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# Digital Data Acquisition and Preliminary Instrumentation Study for the F-16 Laminar Flow Control Vehicle

by

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Preliminary studies have shown that maintenance of laminar flow through active boundary-layer control is viable. Current research activity at NASA Langely and NASA Dryden is utilizing the F-16XL-1 research vehicle fitted with a laminar-flow suction glove that is connected to a vacuum manifold in order to create and control laminar flow at supersonic flight speeds. This experimental program has been designed to establish the feasibility of obtaining laminar flow at supersonic speeds with highly swept wing and to provide data for CFD code calibration. Flight experiments conducted at supersonic speeds have indicated that it is possible to achieve laminar flow under controlled suction at flight Mach numbers greater than 1. Currently this glove is fitted with a series of pressure belts and flush mounted hot film sensors for the purpose of determining the pressure distribution and the extent of laminar flow region past the stagnation point. The present mode of data acquisition relies on out-dated on board multi-channel FM analogue tape recorder system. At the end of each flight, the analogue data is digitized through a long laborious process and then analyzed. It is proposed to replace this outdated system with an on board state-of-the-art digital data acquisition system capable of a through put rate of up to 1 MegaHertz.

The purpose of this study was three-fold:

- Develop a simple algorithm for acquiring data via 2 analogue-to-digital convertor boards simultaneously (total of 32 channels)
- Interface hot-film/wire anemometry instrumentation with a PCAT type computer
- Characterization of the frequency response of a flush mounted film sensor

A brief description of each of the above tasks along with recommendations are given below.

## Part I - Digital Data Acquisition

### Hardware Description

The analogue-to-digital boards utilized were manufactured by RC Electronics (Model ISC-16). The ISC-16 board is designed to permit an IBM PC computer to perform as a sophisticated data acquisition laboratory instrument. The ISC-16 consists of a 16-channel analog to digital (A/D) plug-in interface and a BNC termination box. The system is capable of digitizing 16 analog data channels with individual time bases, input at an aggregate sampling rate of up to 1 MHz. When more than 16 input channels are required, it is possible to support multiple boards (up to 4 cards, or 64 channels). Analog to digital conversion is achieved with 12 bit accuracy over a maximum voltage range between $\pm 10$ V. Each data sample is stored in a 16 bit word (two 8 bit bytes).

A 64K sample memory (65,536 words) on the ISC-16 card is used to capture input signals. The memory is sectioned into two buffers, each with 32K sample (32,768) maximum memory. The two buffers are used interchangeably to simultaneously capture the input signal. The buffer size determines the total number of data points that will be collected per channel each time data acquisition is initiated.

A complete mechanization of the ISC-16 hardware is shown in Figure 1. A brief description of some of the key features are summarized below.

- 12 bit 1 usec A/D conversion
- 1 to 16 channel programmable input multiplexer
- 64K sample double buffered memory
- 12 bit trigger threshold DAC output
- trigger any channel or on external input
- trigger slope, level or threshold
- variable trigger delay (1 to 65,384 samples)
- internal clock rate (1 to 65,384 usec)
- external clock input
- 2 digital outputs

## Software Description

The software developed for the above ISC-16 board was written in C language. The drivers supplied with this board consist of "outp" calls directed to a given board address. These drivers can only be used with the Microsoft C compiler (ver 6.0 and above) with the small library option. The software written consisted of standard I/O calls and basic calls to the C drivers provided by the manufacturer. Many of these drivers were modified to overcome a hardware interrupt problem that was encountered when other computer peripherals were being used. The A/D boards were supplied with a hardware interupt that was in direct conflict with COM2 port address. This hardware interrupt was used to provide the necessary high signal when the A/D board had completed the data acquisition cycle. Since each board was assigned a unique address location, it was decided to disable (permanently) the hardware interrupt while still being able to read and process the 64K buffer memory (sample and hold).
The software written in C can be used to acquire data from two boards with different base address locations simultaneously. The simultaneous acquisition is only possible if an external trigger signal is used to activate both A/D boards. This was accomplished by sending a positive analogue voltage out via one of the board's digital-to-analogue port during each sample burst. This output signal was then used as trigger signal and was connected to the trigger input of both boards.

Before a sample burst, the software is constantly interrogating the hardware trigger before data acquisition begins. Upon activation of the hardware trigger, the two boards will sample data at the specified rate and the assigned channels. Since two independent calls are made to activate each A/D card, there is a time delay between the start of data acquisition on the first board and the second board. This time delay was estimated to be of the order of $10^{-9}$ seconds which is 3 orders of magnitude faster than the A/D conversion speed ( $10^{-6}$ sec.) between consecutive samples. Hence it was felt that this software delay was insignificant.

In order to acquire data at the fastest possible rate when several channels are to be sampled, it is necessary that all unassigned channel numbers to be multiplexed and looped back. The input multiplexer consists of a 16 to 1 analog data selector controlled by a 16x4 bit RAM. This allows for 16 separate multiplexer selections to be made with each sample pulse causing the multiplexer RAM to cycle to the next multiplexer setting. In this manner, the total number of channels in use can only be 1, 2, 4, 8 or 16 (e.g. 6 would not work). The current software assumes that if two boards are to be used, then both will have exactly the same number of channels and utilizing the same numbering sequence. The latter is not a restriction and can be easily modified to accommodate other arrangement and combinations.

Since the total number of channels that can be connected are restricted to the above combinations, the maximum throughput rates are listed below (based on the Nyquist criteria):

| Number of Channels | Maximum Sampling Rate (KHz) |
|---|---|
| 1 | 500 |
| 2 | 250 |
| 4 | 125 |
| 8 | 62.5 |
| 16 | 31.75 |

The source code flow diagram is shown in Figure 2.

## Part II - Interfacing of Hot-film/wire Anemometry to a PCAT Computer

The basic anemometry system consisted of a TSI-IFA100 system which includes a master module that is used to control 4 channels of a constant temperature anemometer circuitry. The LFC branch has purchased a total of three complete stand-alone system which can provide 12 anemometry channels. Ideally, a single master module should be used to control all three units, via a single RS232 connection to a PCAT type computer. However, the current configuration requires that each of these units to be controlled via a dedicated RS232 connection. Due the severe limitations associated with available number of communication ports in a PCAT, it was recommended that the LFC branch purchase two slave interface cards which replaces the master module cards, allowing control to be passed on to the single master module to control all channels.

The IFA-100 Master boards are designed to accept ascii instructions in determining and setting some of the anemometer reference condition for each channel (e.g. sensor resistance, cable resistance, amplification, filter setting, overheat ratio etc.). However, the control resistor, which determines the overheat ratio (i.e. sensor operating temperature) can only be set by manual means. Hence the only reason for utilizing the computer interface would be to download for each channel, the sensor characteristics which needs to be determined during a calibration procedure and before an actual test run.

The IFA-100 only supports a 2 way communication (pins 2&3 of an RS232) without any handshaking. Unfortunately neither C or Fortran support this mode of communication via a serial port. Hence we are restricted to using "QBASIC" as a means of sending information to the IFA-100 master module. The following statement is required before any communication can be established:

```
OPEN "COM1:1200,N,8,1,CD0,CS0,DS0,OP0,RS,TB2048,RB2048"
```

This particular statement is only supported in Microsoft QBASIC and is not available in GWBASIC.
It is recommended that similar routine be developed in assembly language which can then be linked to C or Fortarn. Further information on the use of IFA-100 can be found in the supplied instruction manual.

## Part III - Frequency Response of a Typical Flush-Film Sensor

It is well known that hot wires/films respond quite rapidly to flow transients. This response has been estimated to be in the Khz range, for both type sensors, but have rarely ever been measured in a controlled environment where the fluctuations are known (e.g. 100KHz pulsed flow). As a result most frequency response calibrations are done with an artificially induced square wave amplitude across a constant temperature sensor. The anemometer output is monitored and tweaked to provide the shortest time response, without too much overshoot, to this input pulse. A typical response curve for a square wave input is shown in Figure 3.

For the hot-wire anemometer the pulse response has been investigated in detail by many researchers. Excellent response to velocity steps is achieved if the pulse is short without undershoot and in this case the cutoff frequency, $f_{cut}$, of the anemometer can be estimated by

$$f_{cut} = 1/1.5\tau$$

where $\tau$ is the time from the start of the pulse until the pulse has decayed to 3% of its maximum value. Another complication that occurs for non-cylindrical film sensors (e.g. flush mounted, wedges, cones etc.) is the thermal lag caused by heat loss to areas not covered by the heated film at low speeds. It is believed that this heat loss becomes negligible at high velocities, but this still does not account for thermal loss to the supporting material (substrate), which becomes particularly important when this film will be of the direct deposit type on a lightly coated surface (epoxy based).

Experiments were conducted to determine the electronic frequency response of the system for 3 different type sensors. The following measurements were made for the configurations listed below:

| Configuration | Frequency Response (KHz) |
|---|---|
| Hot-Wire (1210-T1.5, 5 meter cable) | 230 |
| Hot-Film (Flush Mounted, 5 meter cable) | 120 |
| Hot-Film (Flush Mounted, 15 meter cable) | 115 |

The above results are the "electronic" response" of the sensors in still atmosphere and does not represent the actual thermal response which may be lagging due to other factors. It is recommended that a carefully designed experiment be conducted so that a flush type sensor along with a conventional hot wire sensor be placed at approximately the same position in an axi-symmetric fully developed jet discharging into still atmosphere. Measurements of flow frequencies should be made simultaneously and compared. This should reduce uncertainties associated with frequency response.

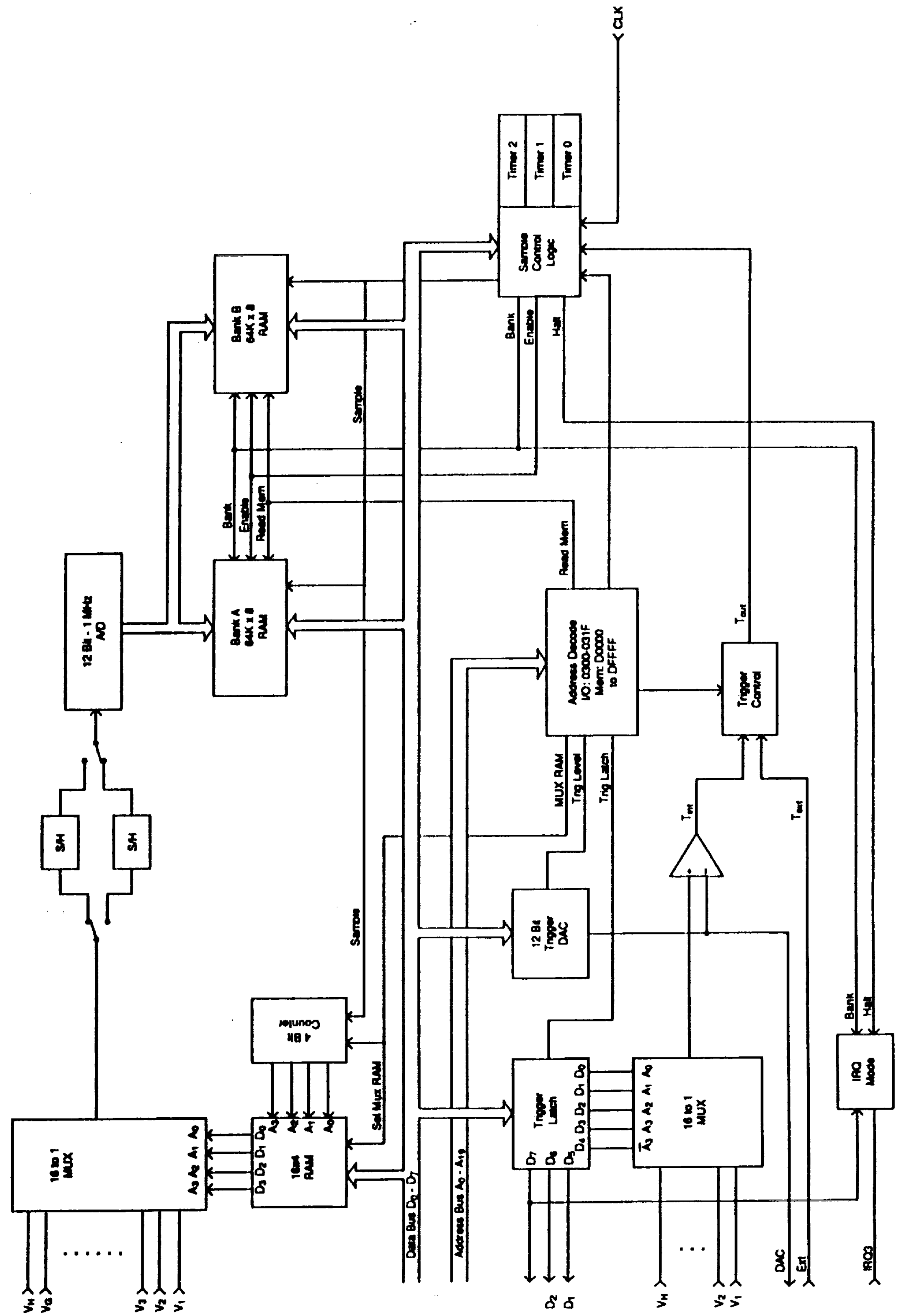


Figure 1 - ISC-16 A/D Board Hardware Schematic

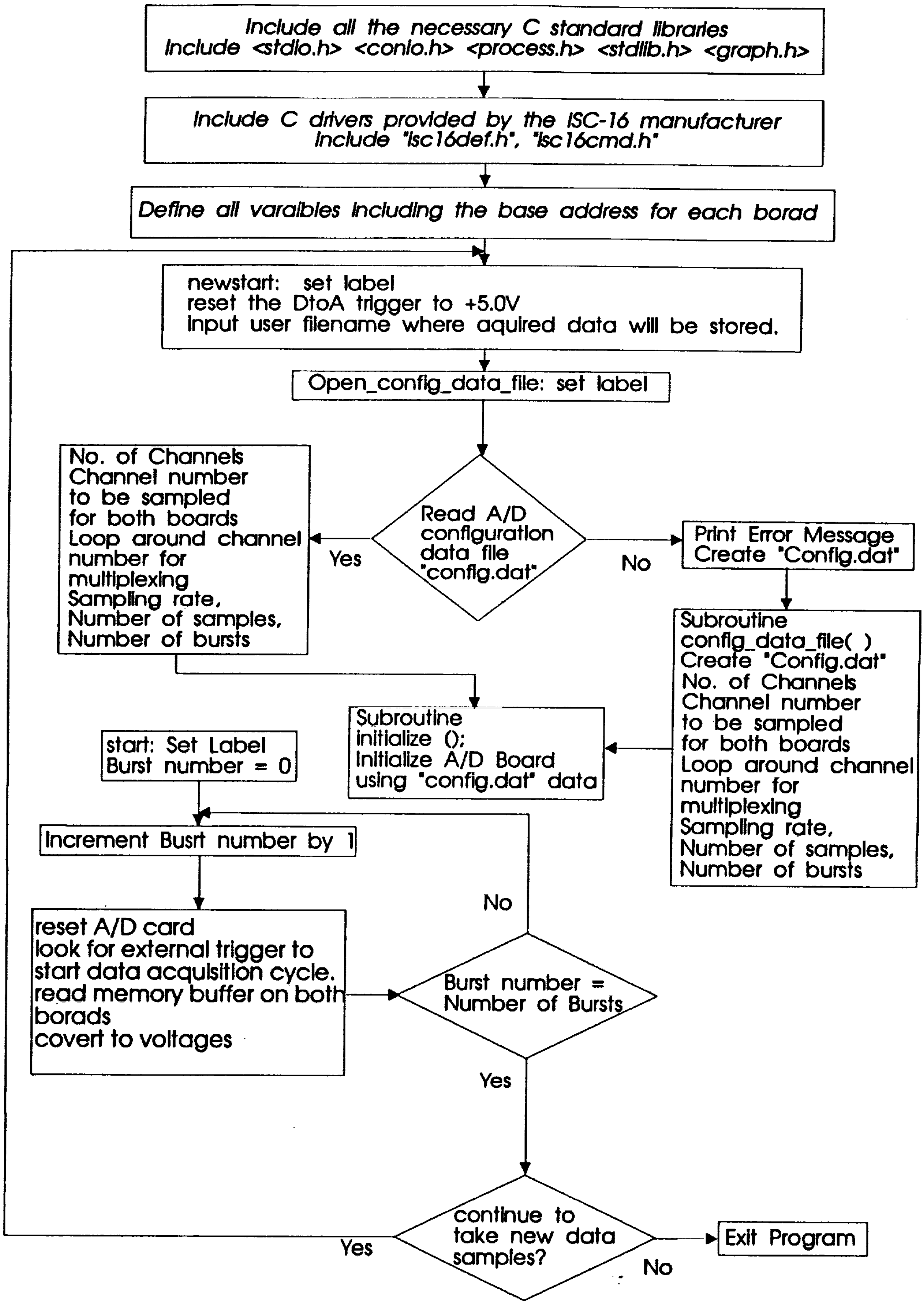


Figure 2 - Data Acquisition Source Code Flow Diagram

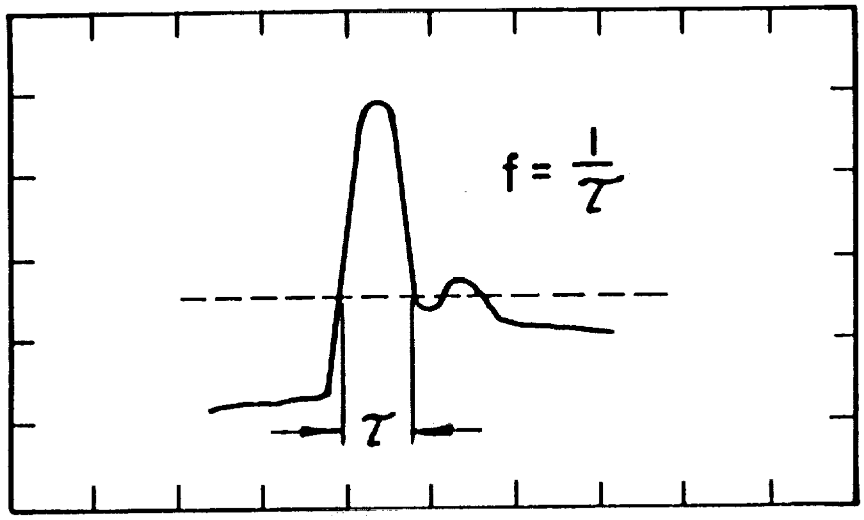


Figure 3a - Square wave test frequency response estimates for film sensors

Curve 1 - ideal response with hot-wire
Curve 2 - ideal response with hot-film
Curve 3 - actual response after tuning

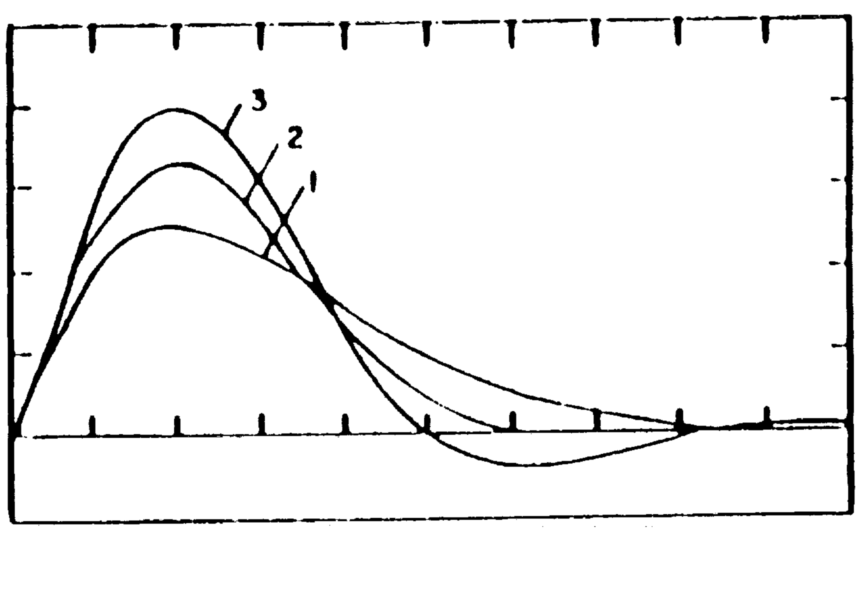


Figure 3b - Pulse shapes in response to a square wave.