to three times test liquid impedance.

What kind of materials can be used for the container wall on which a transducer is fixed?

Generally, the ultrasound is reflected at the interface where acoustic impedance (density x sound speed) changes discontinuously. Thus, when the transducer is set outside the container wall for non-invasive measurement, a combination of liquid and wall is limited as follows:

- Water (1.48 MRay) – Plexiglas (3.15 MRay), PVC (3.27 MRay), thin glass (12 MRay)
- Freon (1.12 MRay) – thin glass (12 MRay)
- Mercury (19.6 MRay) – Aluminium (17.3 MRay), Stainless Steel (45.7 MRay)
- Pb-Bi Eutectic (~20 MRay) – Aluminium (17.3 MRay)
- Petroleum based ferromagnetic liquid (~1.4 MRay)– Plexiglas (3.15 MRay)
- Water based thin slurry (1.48 MRay) – Plexiglas (3.15 MRay)

The following combinations need careful consideration:

- Water (1.48 MRay) – Metal (20 – 50 MRay)
- Mercury (19.6 MRay) – Glass (12 MRay)

How can the possibility of measurement in certain media be tested?

The easiest method is the following: fill a beer bottle with test liquid. Then sink transducer into the liquid and pull it out repeatedly. If measurement is acoustically possible, on UVP Monitor screen you will see profile movement corresponding to the transducer movement.

Does there exist any medium impossible to measure with UVP Monitor?

Yes. For example in collagen, measurement is impossible. Thanks to its fibrous structure, colagen features very high absorption of ultrasound so no echoes return to transducer. There exist more media like this. Ultrasound measurement in very high absorption media is impossible.

How can I measure water flow in relatively thick cast iron pipe?

It is not practical to transmit ultrasound through a cast iron wall (which acoustic impedance is about 30 times the one of water) into water, since the interface would largely reflect incident pulses.

In most cases, it is preferable to drill a small 8mm diameter port into the pipe (4 MHz transducer with 5 mm active diameter) and insert transducer into a pipe flush with its inner surface. The transducer can be sealed with an O-ring. This removes all problems with wall impedance.

10.7 Seeding

What should be the size of the reflecting particle (seeding)?

To generate a significant echo a particle should have a diameter at least equal to the quarter of the ultrasound beam wavelength (i.e. for 4 MHz in water a minimum of 93 µm of diameter is required).

On the other hand, it is known that a particle as a reflector follows the flow motion faithfully, when the density is nearly equal to the fluid itself and the size is smaller than 100 µm (in water). From these facts, the particle is expected to be larger as a reflector and at the same time to be smaller as a tracer.

What should the reflecting particle be? – Particle concentration

Ideally, the reflecting particle should have as different acoustic impedance from the measured liquid, as possible (or as practical). Since the reflecting particle size is usually much smaller than the ultrasound wavelength, signal is formed by reflections from many particles, and measured profile is affected by its concentration. When concentration of particles is smaller, some points of profile may not be measured during a single US pulse. This does not mean that the accuracy in velocity value becomes lower, but that the instantaneous profile has some points missing. These points have zero value because of no reflection, or are set to zero by the algorithm when too weak a reflection is detected. When the UVP is to be applied to a configuration with low concentration of particles, the average velocity profile can be reconstructed from many profiles stored on a disk file. This can been successfully done for the stationary flow.

Is natural particle contamination of water sufficient for measurement?

Usually natural particle contamination of water is sufficient for UVP Monitor measurement. If media is very clean or if you want to improve measurement, it is possible to introduce tracing particles. A little mud in hydraulic models or stirring of bottom slurry is usually enough. Other particles (hollow glass spheres, nylon or polystyrene powder) can be used as well.

10.8 Hardware

Is it possible to synchronise UVP Monitor with external events?

UVP-DUO Monitor features synchronisation input for TTL-level synchronisation (0 – 5 V, min. 20 ns), and with different modes of triggering. This enables to synchronise measurements of periodic flows (e.g. piston pumps), or to measure transient events (e.g. valve opening).

Can UVP-DUO Monitor use external display?

UVP-DUO does not have any display of its own, so it uses host computer display only. The size of such display only depends on used host computer.

11. Literature

Met-Flow cultivates close contacts with main centres of technology in Switzerland, Germany, Japan and UK. This especially concerns such centres, which do research in ultrasound technique field, and apply it to demanding industrial applications.

Such research has been intensively made especially in Paul Scherrer Institute, Villigen, Switzerland, under the leadership of Prof. Yasushi Takeda. Prof. Takeda became the pioneer in measurement of velocity profiles in molten metal by UVP technique as early as 1984. Fe has since made an important contribution to scientific publications in this field. Many other publications from other scientists and researchers exist as well.

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49. Wiklund, J., Johansson, M.: In-line Rheological Measurements of Complex Model Fluids using an Ulatrasound UVP-PD Based Method, Master Thesis, Swedish Institute for Food and Biotechnology, Sweden; Laboratory of Food Process Engineering, Swiss Federal Institute of Technology Zürich (ETH), Switzerland; Chalmers University of Technology, Sweden; July 2001.

12. Appendix: Software demonstration version

12.1 Demo software features

For demonstration purposes, the software Version 3 also exists in ‘Demonstration’ version. This is a version of software, which retains most of software features, and enables to a customer to get acquinted with software. However, some of the software features are disabled, so the software cannot be used for serious work.

Special ‘demo’ features include:

- Software does not read files. It ‘reads’ only several example files, which are supplied with the demo.
- Software does not save files.
- Software does not acquire data from UVP-DUO Monitor; instead, it uses internal emulator to produce artificial data for demonstration of data acquisition. Therefore, the ‘Instrument Address…’ dialog for setting up TCP/IP address is missing.
- Software does not use any software key, and can be copied and used free of charge (some formal limitations cited in Software Licence apply).

All other software features are fully unctional. Demo software functioning is time-unlimited.

At present, the following demo files are supplied with the Demo:

Direct flow.mfprof – This is a measurement file of direct flow with very low turbulence (around 1%). Good quality of signal, with the exception of the first several channels, where difficulties of near-field measurement, together with wall effects show.

Cyclic.mfprof – This is an example of forwards-backwards oscillating 'piston' flow. Piston action starts only after Profile 110. Do not forget to run Profile 'movie'. Since the flow has very distinct periodic content, it is well suitable for demonstration of frequency characteristics and correlations.

Taylor-Couette.mfprof – This file demonstrates longitudinal vortice cylinders found in Taylor-Couette flows. This is why Profiles show waves while Time series are almost constant in time. There is no frequency content to speak of, since correlation and power spectrum compute along time axis.

FlowMap.mfprof – This file demonstrates non-perpendicular Flow mapping with six transducers. Please keep in mind that during Flow mapping Time series and Profile window switch to different transducers according to Multiplexer parameters. For observation of results, open the Flow map window.

In later demo software versions, supplied files can change without notice.

12.2 Demo software installation

Demo software Version 3 is supplied on a CD disk. It can be installed on almost any Win32 operating system (Windows 98, ME, NT4, 2000, XP). Windows 95 are not supported.

Insert CD into CD drive, and from Explorer double-click the Setup file. Follow on-line instructions of Installation wizard.

To start Demo software, click *Start | Programs | UVP Demo.*

12.3 Removing demo software

To remove Demo software from your computer, click *Start | Settings | Control Panel.* When Control Panel window opens, double-click *Add/Remove Programs.* Select the item UVP-DUO Demo Software, and click *Add/Remove…* button. The software will be completely removed from your computer.

Installation and removal of UVP-DUO demo software does not leave any files on your computer.

Demo software can be repeatedly installed and removed on the same computer.

13. Appendix: Formulas used in software

Here formulas not described in other chapters are given.

13.1 Flow rate

Symbol	Unit	Description
P_p	m^2/s	Parallel flow rate
P_c	m^3/s	Circular flow rate
d_{ch}	m	Channel distance
$v_{axis\ i}$	m/s	Axis velocity of i-channel
first	-	Number of first valid channel
last	-	Number of last valid channel

Parallel flow rate

a) $a = 90^{o}$:

$$P_p = d_{ch} \sum_{i=first}^{last} v_{axis_i}$$

b) $a < 90^{o}$

$$P_p = d_{ch} \frac{\cos a}{\sin a} \sum_{i=first}^{last} v_{axis_i}$$

Circular flow rate

a) $a = 90^{o}$:

$$P_c = p\, d_{ch}^{\ 2} \sum_{i=first}^{last} v_{axis_i} \left| i - \frac{first + last}{2} \right|$$

b) $a < 90^{o}$:

$$P_c = p \frac{\left(d_{ch} \cos a \right)^2}{\sin a} \sum_{i=first}^{last} v_{axis_i} \left| i - \frac{first + last}{2} \right|$$

13.2 Flow mapping

Symbol	Unit	Description
x_1, x_2	m	x - coordinate
y_1, y_2	m	y - coordinate
x_{T1}, x_{T2}	m	x - coordinate of transducer front face center
y_{T1}, y_{T2}	m	y - coordinate of transducer front face center
y_1, y_2	°	Transducer axis azimuth
d_1, d_2	m	Distance from transducer front face
v_1, v_2	m/s	Velocity on transducer axis in a crossing point
v_x	m/s	x - component of velocity
v_y	m/s	y - component of velocity

Axis 1 definition:

$$x_1 = x_{P1} + d_1 \cos y_1$$
$$y_1 = y_{P1} + d_1 \sin y_1$$

Axis 2 definition:

$$x_2 = x_{P2} + d_2 \cos y_2$$
$$y_2 = y_{P2} + d_2 \sin y_2$$

Distances d_1 and d_2 of crossing point of axes 1 and 2:

$$d_1 = \frac{(x_{P1} - x_{P2}) \sin y_2 - (y_{P1} - y_{P2}) \cos y_2}{\sin(y_1 - y_2)}$$
$$d_2 = \frac{-(y_{P1} - y_{P2}) \cos y_2 + (x_{P1} - x_{P2}) \sin y_2}{\sin(y_1 - y_2)}$$

Calculation of velocity x-component and y-component from velocity projection into axis 1 and 2:

$$v_x = c_{x1} v_1 + c_{x2} v_2$$
$$v_y = c_{y1} v_1 + c_{y2} v_2$$

Where

$c_{x1} = -\frac{\sin y_2}{\sin(y_1 - y_2)}$	$c_{x2} = \frac{\sin y_1}{\sin(y_1 - y_2)}$
$c_{y1} = \frac{\cos y_2}{\sin(y_1 - y_2)}$	$c_{y2} = -\frac{\cos y_1}{\sin(y_1 - y_2)}$

14. Appendix: Format of Data File (*.mfprof)

Data file consists of:

1. FileHeader
2. Profiles
3. Measurement parameters

File Header

Type	Variable name	Description
char[64]	signum	64-symbol file type signature. In the current version it is "Met-Flow UVP Monitor\n4\n" *Comment:* \n is a symbol for end of line, hexadecimal 0x0A
UInt64	measParamsOffset	64-bit number giving position of beginning of measurement parameters
UInt32	nProfiles	Number of profiles saved in the file
UInt32	reserved1	Always 0
UInt32	flags	Flags, at present only bit 0 (0x0001) is in use. If this flag is set (=1), Profiles also include amplitude.
UInt32	recordSize	Size of data in a single profile
UInt32	nChannels	Number of points in a profile
UInt32	reserved2	Always 0
UInt64	startTime	Time of measurement start (first profile) in the format FILETIME (Win32) structure (The **FILETIME** structure is a 64-bit value representing the number of 100-nanosecond increments since January 1, 1601 (UTC).)

Profiles

Profiles follow immediately after File Header. File consists of nProfiles profiles. If flags&0x0001 is non-zero, then the profile also includes amplitude data. Each profile consists of:

1. Profile Header
2. Doppler Data
3. AmplitudeData (optionally – see flags file header variable).

Profile Header

Type	Variable name	Description
UInt32	status	Always 0
UInt32	transducer	Transducer number
UInt64	profileTime	Time of measurement of the profile in 100-nanosecond increments since first profile (startTime file header variable)

Doppler Data

Doppler Data block contains nChannels Int16 Doppler values received from UVP hardware.

Amplitude Data

Amplitude Data block contains nChannels Int16 amplitude values received from UVP hardware.

Measurement parameters

Measurement parameters are stored at measParamsOffset position. Measurement parameters are saved in text form. Values of parameters are saved in a form: parameter name=parameter value. Each parameter is given in one line. In case of text values including more lines, at the end of line (with the exception of the last line) a symbol '\' is added. E.g. comment including two lines

Piston action starts only after Profile 110.

will be saved as

Comment=An example of forwards-backwards oscillating 'piston' flow.\
Piston action starts only after Profile 110.

Measurement parameters consist of two blocks:

1. UVP parameters, and
2. Mutex parameters.

UVP parameters:

These begin with a line "[UVP_PARAMETER]", and contain (in any sequence):

Label	**Type used in UVP**	**Name in a dialog**	**Description**
Frequency	UInt32	Frequency	
StartChannel	double	Start	
ChannelDistance	double	Channel distance	
ChannelWidth	double	Channel width	
MaximumDepth	double	Maximum depth	
SoundSpeed	UInt32	Sound speed	
Angle	double	Angle	
GainStart	UInt32	Gain start	
GainEnd	UInt32	Gain end	
Voltage	UInt32	Voltage	
Iterations	UInt32	# of repetitions	
NoiseLevel	UInt32	Noise filter	
CyclesPerPulse	UInt32	# of cycles	
TriggerMode	UInt32	Trigger (index)	
TriggerModeName	string	Trigger (text)	
ProfileLength	UInt32	# of channels	
ProfilesPerBlock	UInt32	# of samples	
Blocks	UInt32	-	Always 1

AmplitudeStored	bool	Read amplitude	
RawDataMin	int	-	Minimum possible value of raw data
RawDataMax	int	-	Maximum possible value of raw data
RawDataRange	UInt32	-	RawDataMax-RawDataMin+1
VelocityInterpretingMode	int	-	Negative=-1, normal=0, positive=1
UserSampleTime	bool	Minimum sampling time / Specify sampling time (flag)	
SampleTime	UInt32	Minimum sampling time / Specify sampling time (value)	
UseMultiplexer	bool	Multiplexer	
FlowMapping	bool	Flow mapping	
FirstValidChannel	UInt32	Flow rate – First channel	
LastValidChannel	UInt32	Flow rate – Last channel	
FlowRateType		Flow rate - parallel / circular	Parallel=0, circular=1
PeriodEnhOffset	UInt32	Period enhancement - Offset	
PeriodEnhPeriod	UInt32	Period enhancement - Period	
PeriodEnhNCycles	UInt32	Period enhancement - Cycles	
Comment	string	Notes	
MeasurementProtocol	string	-	

Multiplexer parameters

These begin with a line "[MUX_PARAMETER]", and contain (in any sequence):

Label	**Type used in UVP**	**Name in a dialog**	**Description**
NumberOfCycles	UInt32	# of cycles	
CycleDelay	UInt32	Delay between cycles	
Version	UInt32	-	Currently 2
Table	-	Multiplexer table	Each line contains (separated by space): Use(0 or 1), Transducer# Samples, Angle (or Azimuth), X pos, Y pos, Delay, Valid from, Valid to.

15. Appendix: Communication set-up

This Appendix describes how to set up communication and TCP/IP addresses on UVP-DUO and host computer. Different operating systems of host computer are considered.

UVP-DUO Monitor is equipped by Ethernet card with RJ-45 connector (‘telephone’-like connector). It can be connected to a host PC computer, which is also equipped by at least one Ethernet card with RJ-45 connector. **The interconnection cable is of a ‘crosswire’ type.**

Note ***For connection of a computer with fixed network connector on a wall, a ‘straight’ cable is used. Therefore, the usual computer-to-wall Ethernet cable is NOT suitable for direct connection of UVP-DUO and host computer.***

Note ***For beginner, it is not suggested to connect UVP-DUO directly to local network (LAN), since these networks usually use automatic assignment of IP addresses and UVP-DUO cannot handle this. For direct connection of UVP-DUO to LAN, please consult your Network manager.***

UVP-DUO software communicates with UVP-DUO hardware by means of TCP/IP protocol. Parameters of TCP/IP communication are set up in Measurement | Instrument Address | Advanced… dialog. Two parameters have to be set:
IP address and Subnet mask. (Default gateway need not be filled, since it is meant for future use only.) Here two typical possibilities will be described:

- Host computer has one Ethernet card
- Host computer has two Ethernet cards.

15.1 Set-up of UVP-DUO communication with one-card PC

In this case the host computer communicates with UVP-DUO only, and is independent on any other network.

Here Met-Flow suggests to keep UVP-DUO factory default TCP/IP communication parameters (IP address: 192.168.0.10, Subnet mask: 255.255.255.0). Host computer TCP/IP parameters should be set up as follows: IP address: 192.168.0.1, Subnet mask: 255.255.255.0. (Default gateway need not be filled, since it is meant for future use only.)

15.2 Set-up of UVP-DUO communication with two-card PC

Warning ***This setup is much more complicated, and we suggest that you leave it up to your Network manager or an experienced network user.***

When a PC computer uses two Ethernet cards, each of them has to work in a different subnet. This means, that IP addresses of these cards, masked (AND) by their subnet mask, have to differ.

Example: If subnet mask is 255.255.255.0, IP address of each card has to differ in the first three digits. E.g., the first card can work with IP address 192.168.0.xxx, and the second card can work with IP address 192.168.1.xxx

For connection of PC computers into LAN, automatic assignment of IP addresses is very often used. Ask your Network manager, which addresses can be assigned to your Ethernet card, and which addresses you can use for the second Ethernet card.

The UVP-Duo address has to use IP address from the same subnet, as uses the network card, with which the UVP-DUO communicates. This means, that its IP address, masked by a subnet mask, must be the same as IP address of host PC network card, masked by the same mask. On the other hand, these two addresses have to differ in the remaining digits.

Example: If IP address of a PC network card (to which an UVP-DUO is connected) is 192.168.0.1, and subnet mask is 255.255.255.0, then UVP-DUO can have an address 192.168.0.10, and subnet mask 255.255.255.0 (company default).

In order to enable other PC computers from local network to communicate with UVP-DUO through computer where UVP-DUO is connected, it is necessary to enter into the UVP-DUO a Default gateway address of network card, to which UVP-DUO is connected.

At the same time a computer from local network, which intends to communicate with UVP-DUO, has to have a possibility to access the subnet UVP-DUO – host PC computer.

If local network is formed by computers with fixed IP addresses only, then a computer wishing to communicate with UVP-DUO, must add an address of UVP-DUO host computer (i.e. address of a network card, through which a host computer is connected to local network) into Default gateways.

Nevertheless, typical local networks use automatic IP address assignment. This is why you should leave accessing of UVP-DUO from other LAN computers up to your Network manager.

15.3 Automatic setup of UVP-DUO's TCP/IP address

UVP-DUO software Version 3 provides a small utility program for automatic set up of UVP-DUO TCP/IP address. In order to do this, it is necessary to interconnect the COM port of UVP-DUO with its host computer COM port by a "null-modem cable" (the same cable as is used for connection of computers for "Direct cable connection").

In order to execute an automatic setup of UVP-DUO's TCP/IP, proceed as follows.

In the main menu of Software Version 3 select *Measurement | Instrument Address.*

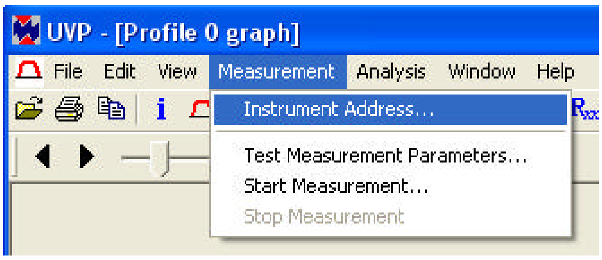

Figure 108 – Setting up of Instrument address

A dialog "*Instrument Address*" opens:

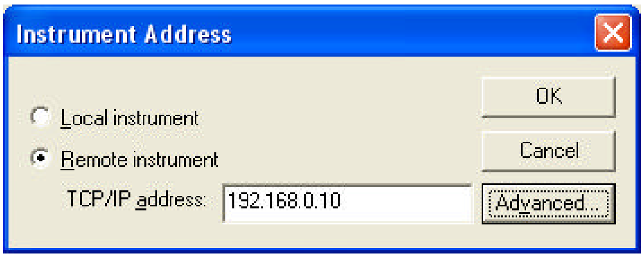

Figure 109 – Dialog Instrument address

Click the "*Advanced…*" button. A dialog "*Advanced Instrument Settings*" opens:

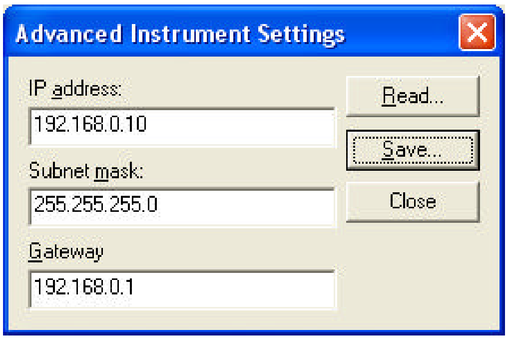

Figure 110 – Advanced Instrument Settings

Fill-in IP address and Subnet mask, and click the "*Save…*" button. A dialog "*Choose Comm port*" opens:

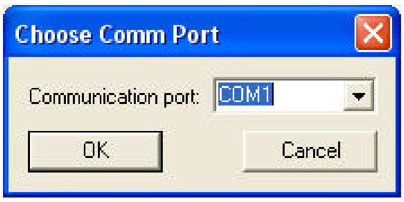

Figure 111 – Choose Comm Port dialog

Select an appropriate COM port of a host computer, where the null modem cable is connected, and click <*OK*> button. This will transfer the set TCP/IP parameters into UVP-DUO.

By clicking a "*Read*" button you can read TCP/IP setup from UVP/DUO and make sure that the parameters are set correctly.

15.4 Host PC computer TCP/IP setup

15.4.1 Windows 98/ME operating system

In a *Start* menu select the "*Settings* | *Control Panel*" item, see Figure below.

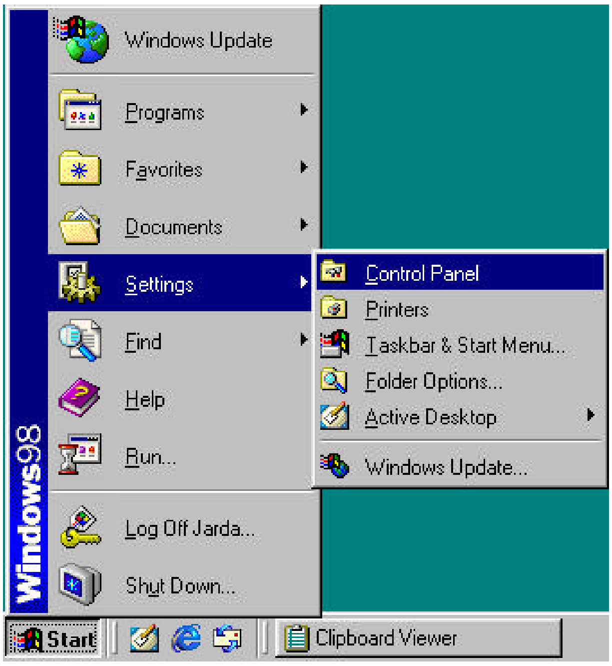

Figure 112 – How to open Control panel window in 98/ME

A "*Control Panel*" window opens.

Figure 113 – Control panel window in 98/ME

In *Control panel* window, double-click the "*Network*" icon. A *Network* setup dialog opens.

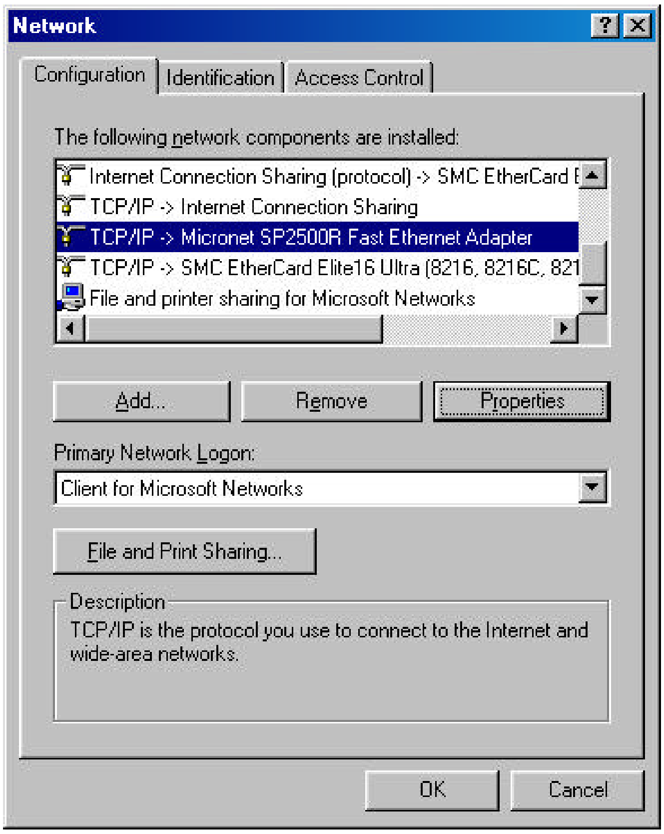

Figure 114 – Network dialog with tabs in 98/ME

In the "*Network*" dialog, select the "Configuration" tab and the "TCP/IP –> XXX" item, where XXX is description of a network card, where UVP-DUO is connected. Then click the "*Properties…*" button. A dialog "*TCP/IP Properties*" opens.

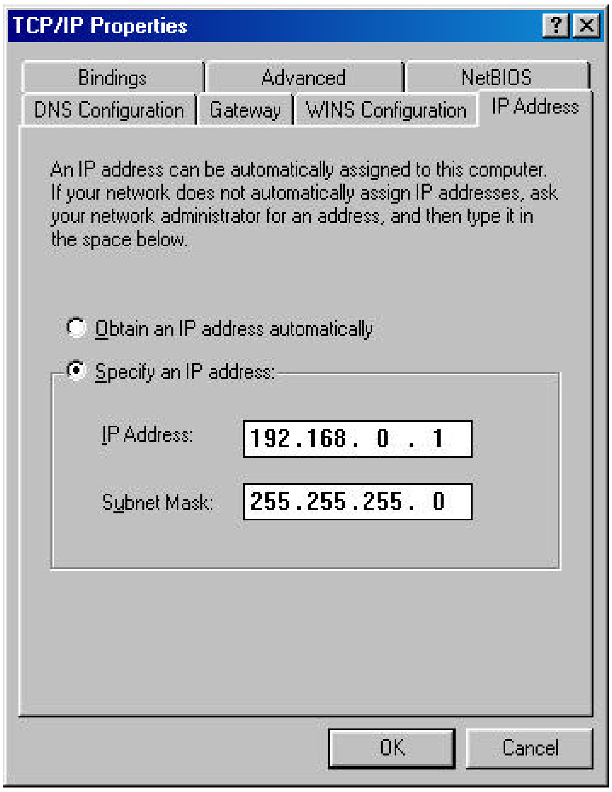

Figure 115 – TCP/IP Properties dialog in 98/ME

In the "*TCP/IP Properties*" dialog, select an "*IP Address*" tab, and click the "*Specify an IP address*". Then enter the IP address and Subnet mask. Then close all opened network setup sialogs by clicking <*OK*>.

15.4.2 Windows NT 4 operating system

In "*Start*" menu, select a "*Settings | Control Panel*" item.

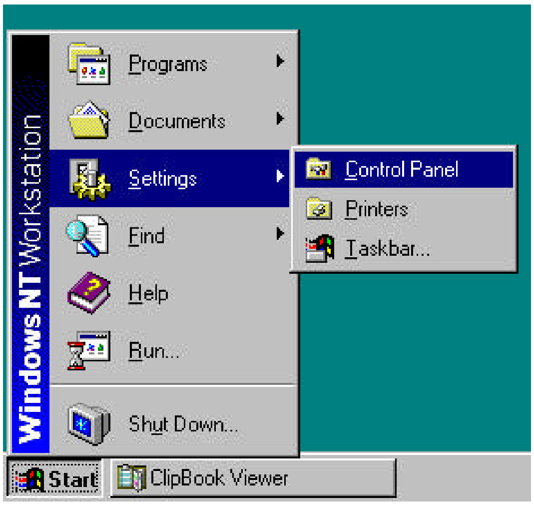

Figure 116 – How to open a Control panel window in NT 4

A "*Control Panel*" window opens.

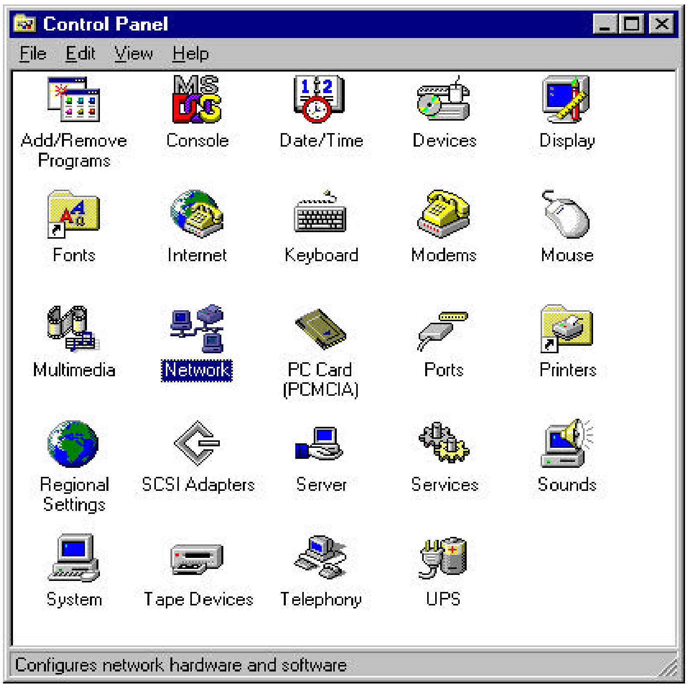

Figure 117 – Control panel window in NT 4

In Control panel window, double-click the "*Network*" icon. A *Network* setup dialog opens.

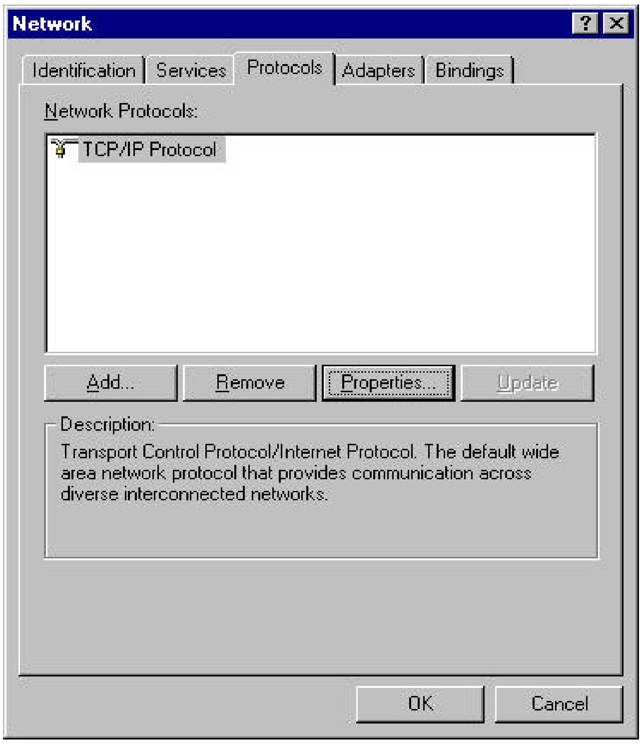

Figure 118 – Network dialog with tabs in NT 4

In the "*Network*" dialog, select the "*Protocols*" tab.

If a list of “*Network Protocols*” does not include the TCP/IP protocol, it is necessary to install it by clicking an “*Add…*” button. A new dialog “Select New Protocol” opens.

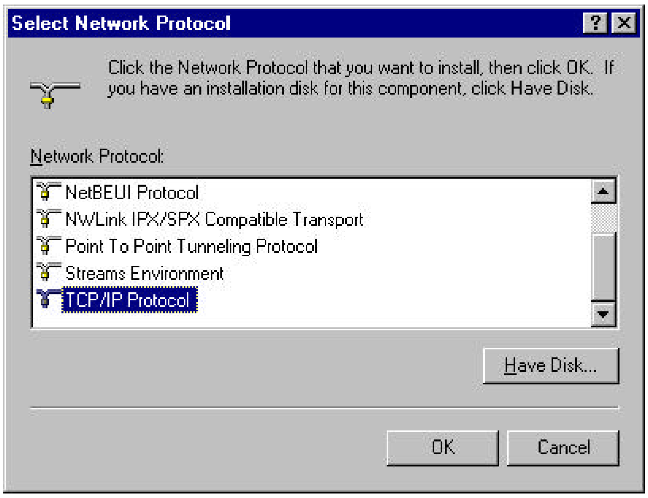

Figure 119 – Select Network Protocol dialog in NT 4

In the “*Select Network Protocol*” dialog, select the “*TCP/IP Protocol*” item, and click the *<OK>* button. This will return you to the “*Network*” dialog, where the “*TCP/IP Protocol*” should already be added to the protocol list.

Now in “*Network Protocols*” dialog, select the “*TCP/IP Protocol*” and click button “*Properties*”. A dialog “Microsoft TCP/IP Properties” opens. Select the tab “*IP Address*”.

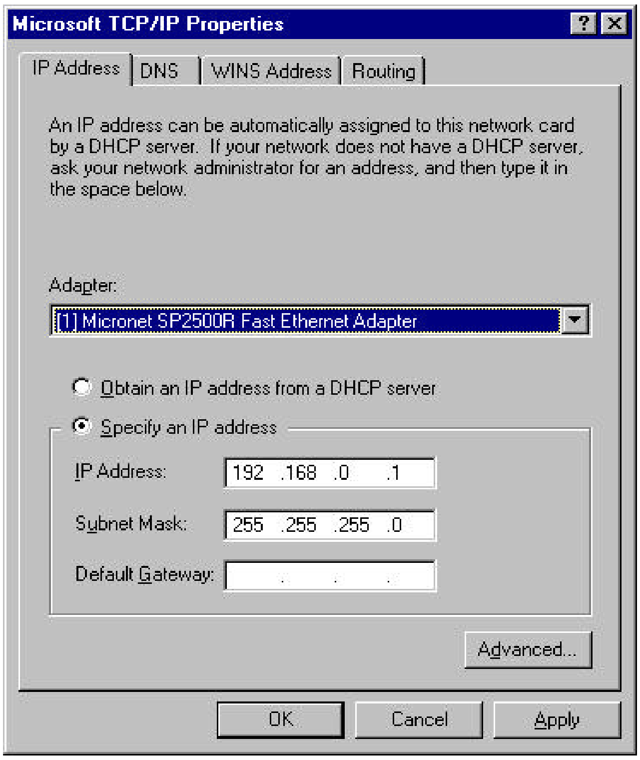

Figure 120 – MS TCP/IP Properties dialog in NT 4

In combo box "*Adapter*" select a network card, to which a UVP-DUO is connected. Then select an item "*Specify an IP Address*" and enter IP address and Subnet mask. It is not necessary to fill in Default gateway. Then close all opened network setup dialogs by clicking respective <*OK*> buttons.

15.4.3 Windows 2000 operating system

In "Start" menu, select "*Settings | Network and Dial-up Connections*":

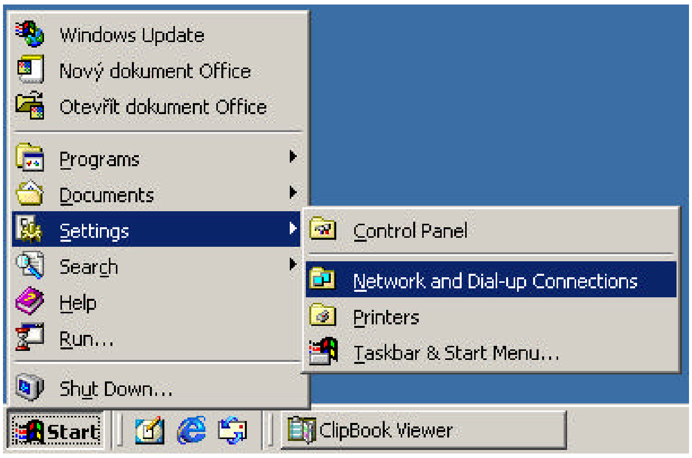

Figure 121 – How to open a Network and Dial-up Connections in 2000

A window "*Network and Dial-up Connections*" opens. Select an icon of local area connection, belonging to the network card where UVP-DUO is connected. Then in menu select "*File | Properties*":

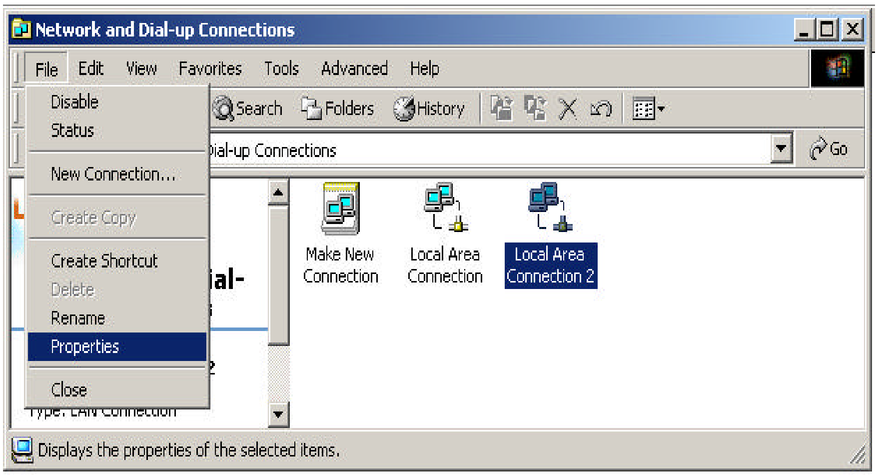

Figure 122 – Network and Dial-up Connections in 2000

A dialog "*Local Area Connection Properties*" opens:

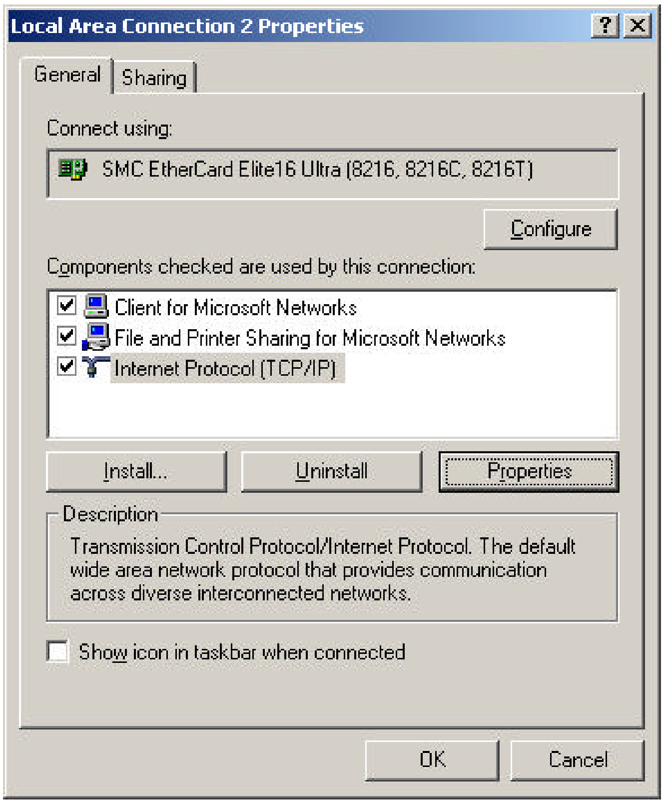

Figure 123 – Local Area Connection Properties in 2000

In "*Local Area Connection Properties*" dialog, select the "*Internet Protocol (TCP/IP)*" item, and click the "*Properties…*" button. A dialog opens:

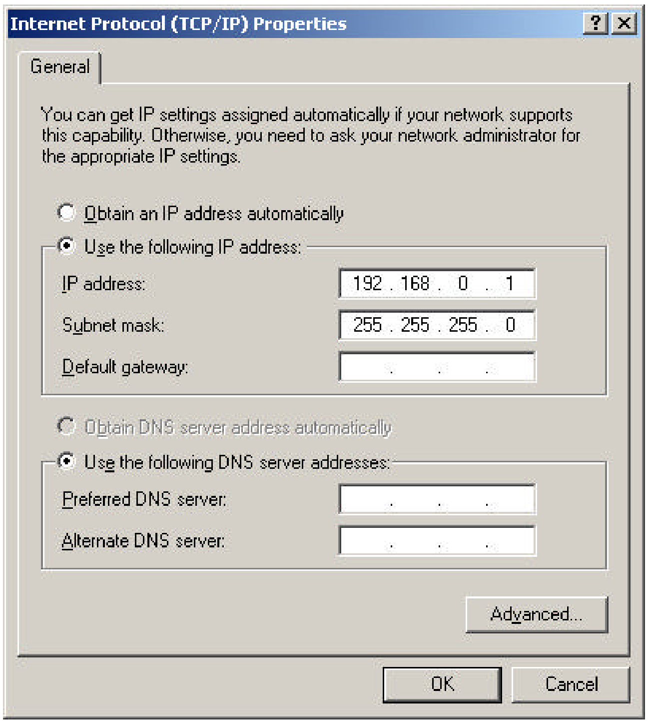

Figure 124 – Internet Protocol (TCP/IP) Properties dialog in 2000

In the “*Internet Protocol (TCP/IP) Properties*” dialog, select the “*Use the following IP address*” and enter the desired IP address and Subnet mask. It is not necessary to enter Default gateway. After this, close all open network setup windows by clicking their respective <*OK*> buttons.

15.4.4 Windows XP operating system

In “Start” menu. select the “*Connect To | Show all connections*” item.

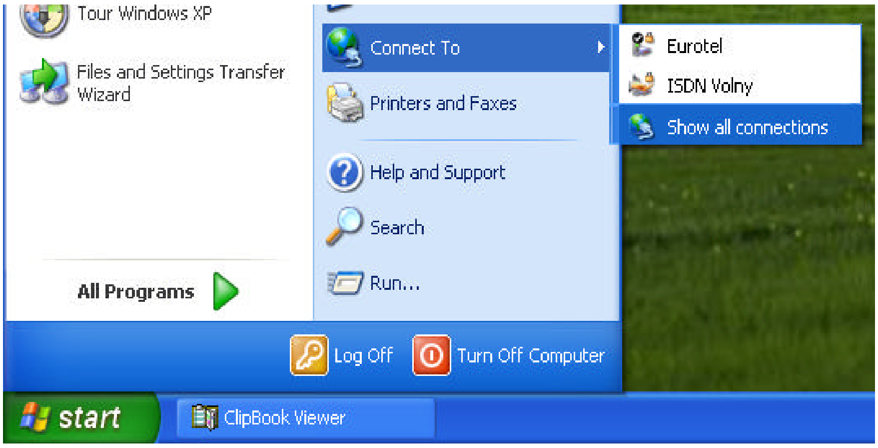

Figure 125 – How to open Show all connections dialog in XP

A window “Network Connections” opens. Select and highlight an icon of local area connection in “LAN or High-Speed Internet” section, which belongs to the network card where UVP-DUO is connected. Then select from menu “File | Properties” item:

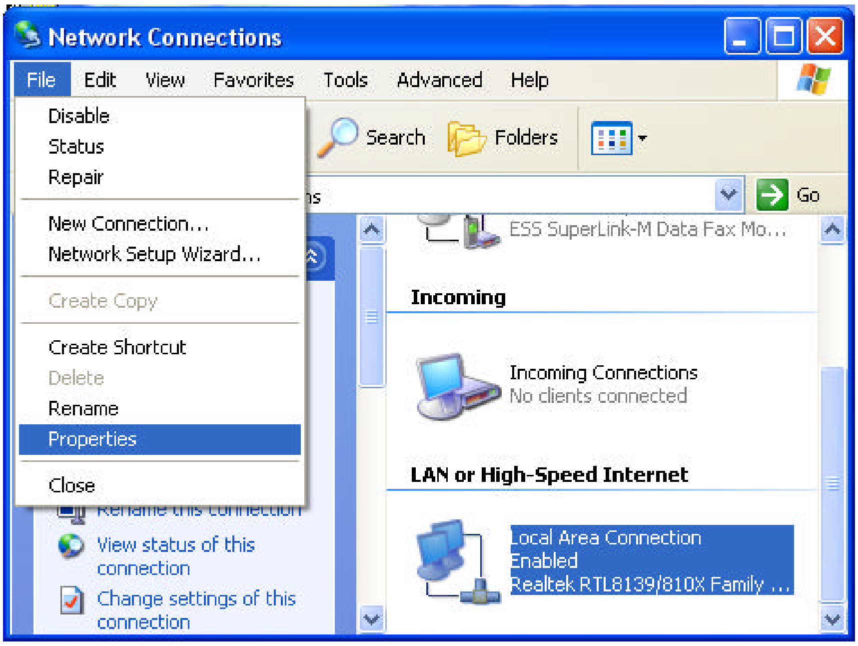

Figure 126 – Network properties selection in XP

In the “*Properties*” dialog of the selected connection, select the “*General*” tab and the “*Internet Protocol (TCP/IP)*” item. Then click the “*Properties*” button.

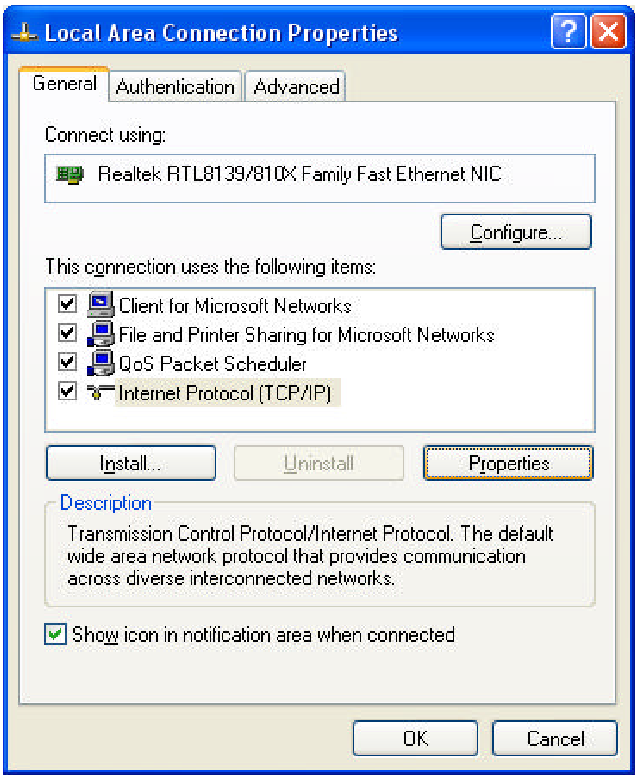

Figure 127 – Local Area Connection Properties in XP

Clicking the “Properties” button opens an “Internet Protocol (TCP/IP) Properties” dialog:

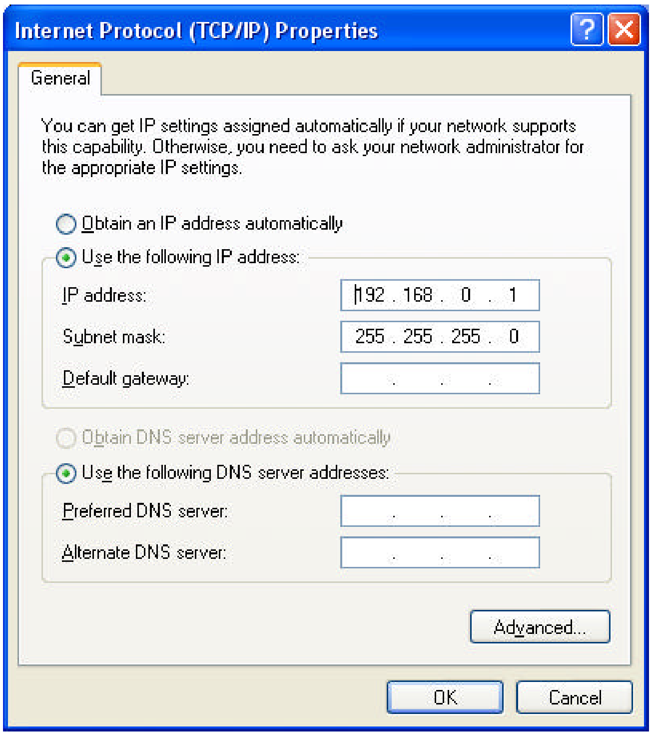

Figure 128 – Internet Protocol (TCP/IP) Properties dialog in XP

In the “*Internet Protocol (TCP/IP) Properties*” dialog, select the “*Use the following IP address*” item, and enter a desired IP address and a Subnet mask. It is not necessary to enter any Default gateway address. Then close all opened network set-up dialogs by clicking their respective <*OK*> buttons.

16. Appendix: Sound velocity in water

As is generally known, sound velocity in water is a function of temperature, salinity and pressure. The following routine in C++ takes these input parameters, and calculates the resulting sound velocity.
For sweet water enter zero salinity. For atmospheric pressure, enter zero pressure.

```
#include <stdafx.h>

#include <math.h>

/*==========================================================================*/
/*                                                                          */
/*      Function: GetSoundSpeed( S,  T, P0)                                 */
/*                                                                          */
/*      It calculates sound speed in sea water.                             */
/*                                                                          */
/*      Input parameters:                                                   */
/*             S      -  Salinity PSS-78                                    */
/*             T      -  Temperature in degrees C                           */
/*             P0     -  Pressure in decibars                               */
/*      Output value:                                                       */
/*             SVEL   -  Speed in meters/second                             */
/*                                                                          */
/*      Reference:  Chen and Millero, 1977, JASA,62,1129-1135               */
/*                                                                          */
/*      Checkvalue: SVEL=1731.995 M/S, S=40 (PSS-78),T=40 DEG C, P=10000 Dbar*/
/*                                                                          */
/*                                                                          */
/*==========================================================================*/

double GetSoundSpeed(double S,double T,double P0)
{
   double P    = P0/10;
   double sr   = sqrt(fabs(S));
   double d    = 1.727E-3 - 7.9836E-6*P;
   double b1   = 7.3637E-5 + 1.7945E-7*T;
   double b0   = -1.922E-2 - 4.42E-5*T;
   double b    = b0 + b1*P;
   double a3   = (-3.389E-13*T + 6.649E-12)*T + 1.100E-10;
   double a2   = ((7.988E-12*T - 1.6002E-10)*T + 9.1041E-9)*T - 3.9064E-7;
   double a1   = (((-2.0122E-10*T + 1.0507E-8)*T - 6.4885E-8)*T
           - 1.2580E-5)*T + 9.4742E-5;
   double a0   = (((-3.21E-8*T + 2.006E-6)*T + 7.164E-5)*T - 1.262E-2)*T
           + 1.389;
   double a    = ((a3*P + a2)*P + a1)*P + a0;
   double c3   = (-2.3643E-12*T + 3.8504E-10)*T - 9.7729E-9;
   double c2   = (((1.0405E-12*T - 2.5335E-10)*T + 2.5974E-8)*T
           - 1.7107E-6)*T + 3.1260E-5;
   double c1   = (((-6.1185E-10*T + 1.3621E-7)*T - 8.1788E-6)*T
            + 6.8982E-4)*T + 0.153563;
   double c0   = ((((3.1464E-9*T - 1.47800E-6)*T + 3.3420E-4)*T
        - 5.80852E-2)*T + 5.03711)*T + 1402.388;
   double c    = ((c3*P + c2)*P + c1)*P + c0;
```

```
   double svel = c + (a + b*sr + d*S)*S;

   return svel;
} // GetSoundSpeed(double,double,double)
```

17. Appendix: Electromagnetic compatibility certificate

UVP-DUO-PSI hardware underwent rigorous electromagnetic compatibility testing in the EMC - TESTCENTER ZÜRICH AG, resulting in granting of the CE label. It complies with rigorous Standards for the following areas:

- Conducted emission
- Radiated emission
- Harmonics emission
- Voltage fluctuation and flicker
- Electrostatic discharge immunity
- Radiated electromagnetic field immunity
- Burst immunity
- Surge immunity
- Conducted disturbances immunity
- Voltage variations, dips, interruptions immunity.

In plain language, this means that your UVP-DUO will not disturb other instruments, and will not be disturbed by other instruments as well.

A short five-page digest from long (43 pages) test report is published here. In case of interest, please contact Met-Flow for the full report.

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Accredited according to EN 45001 / ISO 9002 by:
Swiss Accreditation Service / metas
Registration number 034

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TEST REPORT	EMC 040 / 02
DATE OF ISSUE	04.06.2002
TEST OF	UVP-Duo
CLIENT	Pinter Engineering CH-8272 Ermatingen

S **SCHWEIZERISCHER PRUEFSTELLENDIENST**
T **SERVICE SUISSE D'ESSAI**
S **SERVIZIO DI PROVA IN SVIZZERA**
SWISS TESTING SERVICE

This report shall not be reproduced except in full without the written approval of the testing laboratory.
The results in this report apply only to the sample(s) tested, if technical changes on the sample(s) are performed later a retest shall be necessary.

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Test Report Approval

	Name	Signature	Date
Test performed by:	Max Hunziker		22.05.02
Test report reviewed by:	Armin Frei		04.06.02
Test report approved by:	Max Hunziker		06.06.02

Test Site

☒ Anechoic chamber / Faraday room
☐ Free-field test site 3m / 10m

Test period

Equipment to be tested received on 22.05.2002
Tests were performed on 22.05.2002

Tests performed and witnessing:

☒ Radiated emission : Mr. Pinter
☒ Conducted emission : Mr. Pinter
☒ Harmonics : Mr. Pinter
☒ Voltage variations,dips,interruptions : Mr. Pinter
☒ Voltage fluctuations and flicker : Mr. Pinter
☒ Conducted immunity : Mr. Pinter
☒ Electrostatic discharge immunity : Mr. Pinter
☒ Radiated field immunity : Mr. Pinter
☒ Fast transient immunity, Burst : Mr. Pinter
☒ Slow transient immunity, Surge : Mr. Pinter

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SECTION 6 SUMMARY OF TEST RESULTS

6.1 Emission Test Summary

6.1.1 Normative Test Summary

Standard	Test description	Level, Remarks	Result	Test No.
EN 55022	Conducted Emission	Class B	C	1
EN 55022	Radiated Emission	Class B	C	2
EN 61000 - 3 - 2	Harmonics	Class A	C	3
EN 61000 - 3 - 3	Voltage fluctuation and flicker	Figure 3 - 7	C	4

Results:

C	Complied
NC	Did not comply
WMU	Within measurement uncertainties
NA	Not applicable
NP	Not performed

6.1.2 Result

Conducted Emission

In the configuration tested, the E.U.T. complied with the requirements of the specification.

Radiated Emission

In the configuration tested, the E.U.T. complied with the requirements of the specification.

Harmonics

In the tested configuration the E. U. T. complied with the requirements of the specification.

Voltage fluctuation and flicker

In the tested configuration the E. U. T. complied with the requirements of the specification.

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6.2 Immunity Test Summary

6.2.1 Normative Test Summary

Standard	Test description	Level, Remarks	Result	Test No.
EN 61000-4-2	Electrostatic discharge	4kV CD/ 8 kV AD	C	5
EN 61000-4-3	Radiated rf electromagnetic field	10 V/m	C	6
EN 61000-4-4	Burst immunity test	1 / 2 kV	C	7
EN 61000-4-5	Surge immunity test	1kV sym./2kV asym.	C	8
EN 61000-4-6	Immunity to conducted disturbances	10 V_{rms}	C	9
EN 61000-4-11	Voltage variations,dips,interruptions	30%,60%,>95%/5000ms	C	10

Results:

C	Complied
NC	Did not comply
WMU	Within measurement uncertainties
NA	Not applicable
NP	Not performed

6.2.2 Result

Electrostatic discharge

In the tested configuration the E. U. T. complied with the requirements of the specification.

Radiated rf electromagnetic field

In the tested configuration the E. U. T. complied with the requirements of the specification.

Burst immunity test

In the tested configuration the E. U. T. complied with the requirements of the specification.

Surge immunity test

In the tested configuration the E. U. T. complied with the requirements of the specification.

Immunity to conducted disturbances induced by rf electromagnetic fields

In the tested configuration the E. U. T. complied with the requirements of the specification.

Voltage variations,dips, interrruptions test

In the tested configuration the E. U. T. complied with the requirements of the specification.

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APPENDIX 2 **TEST CONFIGURATION PHOTOGRAPHS**

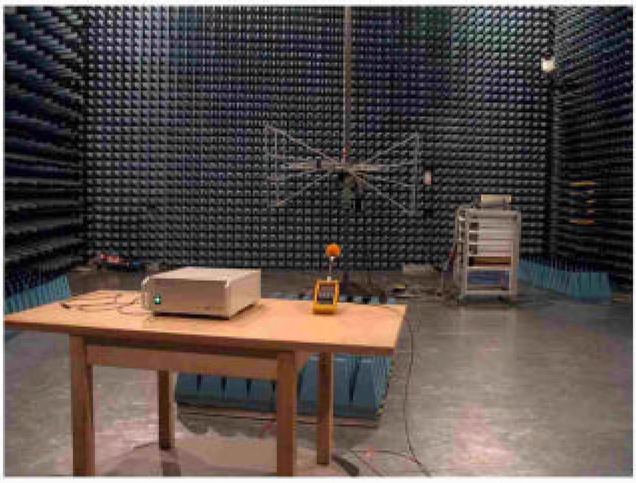
Test No. 6 **Position "180°"**

Test configuration for measurement of immunity to radiated rf electromagnetic field in accordance with EN 61000-4-3 (IEC 61000-4-3).
- Antenna distance 3m
- Prior calibration of the field level according to the standard.
- Antenna heights: Horizontal polarisation: 1.50 m
  Vertical polarisation: 1.50 m

No E.U.T. specific test setup necessary.

Frequency range 80 MHz to 1000 MHz and 1.4 GHz - 2 GHz, vertical polarisation

Frequency range 80 MHz to 1000 MHz and 1.4 GHz - 2 GHz, horizontal polarisation



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