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# A TWO COMPONENT LDA AND ITS APPLICATION TO NARROW CHANNEL FLOW

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## ABSTRACT

One of the most significant developments in laser Doppler anemometry (LDA) in recent years has been the introduction of solid-state components (laser diodes and avalanche photo-diodes). With these components, compact, inexpensive LDAs can be constructed resulting in wider application of LDA. This paper reports on the design and application of a two-component solid-state LDA to flow across a step in a narrow channel.

## INTRODUCTION

The principal of LDA is well known and can be modelled as the projection of interference fringes (Doppler fringes) from a laser into the flow field. When a particle passes through these fringes it scatters light modulated in frequency according to the spacing of the fringes.

Two component LDAs operate by producing two orthogonal sets of Doppler fringes. The fringes are "labelled" using properties of the laser to enable the detector to distinguish between the signals from each set of fringes. The most widely adopted method of labelling the fringes is to use two different colours of a multi-colour laser (Grant and Orloff) or from two separate lasers (Forder et al). Another technique is to use different polarisation states of the laser (Bossel et al). However this Method requires care in application because the laser loses its polarisation state after scattering from a particle which introduces cross-talk between the channels.

The technique employed in this work is to label the fringes with two different frequency shifts and separate the signals electronically with filters (Adrian). This has the advantage over the two colour LDA of simpler optical design and fewer components. Furthermore it is easier to cross the beams since the transmitting lens does not have to be corrected for colour aberrations. The last point is of particular importance for measurements in narrow gaps where an LDA of high spatial resolution is required resulting in difficult alignment especially if using two colour lasers. On the negative side, the dynamic range is more limited than for a two colour LDA.

## OPTICAL DESIGN

The design of the LDA is derived from a system first employed by Li which employs optic-electro hybrid feedback to achieve a high signal to noise ratio. For reasons of simplicity the feedback was not used in this work although it may be incorporated at a later date.

Figure 1 shows a schematic diagram of the LDA. A visible laser diode (LD), with a wavelength of 685 nm and a maximum power of 30 mW, was chosen since this type of diode is convenient for producing a small measurement volume (Tieu et al). The laser beam from the LD was first collimated by a gradient index rod lens, CL, and then split into three parallel beams by two beam-splitters, BS1 and BS2. All the beams were of nearly equal intensity. The lower beams consisted of the first-order diffracted beams of two Bragg cells, BC1 and BC2, which introduced optical frequency shifts of 60 MHz and 70 MHz respectively. Two optical wedge pairs, WP1 and WP2, were positioned after the Bragg cells to adjust the direction of the diffracted beams to be parallel to the top beam. The three incident beams, BM1 (60 MHz shifted), BM2 (70 MHz shifted) and BM3 (unshifted) were crossed by a transmitting lens, TL, to form the measuring volume. BM1 and BM3 were used to measure the velocity component V1, as shown in figure 2. The other velocity component, V2, which is perpendicular to V1 was measured by the combination of BM2 and BM3. The front lens, which was composed of a 50mm and 100mm convex lens, produced a measurement volume resolution along the optical axis of approximately 100μm. The backscattering light from particles in the measuring volume was focused by the receiving lens, RL, onto a photo-detector, PD, which consisted of an APD and a pre-amplifier (Mackenzie et al).

Special attention was paid in the alignment of the LDA optics. In particular, to minimise the fringe gradients in the measuring volume, the collimating lens was carefully adjusted to ensure the waists of the incident beams locate at the measuring volume (Durst and Stevenson). Precise beam crossing at the measuring volume was achieved by fine adjustment of the direction of BM1 and BM2 provided by WP1 and WP2.

## ELECTRONIC DESIGN

Figure 3 shows a schematic diagram of the electronics developed for the two component LDA system. The signal from the photo-detector was first filtered and amplified, then separated into two channels with band-pass filters. The separated signals were then down mixed into a more convenient frequency range.

The generation of the sine wave signals for down-mixing and for driving the Bragg cells was achieved with a commercial signal generation board. The board, which plugs into a PC computer, contains four independent phase-locked-loop (PLL) synthesisers. Through software provided with the board, the frequency of each channel can be changed from 360 kHz to 120 MHz in steps of 100 kHz. The two channels CH0 and CH1 were used for down-mixing whilst channels CH2 and CH3 were used to generate the driving signals for the Bragg cells. The frequency difference between CH0 and CH2 and that between CH1 and CH3 are the actual frequency shifts added to the Doppler signals corresponding to V1 and V2 respectively.

The frequency shift (60 MHz) is near the upper end of the pass band of the first channel whilst the other (70 MHz) is at the lower end of the second channel. If the probe is orientated so that the vector from BM1 to BM2 is parallel to the main flow, then when flow velocity increases the signal frequency of the first channel will decrease from 60 MHz while that of second channel will increase from 70 MHz hence providing a wide dynamic range. It should be noted that a third signal frequency is produced by the combination of BM1 and BM2 but this frequency component locates at the lower part (near 10 MHz) of the spectrum and is removed by filters.

## APPLICATION

To investigate the performance of the LDA it was applied to water flow in a narrow channel containing a sloped step (figure 4). The channel was constructed of perspex sheet with aluminium plate (1mm thick) sandwiched between. The flow system consisted of a series of reservoirs arranged in such a way that the inlet and outlet pressures were constant and therefore constant flow was achieved.

The LDA probe and the flow channel were mounted on a common base to eliminate the vibration between them. The position of the measuring volume was adjusted by moving the LDA probe with a two-dimensional traverse stage which has a resolution of 5 μm.

A dual-channel IFA750 burst digital correlator from TSI was used as the Doppler signal processor. The measurement data were transmitted to a Pentium 100 PC computer through direct memory access (DMA) and analysed by FIND software provided by TSI.

Figure 5 shows a depth profile upstream of the step. As shown a wall approach of 100μm was possible indicating that the LDA has high resolution. The velocity vectors of the flow are shown in figure 6.

## CONCLUSION

A two component solid-state LDA system has been developed and applied to the flow in a narrow gap of 1mm. It was demonstrated that the performance of the LDA system is satisfactory. Future research is concentrating on reducing the length of the measuring volume to enable flow in smaller gaps such as that occurring in a journal bearing.

## ACKNOWLEDGMENT

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## REFERENCES

Adrian, R. J., 1975, "A bipolar, two component laser-Doppler velocimeter", *J. Phys. E: Sci. Instrum.*, 8, pp 723-726.

Bossel, H. H., Hiller, W. J., and Meier, G. E. A., 1972, "Self-aligning comparison beam methods for one-, two- and three-dimensional optical velocity measurements", *J Phys. E: Sci. Instrum.*, 5, pp 897-900.

Durst, F., and Stevenson, W. H., 1979, "Influence of Gaussian beam properties on laser Doppler signals", *Appl. Opt.*, 18, pp 516-526.

Forder, P. W., Pannell, C. N., Jones, J. D. C., Jackson, D. A., and Brown, R. G. W, 1987, "Designs of fibre optic probes for laser anemometry", *Proc. 2nd Int. Conf. on Laser Anemometry Advances and Applications,* (Strathclyde, Scotland, UK), pp 207.

Grant, G. R., and Orloff, K. L., 1973, "Two-color dual-beam backscatter laser Doppler velocimeter", *Appl. Opt.*, 12, pp 2913-2916.

Li, E., and Wang, S., 1989, "Two-component LDA system with optic-electro-hybrid feedback", *Proc. Int. Conf. Fluid Dynamic Measurement and its Applications*, Pergamon Press, New York.

Mackenzie, M. R., Tieu, A. K., Kosasih, P. B., and Binh, L. N., 1992, "A visible wavelength solid-state LDA and application to thin channel flow", *Meas. Sci. Technol.*, 3, pp 852-857.

Tieu, A. K., Mackenzie, M. R., and Li, E., "Measurements in microscopic flow with a solid-state LDA", accepted for publication in *Experiments in Fluids*.

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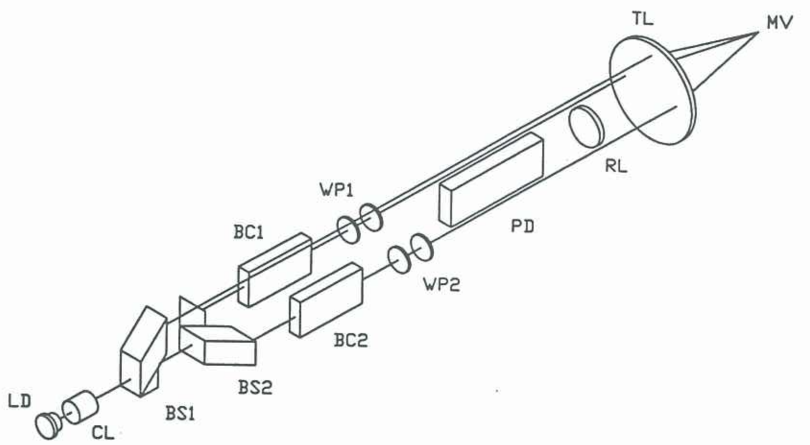


FIGURE 1 OPTICAL LAYOUT OF THE TWO-COMPONENT SOLID-STATE LDA; LD--LASER DIODE, CL--COLLIMATING LENS, BS1--BEAMSPLITTER 1, BS2--BEAMSPLITTER 2, BC1--BRAGG CELL 1, BC2--BRAGG CELL 2, WP1--WEDGE PAIR 1, WP2--WEDGE PAIR 2, PD--PHOTO-DETECTOR, RL--RECEIVING LENS, TL--TRANSMITTING LENS

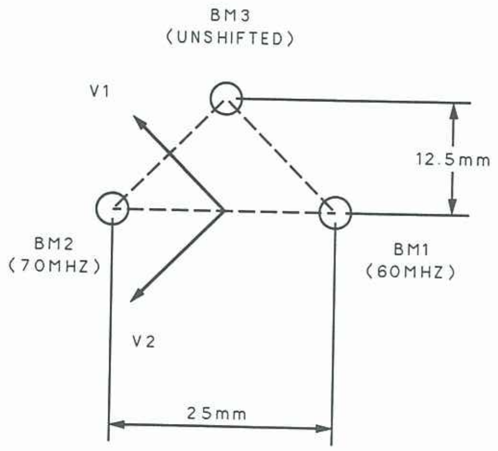


FIGURE 2 CROSS-SECTION OF THE TWO-COMPONENT LDA OPTICS (LOOKING AWAY FROM LASER) SHOWING INCIDENT BEAMS, FREQUENCY SHIFTS AND VELOCITY COMPONENTS

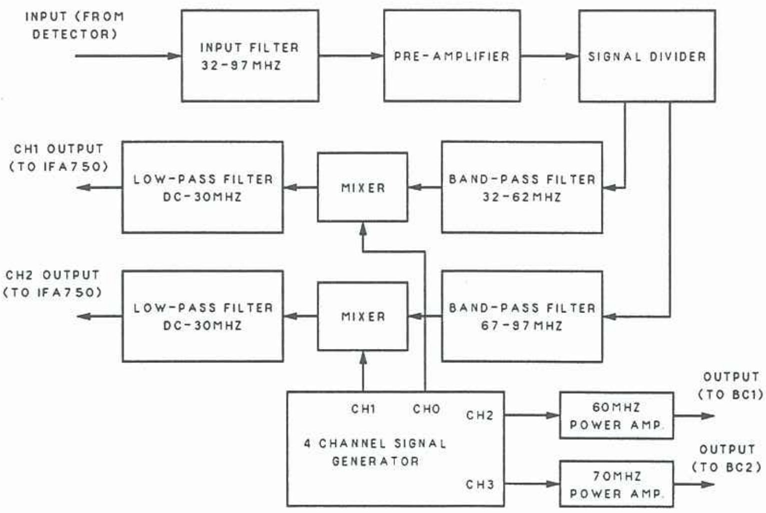


FIGURE 3 SCHEMATIC DIAGRAM OF THE ELECTRONICS OF THE LDA SYSTEM

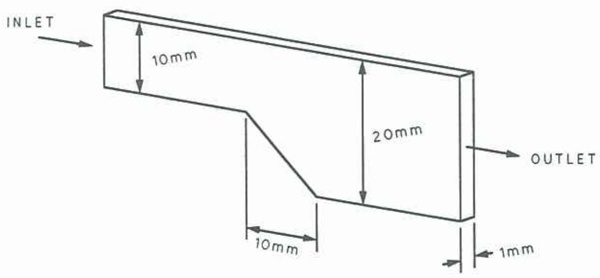


FIGURE 4 DIMENSIONS OF THE NARROW CHANNEL WITH SLOPED STEP

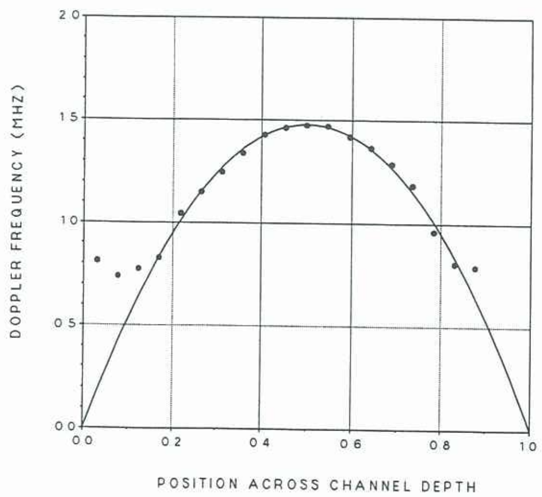


FIGURE 5 VELOCITY PROFILE ACROSS CHANNEL AT A POSITION UPSTREAM OF STEP

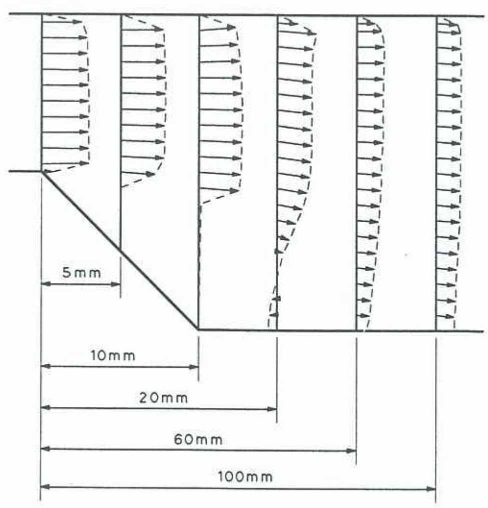


FIGURE 6 FLOW VECTOR DIAGRAM OF STEP FLOW MEASURED WITH THE LDA SYSTEM