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Highly Accurate Processing of Low Quality LDA Signals Using Contiguous Data Blocks

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Abstract

A modular and transparent LDA data acquisition/processing system has been developed. The system, composed of general-purpose hardware units, operates in a block mode. Contiguous blocks of digitized bursts are recorded and processed by spectral methods in the host computer. This strategy has been found to overcome conflicting goals usually sought in measurement practice: high data rate typical for counters; robust detection and high accuracy of individual frequency estimates for low quality signals; flexibility that facilitates further modifications and comparison tests.

Introduction

A contemporary trend in measuring and processing devices (including computers!) seems to be unanimously in favour of transparency and modularity. Dedicated pieces of hardware are becoming less convenient, particularly for research applications. The main reasons are more frequent modifications to measuring procedures, and some lack of insight in the processing of data. Therefore the main guidelines in designing the data acquisition and processing system described in this paper were modularity and transparency. The objection commonly raised against such strategy is that it tends to focus an experimentalist's attention towards operational rather than application aspects of LDA. However, modular and transparent system can still appear as a "black box" to some end users while offering the opportunity of ease of upgrading and modifications to the others.

The burst detection and processing section of commercial LDA systems is still behind this general trend. Despite a variety of commercial signal processors, an LDA user normally spends a large portion of their time on modifications to, or design of, the entire system. This is not primarily the result of substantial cost and physical size of such devices but rather of the benefits in terms of flexibility, transparency and modularity that such user designed or modified units provide. A good example is the influence of triggering scheme on processing results. Although it becomes evident that advanced triggering strategy can substantially improve overall performance of the system, the trigger circuitry usually incorporated into a commercial processor limits the user who wants to resort to more elaborate detection scheme (for examples of such schemes, see Kobashi, Hishida, Maeda, 1990; Blancha and Murphy, 1990; Qiu, Sommerfeld and Durst,1990). Users' choice of processing parameters influences the output much more than the manufacturers' manuals might suggest (Tropea, 1989). Large-scale and/or multi-phase measurements using backscatter or off-axis detection require processing of low quality signals (Shinpaugh et ah, 1990). In presence of walls and windows, and when frequency shifted laser beams are used, additional efforts are necessary to eliminate erroneous frequency detection (Blancha and Murphy, 1990). The error in individual frequency estimates should be minimized when accurate rms velocity data are required because it always increases the value of rms velocity. If the bursts are processed on-line, as usually in LDA practice, the experimentalist is forced to make the following compromise: either to operate with high data rate and low accuracy of individual velocity data typical of counter processors, or to achieve higher accuracy by processing in the spectral domain but at a lower data rate as a result of increased computational load. In the latter case data rate often becomes so low that velocity time series does not reflect high frequency turbulent fluctuations. The choice becomes difficult when both accurate rms velocity data and time resolved velocity records are required.

An alternative approach aimed to overcome these limitations is to record all bursts at a measurement point and process them afterwards. Although now technically possible other drawbacks become evident. Signal conditions often vary during measurement with readjustment taking place as the acceptance rate is reduced. This results in large overhead in measurement time when measurements at a point must be repeated. Moreover, the data records have to be longer to provide enough validated velocity values. These considerations led to development of a strategy of data collection and processing in contiguous data blocks. This should be accomplished using general-purpose hardware and custom designed software for data collection and processing of LDA signals.

The Experimental Configuration

Velocity measurements were carried out using a two-colour three-beam optical LDA system with a 3W Argon laser (Fig. 1). The optics are modified to provide a large scanning range (2 m x 1 m x 0.5 m). The front lens was detached from the integral optical unit and mounted on a separate 2D traverse system. Three parallel beams were deflected by two flat mirrors (surface flatness= A/10) allowing the traverse system to scan the flow field in two coordinate directions without moving the whole optics. The third coordinate movement is obtained by traversing of the entire LDA assembly along horizontal tracks.

Burst detection and data processing is illustrated by a schematic diagram in Fig. 2. Photo-detector signals were passed through the downshifting modules of the TSI Bragg cell drivers. Filtering and burst detection were performed using the input filter and threshold circuits of the two TSI 1990C counters. Filtered signals were digitized by means of a transient recorder (LeCroy 9400A digital oscilloscope), operating in burst (sequential) mode, externally triggered. In this mode, a contiguous block of bursts was recorded simultaneously for two channels. A Dostek 1400A interface board was used to synchronise two trigger sources ("data ready" signals from the counters), to pass them through a coincidence window of user specified length, and to generate an external trigger pulse for the transient recorder if the bursts are detected at both channels within the time window. Since the trigger pulse issued to the transient recorder occurs after the burst, pre-trigger recording of up to 100% of segment length was used to digitize the signal prior to the trigger pulse issued by the interface board. By choosing high gain and a loose validation criterion (8 or 16 cycles detected without in-burst frequency comparison), high data rates at the counter outputs were obtained. The quality of the bursts detected in this way was far below the for counters' ability to successfully process them. However, as trigger detection devices, they are capable of distinguishing low amplitude signals from high amplitude noise spikes, similar to filter bank trigger used elsewhere (see for example, Blansha and Murphy, 1990). The data blocks (usually 125 bursts long) were transferred via GPIB link to the host computer (386 Zenith PC) at the rate of 400 kB/s.

Signal processing was performed by software in the host computer using an FFT transform. The newly developed peak interpolation scheme (Matovic and Tropea, 1990) was incorporated into the processing algorithm, which increased frequency resolution and improved SNR estimation .

Test Results and Discussion

A system performance was assessed using two test cases: velocity measurements of rotating fibre and of developed channel flow of air seeded by $1\mu m$ TiO_2 particles. Results obtained by processing the contiguous blocks of bursts recorded by LeCroy 9400A transient recorder, were compared with the measurements obtained from the pair of TSI 1990C counters under the same experimental conditions. In both cases, optical access was provided through 10 mm thick glass windows as typical obstacles encountered in practice. The optics were rotated by 45° relative to the velocity vector, thereby obtaining similar bursts on both channels. Frequency shift was applied in both cases: 2 MHz for the rotating fibre (more than 250 cycles/burst) and 0.5 MHz for the channel flow (more than 100 cycles/burst). Mean and rms velocities were calculated by a coordinate transform of the data of the two channels. Measurements obtained using the counters were repeated with gradually increased validation criterion for minimal cycle count and in-burst frequency comparison for as long as any valid signals were detected, while those by the transient recorder were performed with the loosest validation criterion set on the counters which now served as trigger sources.

The results of the rotating fibre measurements are shown in Table 1. Data in the Table were obtained by averaging a 1000 1000 burst sample. Since the fibre was stretched taughtly between two rims of a rotating wheel (Fig. 3) and rotated with constant speed, the "true" rms velocity is practically zero. Thus, measured rms velocities could be entirely attributed to the LDA system itself. Results obtained by the counters show regular improvement as the validation level was increased. The residual rms values are substantial for the strictest validation level, when they correspond to a "fluctuation intensity" of about 4 %. The increase in average time between events for this case indicates that about half the bursts were rejected. Measurements obtained using the transient recorder resulted in a residual rms velocity of 1 % for the same trigger conditions that produced a 10 % rms velocity at the counter output. Half of this 1% can be safely attributed to other sources of error (e.g. rotational speed variations).

The measurements in the channel air flow, in the middle of 340 mm wide channel, 340 mm from the side wall are given in Table 2. The results for this case suggest the same conclusion. Although the true value of rms velocity is less certain in this case, the same trend in test results is apparent.

Table 1: Measurement of fibre velocity: m/s

Methods	Counter Setting	U	W	u'	w'
Counters	16 eye/burst, no comparison	3.4349	0.1387	0.3240	0.3334
	16 cyc/burst, 1% comparison	3.2810	-0.0083	0.1581	0.1518
	128 cyc/burst, 1% comparison	3.3761	0.0869	0.1229	0.1233
Trans. Recorder	16 cyc/burst,no comparison	3.2931	-0.0082	0.0355	0.0338

Table 2: Measurement in channel flow: m/s

Methods	Counter Setting	U	W	u'	w'
Counters	16 eye/burst, no comparison	1.0429	-0.2207	0.2176	0.2169
	16 cyc/burst,1% comparison	1.0968	-0.1733	0.2373	0.2339
	32 cyc/burst,1% comparison	1.1845	-0.0943	0.0851	0.0763
Trans. Recorder	16 cyc/burst,no comparison	1.2192	-0.0865	0.0450	0.0291

Further insight into the nature of rms error and corresponding bias in mean velocity might be obtained by examining the velocity time series. They are presented in Figs. 4 and 5 for the fibre and flow velocity measurements respectively. Time series consist of 100 data points for counter data (solid diamonds) and 62 points for transient recorder data (empty diamonds). Plots a, b, and c in Fig. 4 correspond to rows 1, 2 and 4 in Table 1. In Fig. 5 plots a, b, c and d correspond to rows 1, 2, 3 and 4 in Table 2. Different time scales in the graphs for the same number of bursts indicate how validation criteria at the counters affect data rate. The loose setting would bring about much higher data rate which is obviously desirable and sometimes imperative, e.g., for spectrum analysis of turbulence. As may have already been noticed, sudden jumps appear in the time series as measured by the counters which is an obvious result of incorrect frequency estimation, even when

1% comparison criterion is set. As these errors tend to appear on the same side of the main data population, they result in significant bias of the mean velocity. The dashed lines in each graph, which represent the mean value for the time series, are clearly moved away from the main body of data points in plots in which such jumps are in evidence.

Conclusions

The LDA data acquisition and processing system composed of general-purpose hardware units and application/specific software was developed for accurate processing of low-quality Doppler bursts. The list of system features include:

1. use of general-purpose hardware which facilitates flexibility;
2. burst recording in contiguous blocks (usually 125 bursts/block) including the arrival time data;
3. flexible coincidence detection with a user defined time window;
4. burst detection based on a threshold level and the minimum number of cycles;
5. robust frequency estimation based on FFT with effective removal of harmonic noise from reflected frequency shifted illumination as is commonly encountered when using backscatter mode;
6. reliable and high resolution estimates of frequency and SNR using a new interpolation technique;
7. use of SNR threshold as a validation criterion.

Block-sequential strategy is preferred over on-line methods in these situations when reliable and high-resolution results are required from medium to low quality Doppler bursts. Test comparisons with counters have shown superior performance of such a system both in terms of higher data rate and lower rms velocity error.

Acknowledgments

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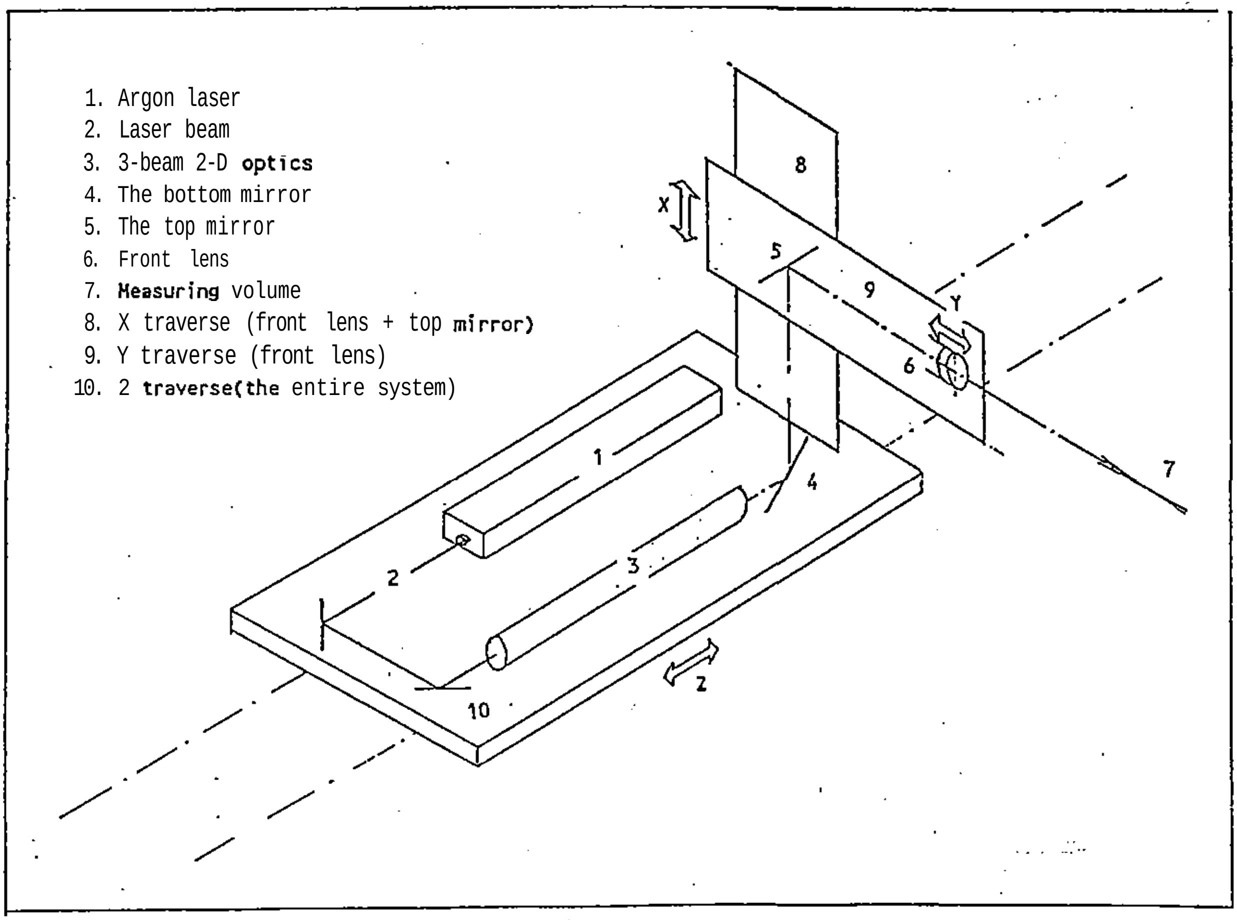

Figure 1: Outline of the LDA optics system

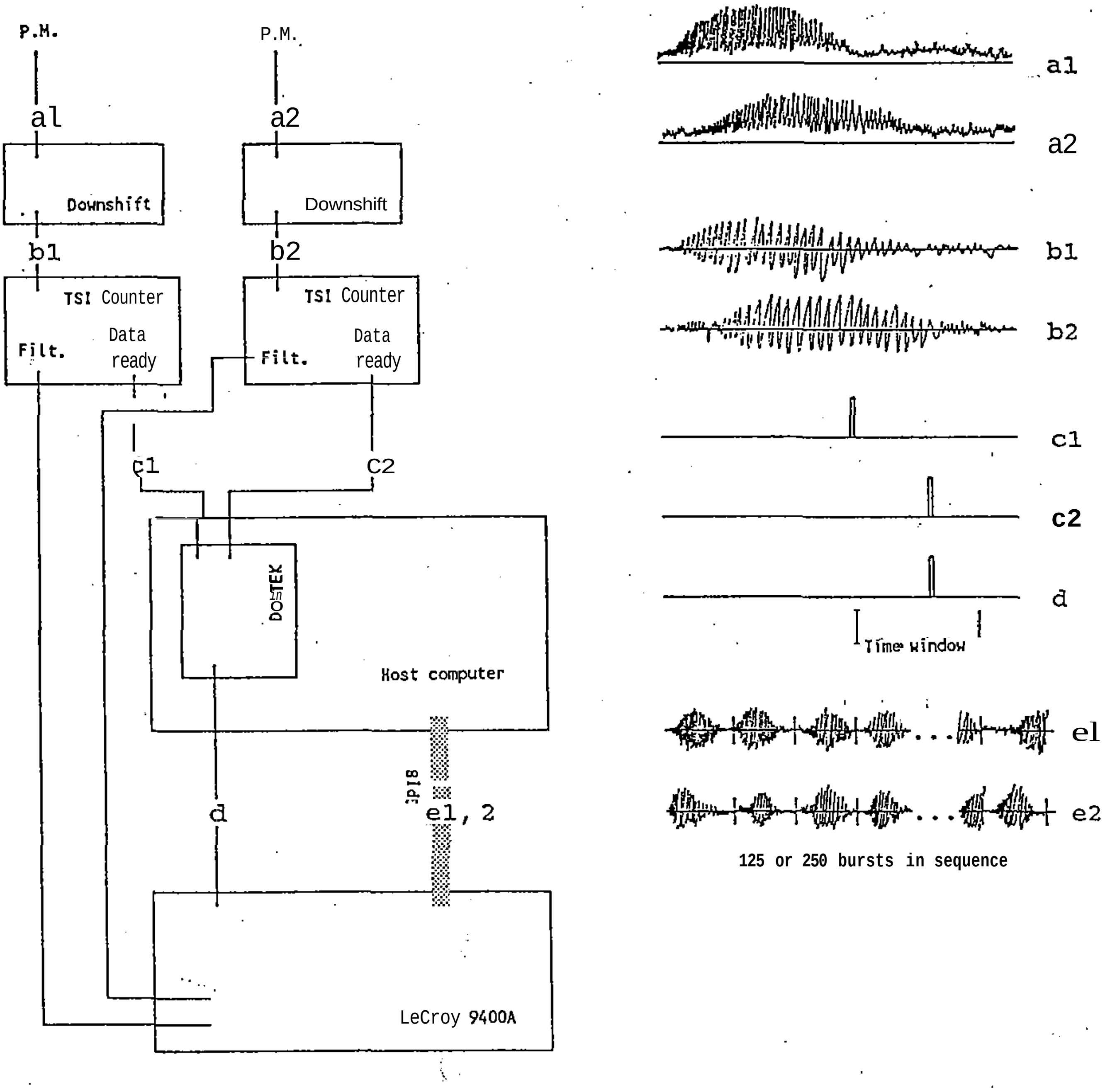

Figure 2: Schematic of data acquisition system

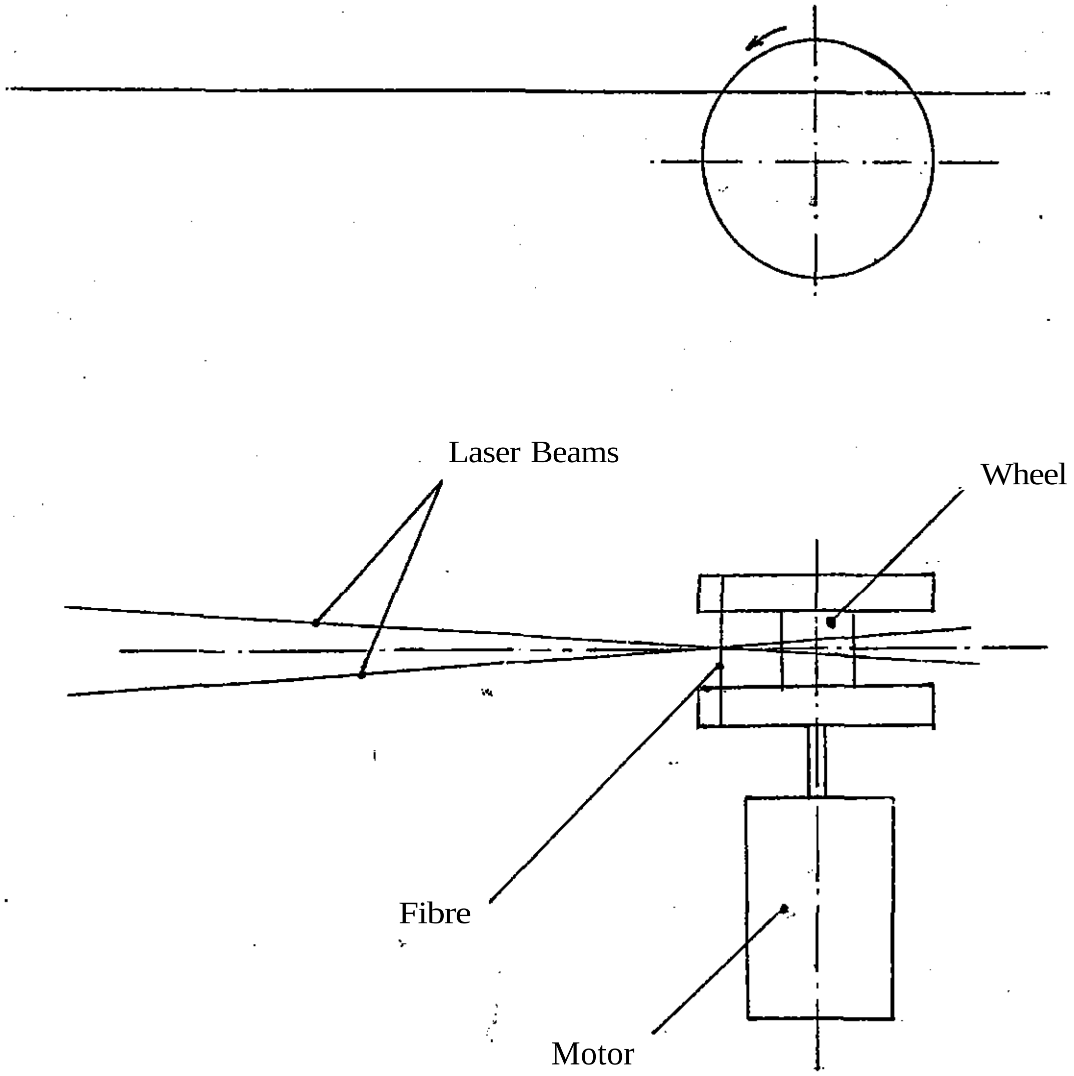

Figure 3: The rotating fibre assembly

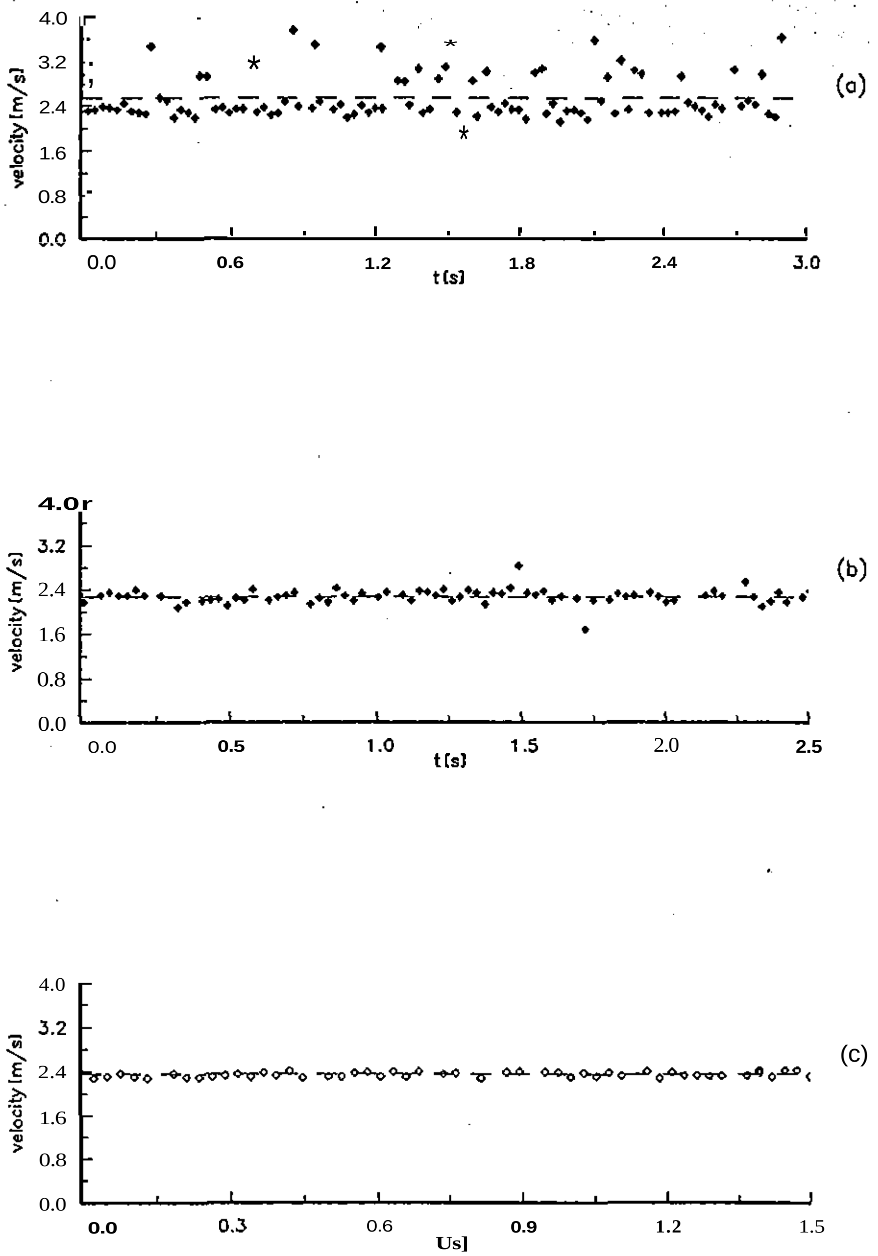

Figure 4: Velocity time series of the rotating fibre. a) 16 eye/burst, no comparison/counter; b) 16 eye/burst, 1% comparison/counter; c) 16 eye/burst, no comparison/transient recorder.

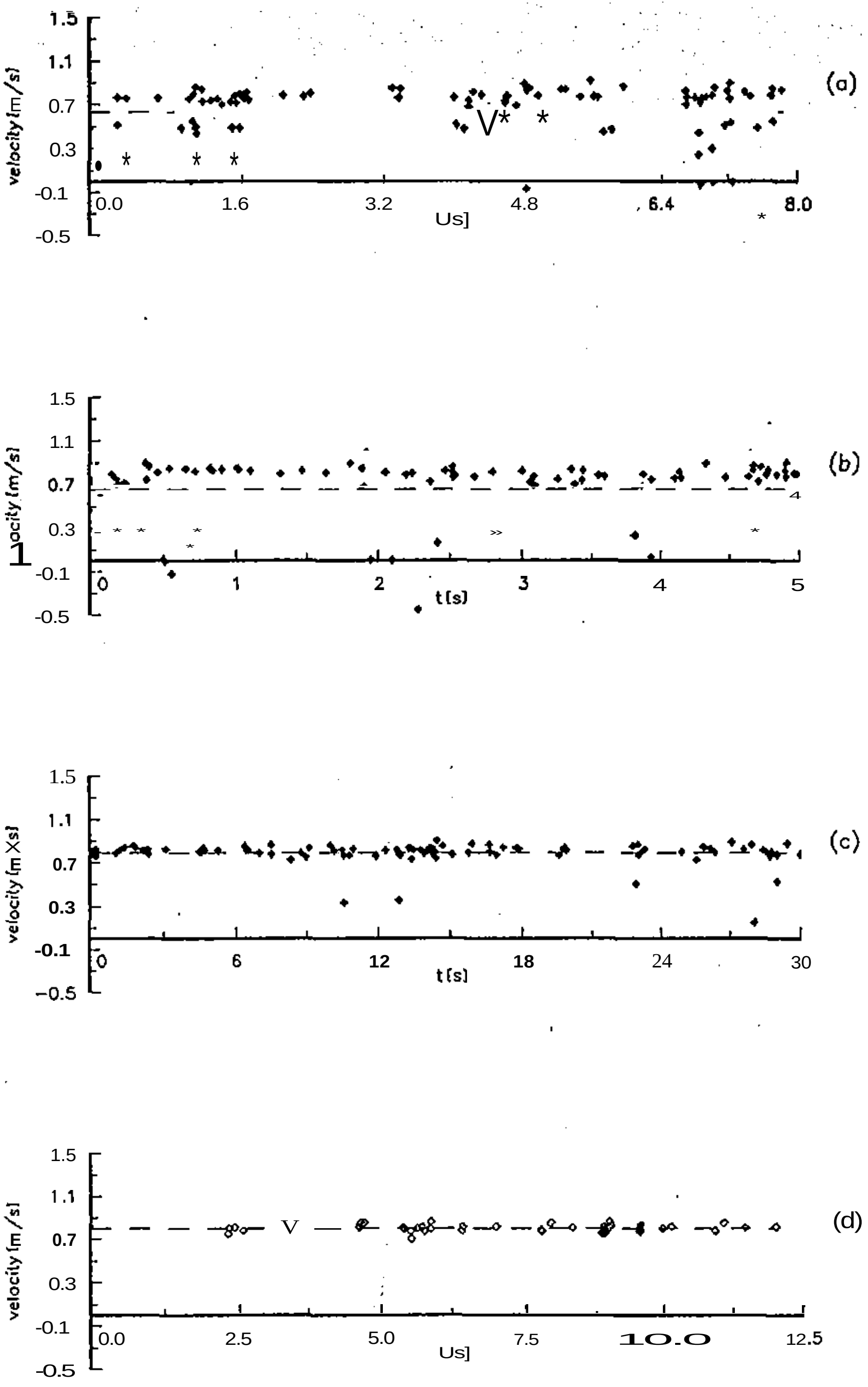

Figure 5: Velocity time series of the channel flow. a) 16 eye/burst, no comparison/counter; b) 16 eye/burst, 1% comparison/counter; c) 32 eye/burst, 1% comparison/counter; d) 16 eye/burst, no comparison/transient recorder.