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Laser Velocimeter (Autocovariance) Buffer Interface

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and Space Administration

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INTRODUCTION

A laser velocimeter (LV), when used in wind-tunnel applications, can generate large amounts of data arriving randomly at a high average rate. Data acquisition by state-of-the-art laser velocimeter instrumentation and data handling by minicomputers are not adequate, since the full potential of the laser velocimeter is not realized. Loss of data can occur when using a minicomputer because of the incompatibility of the computer's operational speed and the laser velocimeter instrumentation's output rate. Further, advanced measurement concepts, such as vectorial flow-field analysis, turbulence power-spectral-density studies, and conditional sampling of other phenomenon relating to the laser velocimeter data, can not be undertaken unless additional instrumentation is used. Current methods of processing laser velocimeter data determine the velocity statistics of an independent component of the flow field. These methods do not assure the researcher that each data point is based upon multicomponent measurements of each seeding particle. However, known, coincident, multicomponent measurements of each seeding particle would permit the statistical analysis of the flow-velocity vectorial quantities of magnitude and angle. The measurement of power spectral density requires time dependent data; therefore, the time interval (interarrival time, Δt) between successive measured events must be known. In practice, the autocovariance function is determined by using the velocity data along with the interarrival-time data in a Fourier transform to obtain the power spectral density (ref. 1). In typical applications, data from the laser velocimeter, pressure probes, balances, model position encoders, and sensors are combined to produce an overall view of the flow field. A more in-depth study of the flow field may be made by utilizing conditional sampling of all parameters, since the measurements would be related to each other by known time periods. There is an obvious need for conditional sampling to relate laser velocimeter measurements with the position of a helicopter rotor or a turbine compressor blade. But, comparison of laser velocimeter data with surface pressure data by conditional sampling would allow study of the propagation of structured flow phenomenon from creation to dissipation.

An instrument, the laser velocimeter (autocovariance) buffer interface (LVABI), has been developed (ref. 2) which accepts data from laser velocimeter high-speed burst counters, determines the interarrival time between velocity measurements, sets a coincidence requirement on data, and permits the conditional sampling of other phenomena. The LVABI will accept data from three counters, each capable of data transfer rates of up to one-million data points per second. It will determine the interarrival times of velocity data up to 655.35 msec with a resolution of 100 nsec. The coincidence requirement may be set for any combination of two or all three input channels with the coincidence condition being satisfied if the measured events occur within 1 μsec. The instrument may also be set to conditionally sample nonvelocity data being acquired by any channel. The functions, circuits, and typical applications of the laser velocimeter (autocovariance) buffer interface are described, with the overall system specifications given in table I.

CIRCUIT DESCRIPTION

The LVABI has two major circuit divisions: the data acquisition channels, and the system control and computer interface circuits. There are three data acquisition channels, each having its own timing and control circuit, interarrival-time measurement circuit, and memory. The system control and computer interface section serves all data acquisition channels and includes the coincidence circuit. The system control and computer interface section also includes a measurement-time clock for limiting the time that the LVABI will acquire data. A block diagram of the LVABI is shown in figure 1.

The LVABI has two major operational modes: a data acquisition mode and a computer communication mode. During the data acquisition mode, each channel acquires data while the system control and computer interface section remains idle, with the exception of the measurement-time clock. The interarrival times are continuously computed in parallel with the acceptance of velocity data, the storing of the velocity and interarrival-time data into memory, and the coincidence determination. In the data acquisition mode, the timing and control signals used to direct the above processes are generated as a serial sequence. The second mode of operation is the LVABI-to-computer communications mode which is serial by function. Transfer of control instructions from the computer, the transfer of LVABI status information to the computer, and measurement and diagnostic data transfers are examples of the functions performed in the communications mode.

Data Acquisition Channel

Each of the three data acquisition channels acquire data from a single, laser velocimeter high-speed burst counter. Every channel is fully independent of the other data acquisition channels when operating in the noncoincidence mode and may, therefore, acquire data at any rate. In the coincidence mode, the data rate is determined by coincidental events in the channels set for coincidence operation (any two or all three channels). Interarrival timing is computed by each individual channel, in both noncoincidence and coincidence modes, and is measured between successive leading edges of the LV-counter data-valid signals. A block diagram of a data acquisition channel is given in figure 2.

Timing and control circuit.- All functions within a data acquisition channel are controlled by its timing and control circuit. This circuit produces a series of pulses used for the control of the data input latches, the interarrival-time measurement circuits, and the memory. It also generates a 1 μsec coincidence aperture pulse when the LVABI is operating in the coincidence mode. A timing and control cycle begins with the receipt of a data-valid signal from the high-speed burst counter, and proceeds with the generation of the control pulses as shown in figure 3. Following reset of the circuit, it is idle until the next data-valid signal is received, although the timing of the interarrival period continues. The maximum time required to complete the control sequence is $\leqq 1.25$ μsec.

Interarrival-time measurement circuit.- The interarrival timing circuit will measure the time between successive measured events (counter data-valid signals) from a minimum of 1 μsec to a maximum of 655.35 msec. This timing range includes the normal distribution of interarrival times and is compatible with the data rates of the LV high-speed burst counters. Figure 4 is a block diagram of the interarrival-time measurement circuit.

The interarrival interval is measured by a 16-bit binary counter and a 2-bit clock status counter (ref. 3). The timing source for the counter is a multivalue clock with outputs of 10.0 MHz, 1.0 MHz, and 100.0 KHz. The counter will automatically switch from the 10.0-MHz output to the 1.0-MHz output, then to the 100.0-KHz output each time the counter overflows. The count is corrected to the value 6553 when the circuit is switched from the 10.0-MHz output to the 1.0-MHz output and from the 1.0-MHz output to the 100.0-KHz output. The correction value adjusts the counter to the value that would have been present had the counter been operating at the lower frequency from the beginning of the interval. If the counter overflows at the 100.0-KHz rate, it is cleared and halted. The 2-bit status counter maintains the clock frequency information. The counter data and the status word are used by the computer to calculate the actual interarrival time. A data value of zero and a status value of 3_8 indicate that the interval was longer than 655.35 msec. The schematic diagram for the interarrival-time measurement circuit is given in figure 5.

The interarrival-time measurement circuit is used for coincidence and noncoincidence operation. As stated in the circuit description introduction and in the timing and control circuit section, each data acquisition channel generates a 1-μsec coincidence aperture pulse when an LV-counter data-valid pulse is received. The aperture pulses from the active channels are ANDed, and the product is returned to the control circuits in each channel for use when the channel is operating in the coincidence mode. When operating in the noncoincidence mode, the two, interarrival-time measurement circuits (shown in fig. 4) alternately measure consecutive intervals. When in coincidence mode, a special circuit (shown schematically in fig. 6) will control the measurement circuits (ref. 4).

Operational cycles of the interarrival-time measurement circuit (coincidence mode) are shown in figure 7. When the first data-valid signal is received from the LV counter, the time information from the Δt counter measuring the just completed interval (counter A) is written into memory and Δt counter B is started. The interarrival-time counter A continues its count, assuring the maintanence of a valid interarrival measurement should coincidence not occur. Coincidence does occur, however, and the coincidence steering flip-flop (fig. 6) routes control pulse t_{23} to the Δt counter A control flip-flop. This causes the counter to halt and zero, making it ready for the next measurement. When the next data-valid pulse occurs, the interarrival-time value in counter B is written into memory and Δt counter A is started. Again, coincidence occurs and Δt counter B is halted and zeroed. Upon the arrival of the next data-valid pulse, the interarrival-time value in Δt counter A is written into memory and Δt counter B is started. Since coincidence does not occur, the close of the coincidence aperture causes Δt counter B to halt and zero, making it ready for the next measurement. The interarrival-time counter A, which continued to count, preserves the interval timing from the last coincident event and will contain the valid Δt value when the next data-valid signal is received. Because coincidence did not occur during this measurement cycle, the memory address was not incremented and the value contained by Δt counter A at the next coincident event will be written into memory at the same address, thus destroying the previous data.

The errors associated with the interarrival-time measurement include the jitter in the recognition of an LV-counter data-valid signal ($\leqq$50 nsec, based on the LVABI 20-MHz system clock) and the ±1 count of the time-base signal. The technique of switching time bases by the interarrival timing circuit causes the errors to be additive as given by

$$S_1 = J \pm (1 \text{ time-base clock count})$$

where J is the data-valid recognition timing jitter. The errors are given for the following ranges as:

1 μsec to 6.5535 msec

$$\Sigma_1 = J \pm 0.1 \ \mu\text{sec}$$

6.5535 msec to 65.535 msec

$$\Sigma_2 = \Sigma_1 \pm 1.0 \ \mu\text{sec}$$

65.535 msec to 655.35 msec

$$\Sigma_3 = \Sigma_2 \pm 10.0 \ \mu\text{sec}$$

The maximum error for the different timing ranges is shown in figure 8.

Memory.- The velocity/interarrival-time data pairs acquired by a data acquisition channel are stored in the channel's 4096 × 32-bit memory. The memory consists of an array of 1024 × 1-bit NMOS (N-channel metal-oxide semiconductor), static random-access-memory (RAM) integrated circuits. The organization of the memory is shown in figure 9. Prior to a data acquisition cycle, the computer configures the memory by defining the areas into which data will be written. Typically, the entire memory is used for a data acquisition cycle; however, a small block of memory may be used per cycle in order to allow several data acquisition cycles to be performed before the data is transferred to the computer. By using the diagnostic features of the LVABI, the memory may be loaded with known data to provide checks during data processing.

System Control and Computer Interface

The system control and computer interface section serves all data acquisition channels and includes: the system time base, the computer command decode circuits, the coincidence AND circuit, the data acquisition time clock, the status monitoring circuits, and the computer interface. Figure 10 is a functional block diagram of this section. The time base consists of a 20.0-MHz crystal oscillator which is the source for the 10.0-MHz, 1.0-MHz, and 100.0-KHz signals for the data acquisition channels, and the 1.0-Hz signal for the data acquisition time clock. The computer command decode circuits configure the LVABI for data acquisition in either coincidence or noncoincidence modes, sets the memory address parameters, enables the data transfers to and from the computer, and sets the data acquisition time. The coincidence AND circuit determines whether the LV data are coincident, but it is active only when the LVABI is configured for the coincidence mode of operation. The data acquisition time clock controls the data gathering time of the LVABI to a maximum of 9 min and 59 sec. The status monitoring circuits inform the computer of the present operational condition of the LVABI. The computer interface includes two 16-bit input/output ports, one for the transfer of computer commands and status information and the other for the transfer of data. Table II contains a listing of the LVABI-computer input/output functions.

USING THE LVABI

Data Acquisition Sequence

The application of the LVABI to a laser velocimeter may be illustrated by working through a typical data acquisition sequence. The sequence is begun with the computer clearing the LVABI's memory. (When processing data, the computer will check for a zero data word and use it as an end of data indicator.) Next, the memory is configured either as several data blocks or as a full memory of 4096 locations. The data acquisition time clock is set, then the computer will request a noncoincidence or coincidence data acquisition cycle. When the LVABI's memory is filled (block or full) or when the data acquisition time limit has expired, the computer is flagged. The computer then will request a readout of the acquired data, and the process will be repeated if desired.

Applications

An LVABI is being used in the majority of Langley's laser velocimeter systems (refs. 5 and 6). Two examples of applications are: a two-component LV system installed in the 2-inch turbulent subsonic flow apparatus was used to develop advanced data acquisition and processing techniques, and a two-component LV system was used to survey the flow field about a model helicopter rotor. In both examples, the coincidence mode of operation was used, which allowed each measured event to be separated into the magnitude and flow angle of the velocity vector. This separation permitted the researcher to observe apparent swirl structures (fig. 11) along the edges of the flow in the 2-inch apparatus. In the second example, two channels of the LVABI were used to accept the data from the two-component laser velocimeter, and the third channel was used to store rotor-blade position information. With only a slight modification, the LVABI coincidence signal was used to trigger the readout of the rotor position encoder to provide a blade position measurement for each unique coincident event. In off-line data processing, the computer sorted the various data as functions of blade position and the statistical quantities were computed for each blade position.

Although the LVABI was designed for laser velocimeter studies, the system may be used in other applications where high-speed and/or random data acquisition is necessary. The inputs to the data acquisition channels require standard LS-TTL (low-power Schottky, transistor-transistor-logic integrated circuit) levels with a 14-bit data word and a data-valid pulse of 100 to 400 nsec. The data acquisition channels return a busy signal for use in controlling the input instrumentation. The LVABI's computer interface also requires LS-TTL signal levels plus handshaking signals and two 16-bit input/output ports.

A SECOND GENERATION LVABI

A redesign of the LVABI is currently underway. Newer integrated circuits are being used to reduce the chip count and to add capability and flexibility to the system. The flow-field measurements about a rotor blade mentioned previously illustrate the need for auxiliary memory channels which are controlled by the data acquisition channels. These additional channels will allow the use of external devices such as analog-to-digital (A/D) converters, model position encoders, and pressure instrumentation in conditional-sampling data processing methods.

The coincidence circuitry will be improved to allow easy implementation of a variable aperture to permit the customizing of the LVABI to best fit the various LV sample volume changes that occur as the optical configuration is altered to meet the physical requirements of various wind tunnels. This feature will also allow the dynamic modification of the aperture as the time of flight of the seeding particle changes with variations in mean flow velocity of the tunnel. The interarrival timing circuits will be upgraded so that the maximum interarrival time that can be measured will be approximately 1.64 sec, and the data paths within the LVABI will be changed so that LV high-speed counters with 16-bit data words can be accommodated.

CONCLUDING REMARKS

An instrument has been described that links laser velocimeter (LV) high-speed burst counters to a minicomputer. The laser velocimeter (autocovariance) buffer interface (LVABI) arbitrates conflicting speed capabilities between LV counters and minicomputers through the use of a buffer memory. The instrument imposes a coincidence requirement on LV component data allowing the acquired data to be used in vectorial studies of wind-tunnel flow fields. The time interval between measured events is determined giving the researcher time history data that can be used in autocovariance and crosscovariance and in power and cross-power spectra studies. Conditional sampling of other phenomena can also be done with the LVABI for the study of the interaction between the phenomena and the velocity flow field. Several LVABI's are in use in the aeronautical facilities at the Langley Research Center, and work is continuing on improvements to the instrument.

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April 22, 1981

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TABLE I.- LVABI SPECIFICATIONS

LV data acquisition rate (noncoincidence mode), data words/sec/LV component	1 000 000
LV data acquisition rate (coincidence mode), data words/sec/LV component	700 000
LV data word (LS-TTL levels)	14 bits (10-bit mantissa, 4-bit exponent), plus 2-bit status (not stored)
LV data-valid signal (LS-TTL levels), nsec	<600
Interarrival time, msec	0.001 to 655.35
Interarrival time resolution, μsec	
0.001 to 6.5535 msec	0.1
6.5535 to 65.535 msec	1
65.535 to 655.35 msec	10
Interarrival time data word	18 bits (16 bits, time data; 2 bits, status)
First interarrival time	From initialization to first LV data - valid signal
Data storage, 32-bit data words/channel	4096
Computer interface, bits	
Data channel input/output	16
Command/status input/output	16
Data transfer rate, 16-bit words/sec	1 000 000
Software control	(a) First memory address for data storage (b) Last memory address for data storage (c) Time allotted for data acquisition (0 to 9 min 59 sec - 1 sec resolution) (d) Coincidence data acquisition (channels 1 and 2, 1 and 3, 2 and 3, or 1, 2, and 3) (e) Memory diagnostic data
Circuitry	
Processing	Low-power Schottky, transistor-transistor-logic (LS-TTL) families
Memory	Static, N-channel metal-oxide-semiconductor (NMOS) random-access memory (RAM)

TABLE II.- LVABI/COMPUTER I/O SPECIFICATIONS

Command/status channel (type of command/status)	Data channel (type of data)
Computer to LVABI (command):	Computer to LVABI:
Set first memory address	Memory address
Set last data address	Last memory address
Set time clock	Time
Coincidence channel 1 & 2	No action
channel 2 & 3	
channel 1 & 3	
channel 1, 2 & 3	
Send diagnostic data	Diagnostic data
Start data acquisition	No action
Stop data acquisition	No action
Computer to LVABI (command):	LVABI to computer:
Send LVABI data to computer	LV/Δt data
Read memory address, channel 1	Memory address, Channel 1
2	2
3	3
LVABI to computer (status):	LVABI to computer:
Memory full/time limit	No action
Channel 1 active	
2	
3	
Channel 1 transferring data	
2	
3	
LV or Δt data being transferred	
LV counter (X) in 5/8 or 10/16 mode	
LV counter (X) in time or velocity mode	

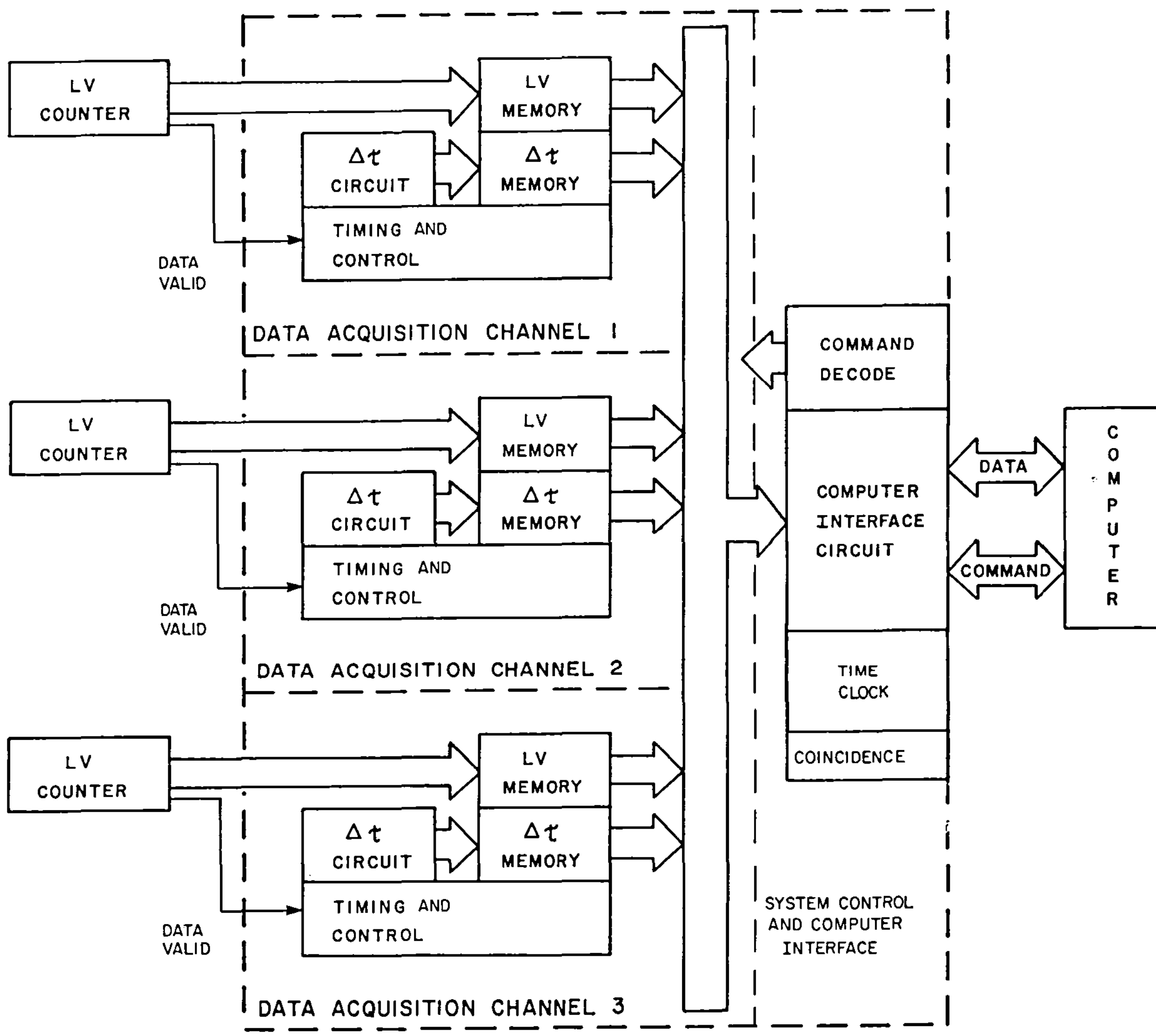


Figure 1.- Block diagram of LVABI system.

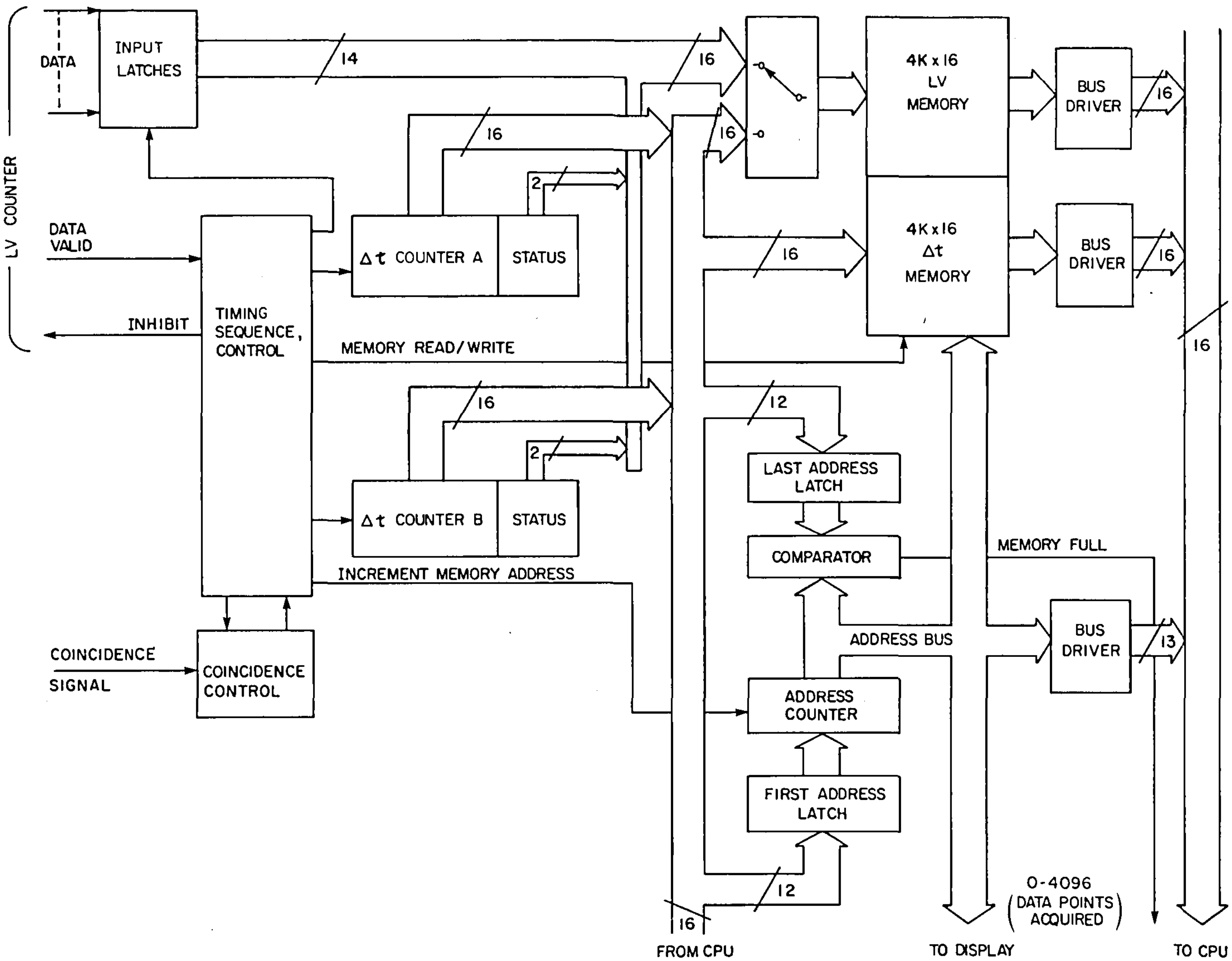
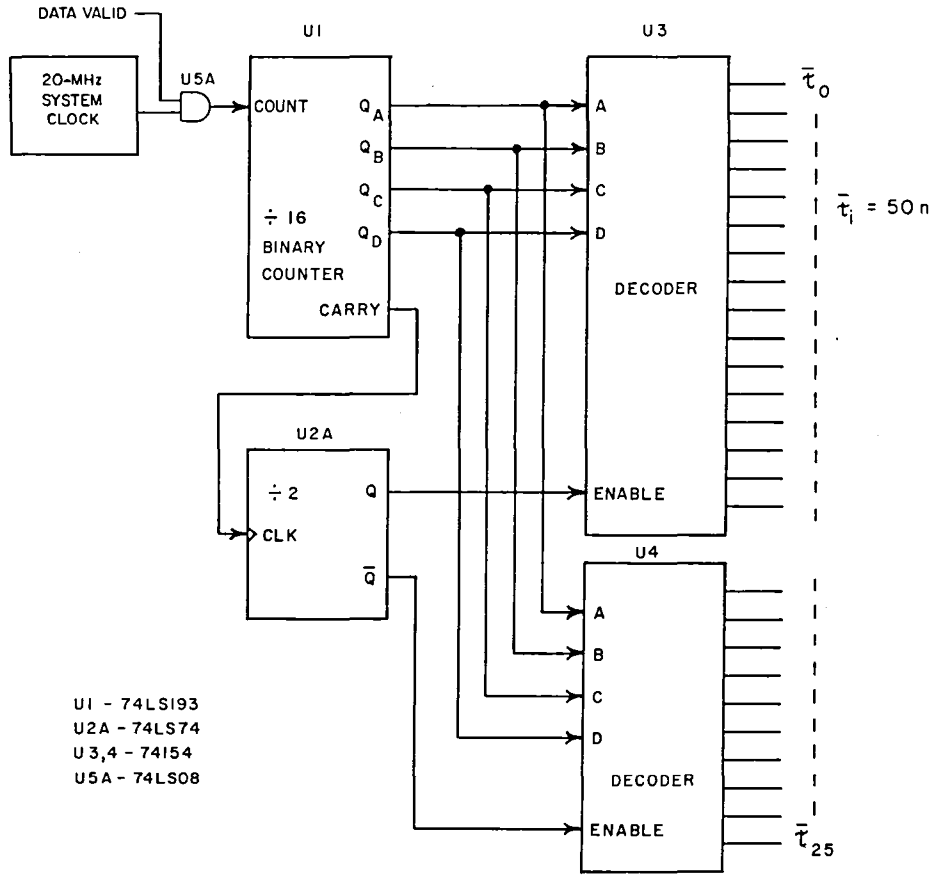


Figure 2.- Block diagram of data acquisition channel.



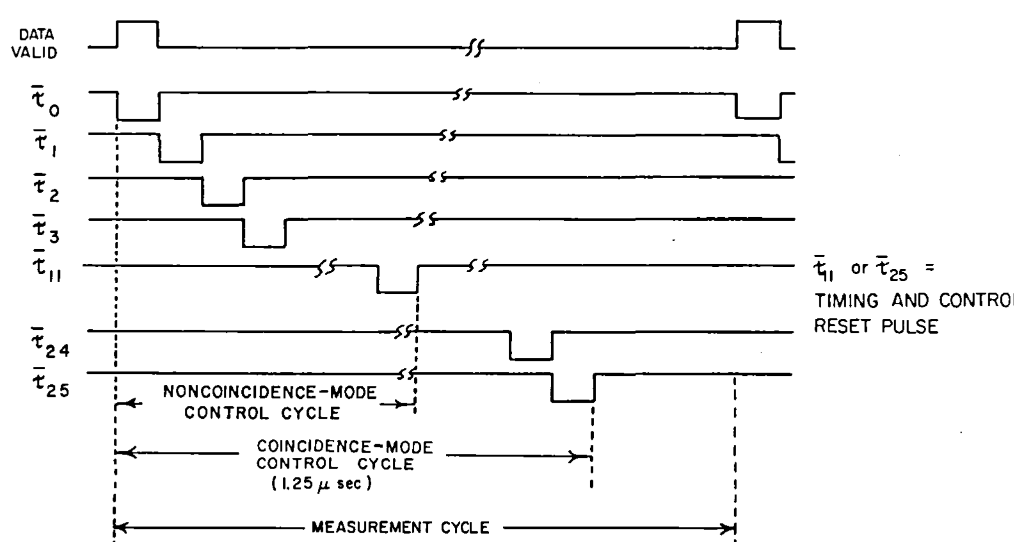


Figure 3.- Timing and control circuit.

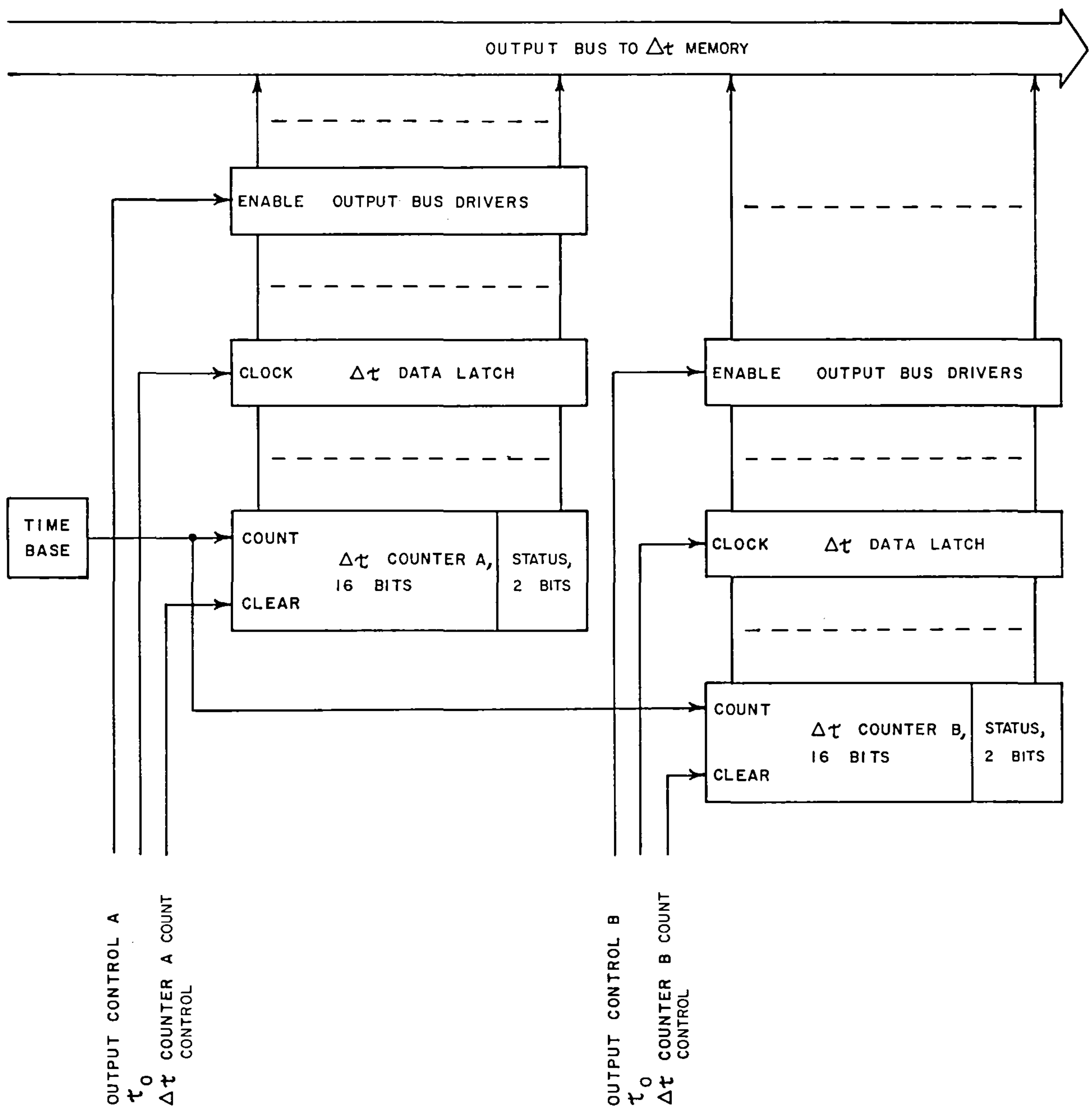


Figure 4.- Interarrival-time measurement circuit.

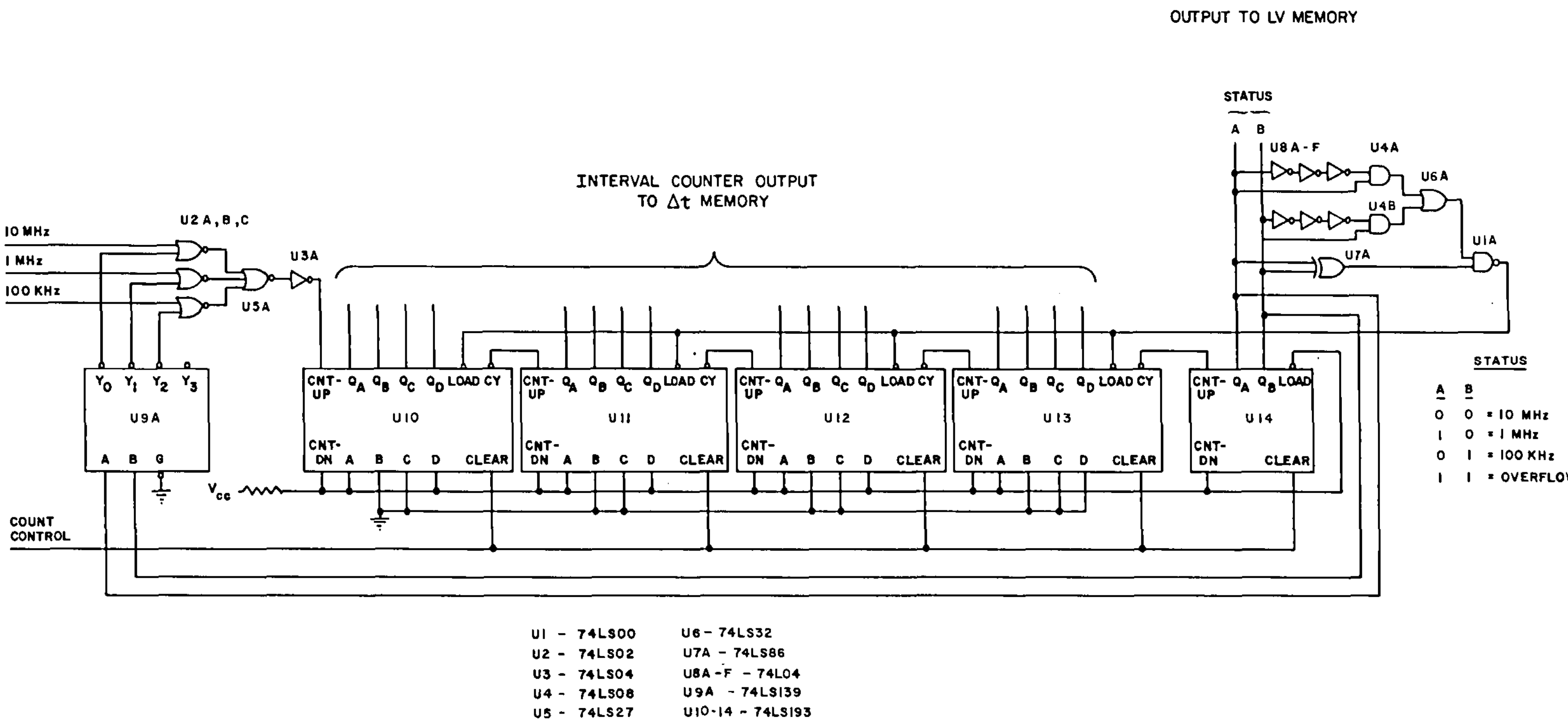


Figure 5.- Interarrival-time counter.

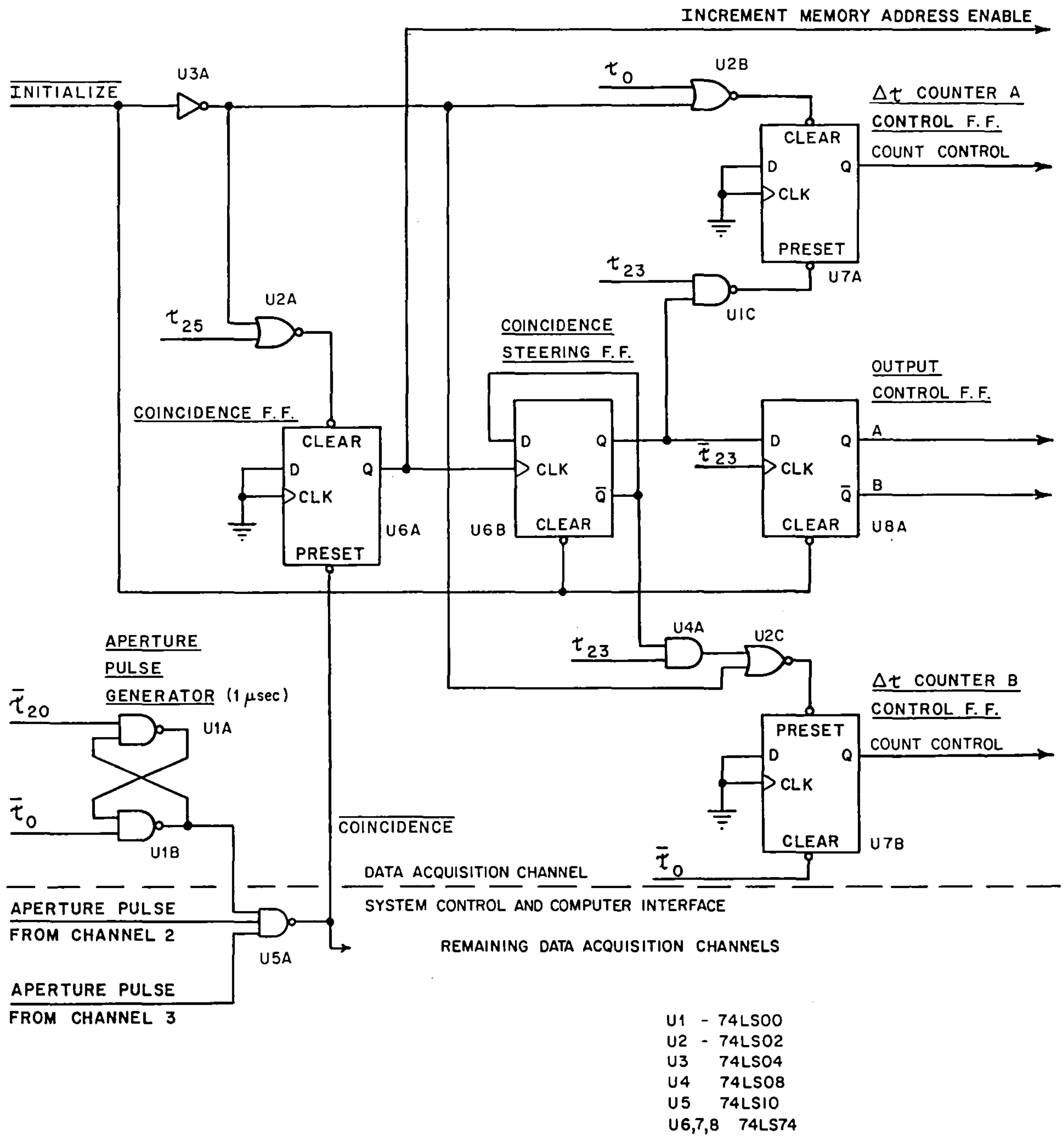
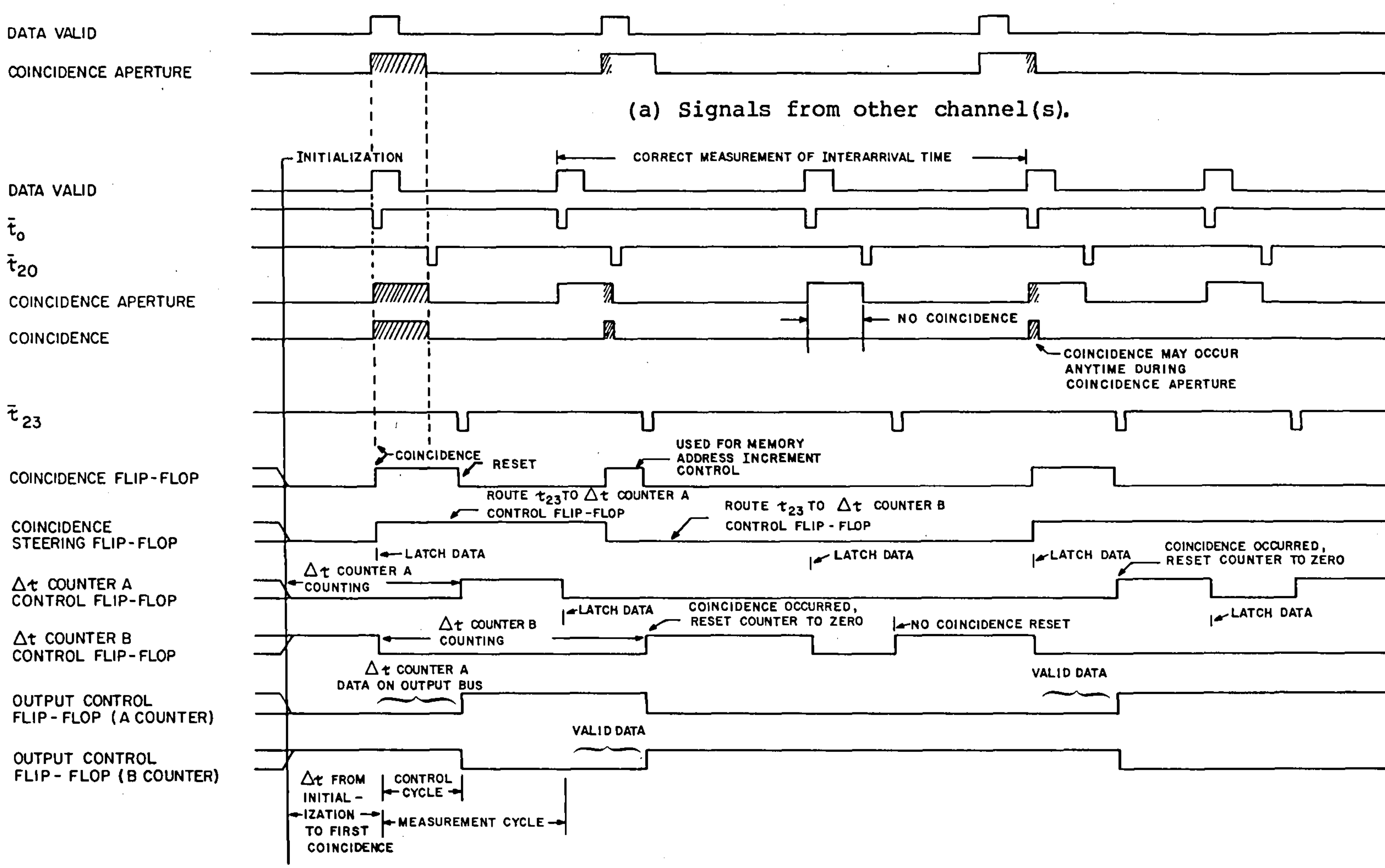


Figure 6.- Interarrival-time measurement circuit (coincidence mode).



(b) Timing diagram for a typical channel.

Figure 7.- Typical operational cycles of interarrival-time measurement circuit (coincidence mode).

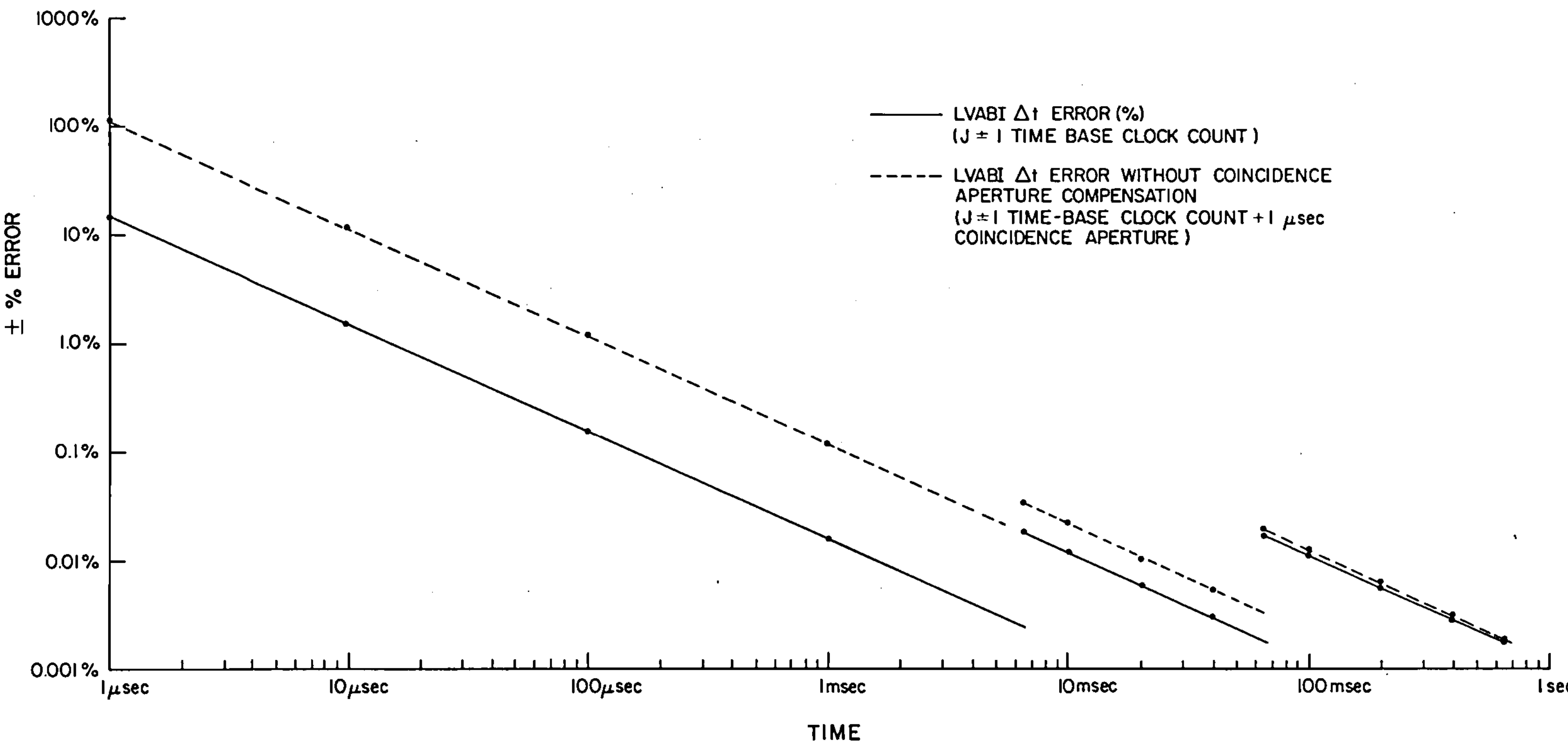


Figure 8.- Errors associated with interarrival-time measurement circuit.

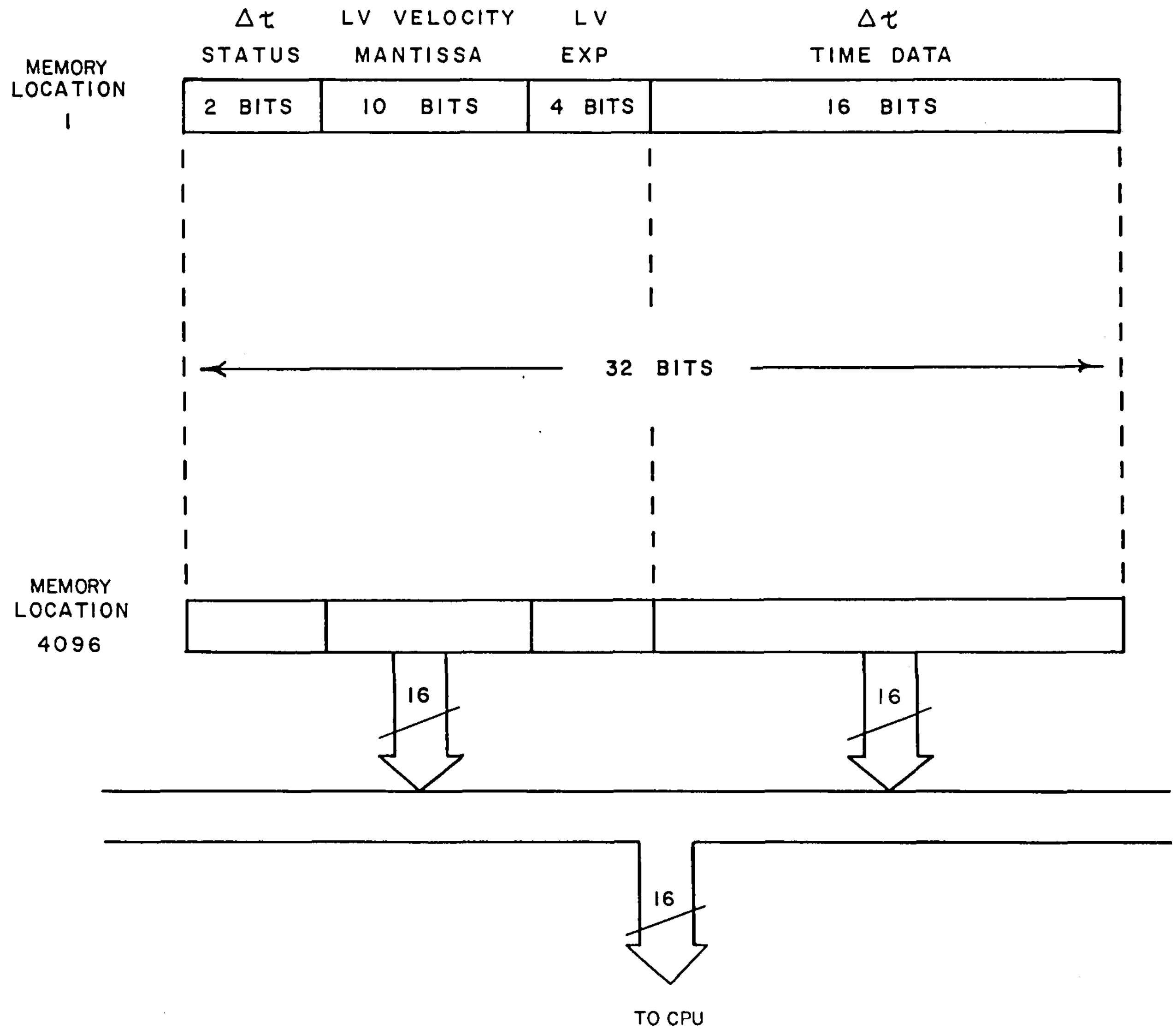


Figure 9.- Organization of memory (single channel).

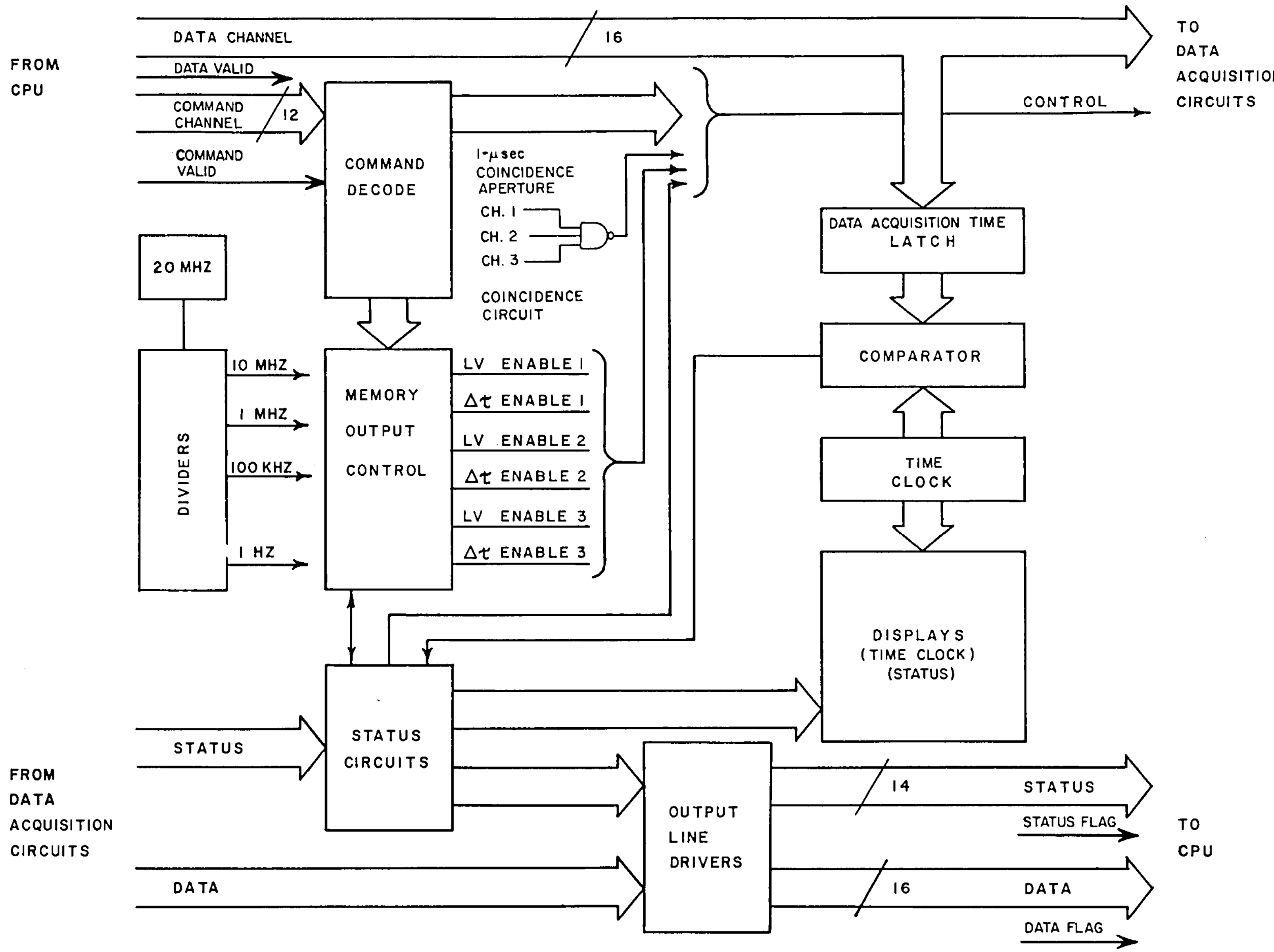


Figure 10.- System control and computer interface circuit.

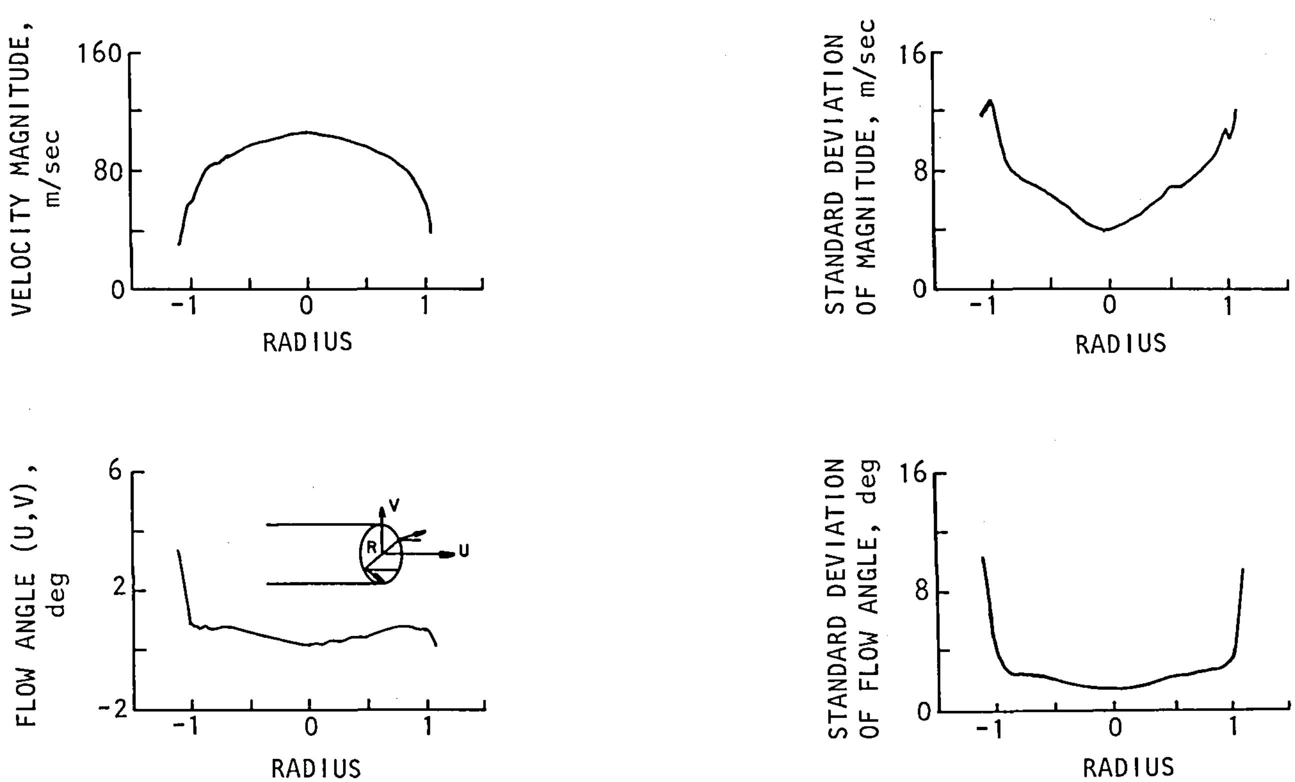


Figure 11.- Surveys of velocity magnitude and flow angle across exit of 2-inch turbulent subsonic flow apparatus.

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15. Supplementary Notes

16. Abstract

A laser velocimeter (autocovariance) buffer interface (LVABI) has been developed to serve as the interface between three laser velocimeter high-speed burst counters and a minicomputer. Presented in this paper is a functional description of the instrument and its unique features which allow the studies of flow-velocity vector analysis, turbulence power spectra, and conditional sampling of other phenomena. Typical applications of the laser velocimeter using the LVABI are presented to illustrate its various capabilities.

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