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# INSTRUMENT TO AVERAGE 100 DATA SETS

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## SUMMARY

An instrumentation system is currently under development which will measure many of the important parameters associated with the operation of an internal combustion engine. Some of these parameters include mass fraction burn rate, ignition energy, and the indicated mean effective pressure. One of the characteristics of an internal combustion engine is the cycle-to-cycle variation of these parameters. These variations are particularly prominent at lean mixture ratios, which are points of great interest for investigating fuel economy and reduction in emissions.

A curve-averaging instrument has been produced which will generate the average curve, over 100 cycles, of any engine parameter. The average curve is described by 2048 discrete points which are displayed on an oscilloscope screen to facilitate recording and is available in real time. Inputs can be any parameter which is expressed as a ±10-volt signal. Operation of the curve-averaging instrument is defined between 100 and 6000 rpm. Provisions have also been made for averaging as many as four parameters simultaneously, with a subsequent decrease in resolution. This provides the means to correlate and perhaps interrelate the phenomena occurring in an internal combustion engine. This instrument has been used successfully on a 1975 Chevrolet V8 engine and on a Continental 6-cylinder aircraft engine.

While this instrument was designed for use on an internal combustion engine, with some modification it can be used to average any cyclically varying waveform.

## INTRODUCTION

An instrumentation system has been developed which will measure, in real time, the important parameters associated with the operation of an internal combustion engine. These parameters include the mass-fraction burn rate, ignition energy, and the indicated mean effective pressure. One of the major characteristics of an internal combustion engine, is the cycle-to-cycle variation of these parameters. These variations are particularly prominent at lean mixture ratios, which are currently points of great interest for

investigating emission reductions and economy gain.

Because of the cycle-to-cycle variation, one cannot use a single curve to characterize engine operation at any given time. The curve-averaging instrument was designed for the purpose of generating an average curve, over 100 cycles of engine operation. Each individual curve is sampled at 2048 discrete points. The values of each curve at these points are added to the corresponding values for each of 100 consecutive curves. Thus, the sum of 100 curves is compiled point by point, and is then divided by 100 to yield the average curve. This calculation is performed in real time; therefore, the average curve over 100 cycles is available immediately after the 100th cycle is complete. Provisions have also been made for averaging as many as four parameters simultaneously, with a subsequent decrease in resolution. This provides the means to correlate and perhaps interrelate the phenomena occurring in an internal combustion engine.

Prior to the construction of this module, oscilloscope pictures would be digitized and values printed out for various crank angles. The points for corresponding crank angles of a series of parameters would then be added and averaged to produce the average curve. The curve-averaging module not only saves many hours of valuable time but also eliminates the time between data acquisition and data presentation.

## DISCUSSION

The 100-sample module can be broken into four sections as shown in figure 1. They are the curve-averaging and storage section, the 100-sample logic, the input and output multiplexing, and the timing logic.

### Curve Averaging and Storage

The curve-averaging and storage section (fig. 2) adds the 100 curves and effectively divides the output by 100. Each $720^{\circ}$ engine cycle is broken up into a number of test points. At each one of these test points the analog-to-digital (A/D) converter digitizes the analog value of the parameter being averaged. The shift registers used to store this digital value can store 2048 bits. Therefore, for a $720^{\circ}$ engine parameter to be divided into 2048 bits, a test point must be made every $(720^{\circ}/2048) \approx 0.35^{\circ}$. The digital crankshaft position can be resolved to $0.35^{\circ}$. This is used to initiate the digitization of the curve being averaged. Ten bits of the digitized test are sent to Adden 1 of a binary adder array.

The output (sum) of the adders is sent to a set of clear/data gates. These gates can allow the adder outputs to pass through to the shift registers unaltered, or they can

clear the shift registers regardless of the state of the adder outputs. Putting the instrument in the same mode clears the shift registers, and then allows the adder outputs to be loaded into the shift registers. Because the shift registers can store only one $720^{o}$ engine cycle (sampled every $0.35^{o}$), as the second $720^{o}$ sample in the series of 100 is digitized and shifted, the first sample is pushed out of the shift registers point by point. As the points are pushed out the information from the corresponding crank angle of the first $720^{o}$ sample is sent back to the Addend 2 input of the adder. In this manner the curves are continually added and stored in a $2048 \times 16$ memory. The A/D conversion is initiated by a signal synchronized with the $720^{o}$ engine cycle, and therefore, the samples are taken at the same crank angle for each of the 100 samples that are averaged. In this manner, 204 800 points ($100 \times 2048$) can be accumulated while only storing 2048 of them at one time. At 12-bit digital-to-analog (D/A) converter converts the 12 most significant shift register output bits to an analog signal. The output of the D/A converter generates the average curve as it is being compiled. The accumulation of curves is continued until the 100-sample logic detects that the 100th sample has been added. The shift registers are then put in a recirculation mode so that the data stored are recirculated but no new data are introduced.

## 100-Sample Logic

The 100-sample logic detects when 100 samples have been averaged and stored. It also generates the clear signal sent to the clear/data gates. It consists of a set of decade counters which are incremented by a digital crank-position signal with a period of $720^{o}$. Putting the instrument into sample presets the counter to $101_{10}$. When the sample button is released, the counters begin to count down. A clear signal is present until the counters reach $100_{10}$ so clear signals are shifted for one $720^{o}$ cycle. When the counters reach 0, the shift registers are placed in a recirculation mode, and no new data are added in.

## Input/Output Multiplexing

The multiplexing circuits allow multiple traces to be averaged simultaneously. The input multiplexing is accomplished by a four-to-one analog multiplexer. Digital logic forms the control signals for four analog sample-and-hold amplifiers. The control logic for the multiplexing, demultiplexing operation is selected by a front panel switch. For single-channel operation, the input multiplexer allows only one input to be digitized and only one sample-and-hold is used. For two-channel operation, the input multiplexer alternates between two input signals while two sample-and-hold amplifiers alternately

demultiplex the waveforms. The digitized values of the two waveforms are stored in alternate shift register locations and, therefore, only half the 2048 bits are allotted to each curve. The points for each input are now resolved every $0.7^{\circ}$ ($720^{\circ}/1024$).

Similarly, for four-channel operation, every fourth shift register location is used for the same curve. The resolution is now $1.5^{\circ}$ because 512 points are known for each curve in a $720^{\circ}$ engine cycle.

### Timing Logic

The timing logic (fig. 3) initiates the analog-to-digital (A/D) conversion (start convert) pulse. The end of convert line from the A/D converter remains high from the end of the start-convert pulse, until the conversion is completed. The conversion time is typically 7 microseconds. When the conversion is complete, the shift register data are advanced. The shift registers require a two-phase clock. The clock inputs ($\varphi_1$ and $\varphi_2$) must thus be clocked alternately. The timing logic also provides the multiplexing/demultiplexing signals. The multiplexing bits must change levels simultaneously with the clocking of the shift registers. This prevents the smearing of output signals into each other.

## CIRCUIT DESCRIPTION

The complete detailed schematic of the 100-sample average module appears in figure 4. The parts list is shown as table I.

### Curve Averaging and Storage

Figure 4(a) shows the curve-averaging and storage section. AD1 is a 12-bit A/D converter. The internal buffer of AD1 is used to maintain a high input impedance on the input signal lines. The A/D converter is programmed to accommodate bipolar signals, and the output digital-to-analog converter (DAC1) is also programmed to output bipolar values. This 12-bit output DAC is wired to the 12 most significant bits of the shift register outputs. R1 is used to scale the input A/D converter so that 100 full-scale samples drive the DAC to its full-scale output. The shifted DAC position provides a division by 64, while the input scaling (R1) provides an additional division so that the net effect is a division by 100. The clear/data gates (IC5 to IC8) are a series of "OR" gates with one input of each tied to a common line. The other inputs come from the adder outputs. Taking the common line high sets all the shift register inputs high, which

is the zero mode of complementary offset binary. With the clear line low, data passes through unaltered.

SR1 to SR16 are dynamic Mos shift registers. Clocking these shift registers requires more than a level shift due to the fact that the minimum clock times for both +5 to -12, and -12 to +5 are 500 nanoseconds, and the capacitance of each gate is 200 picofarads. For 16 shift registers then a capacitance of 3200 picofarads is present. Power amplification stages were required for clock signals $\varphi_1$ and $\varphi_2$ in order to drive this capacitance. T1 - T4 provide this amplification.

## Multiplexing Circuits

Figure 4(b) shows the input multiplexer, the output multiplexer, and the multiplexing logic. The input multiplexer (M1) is a four-to-one analog multiplexer controlled by digital levels. The output multiplexer consists of a series of analog sample and hold amplifiers (SH1 - SH4) which are controlled by a digital demultiplexer (IC14). IC12 and IC13 are flip flops which form the control signals for the input and output multiplexers. The "NOR" gates (IC10) are controlled by the front panel switch which selects the number of channels to be averaged. IC9 (fig. 4(a)) forms a data strobe pulse which is used to shift the data through the shift registers, and additionally to switch the multiplexing address. This ensures that all switching occurs simultaneously with the clocking of the shift registers and thus prevents the smearing of one signal into another when the instrument is in the multichannel mode.

## 100-Sample Logic

The 100-sample logic is shown in figure 4(b). IC15 to IC17 are decade counters which are preset to 101. The counters then count down until IC11 detects that 0 has been reached. The shift registers are then placed in the recirculate mode, and no new data are added.

## Timing Circuit

The timing logic for this instrument appears as part of figure 4(a). The timing logic is based entirely on the digital crankshaft position. This position is made available as a 10-bit number by a Function Generator Module. These bits are available on the "B" edge connector. The strobe available on B15 is a 1-microsecond pulse which occurs every $0.35^{o}$. The A/D conversion is initiated by this pulse which occurs 2048

times for each 720° engine cycle. The end of convert line (EOC) of AD1 remains at a logical high for the duration of the conversion time (fig. 3). The time for conversion is approximately 7 microseconds. On the failing edge of EOC, IC9 strobes the Mos level shifter (DR1) which advances the shift register data. In the multichannel mode this strobe also clocks IC12 and IC13 (fig. 4(b)), which are the multiplexing latches. This ensures that the multiplexing address changes simultaneously with the presentation of new shift register data (fig. 3).

## Additional Circuitry

Figure 4(c) shows the power supply and front panel wiring used. The 100-sample instrument was built into a module-type case which allows it to be plugged into a power supply rack. This rack supplies the ±33 volt and +11 supply lines as well as the external transistors used to decrease the power dissipated in the regulators.

Table I is a complete list of parts required for the 100-sample module.

Throughout the 100-sample module care must be taken to keep analog and digital commons separate from each other. This is to keep the noise on the TTL supplies from altering the noise-sensitive analog signals. As always, attention should be paid to lay-out and supply lines wherever digital and analog circuitry mix.

## Performance

The maximum speed at which the instrument can be used is dependent on the amount of time required to perform the entire curve-averaging operation. The A/D converter requires a maximum of 8 microseconds to resolve 10 bits. The input multiplexing and the buffer of the A/D converter require approximately 3 microseconds for settling. Approximately 1 microsecond is required to call the information from memory, add it, and store it again. But the memory cycle is performed simultaneously with settling time, so a 9-microsecond operation must be performed 2048 times for a 720° engine cycle (2 revolutions); that is,

$$\frac{2 \text{ revolutions}}{2048 \times 9 \times 10^{-6} \text{ sec}} \times \frac{60 \text{ sec}}{1 \text{ min}} = 6000 \text{ rpm}$$

Thus, the performance is defined to 6000 rpm.

The minimum speed of operation is determined by the update time for the dynamic shift registers. A 1.5-kilohertz clock rate must be maintained to prevent losing the

shift register data; therefore,

$$\frac{1500 \text{ bits}}{\text{sec}} \times \frac{2 \text{ revolutions}}{2048 \text{ bits}} \times \frac{60 \text{ sec}}{\text{min}} = 100 \text{ rpm}$$

The engine speed must be at least 100 rpm to maintain proper operation of the shift registers. Minimum clock rate is one of the problems associated with dynamic shift registers, however, this clock rate does not pose a serious limitation in this instance. Advantages of Dynamic Shift Registers over static shift registers or RAM memories include: cost, package size, and power consumption.

Figure 5 is a photograph of the complete curve averaging module. This instrument has been used on a 1975 Chevrolet V8 engine and on a Continental 6-cylinder aircraft engine.

Figure 6 shows the output of the curve averaging module being used to average a cyclicly varying mass-fraction burn rate curve from the Chevrolet engine. The top set of curves is representative of the input to this instrument. The lower curve is the average of 100 curves such as those on the top. The apparent offset of the two is simply to be able to distinguish the curves from each other. They actually both begin from zero volts, and span the same voltage.

For this single-channel case, the output curve is described by 2048 discrete points, and therefore the horizontal resolution is one part in 2048. The A/D converter digitizes approximately 10 bits of binary, resolving to one part in 1000. The vertical output DAC has a resolution of 12 bits, or one part in 4096. The increased resolution in the output stage is justified by the addition that occurs between the input and output stages. The vertical resolution is then approximately one part in 4096. The output signal is between + and - 10 volts, so the output curve is known to 20 volts/4000 = 5 millivolts.

Figure 7 shows the curve-averaging module being used in the two-channel mode. The upper trace is the average Mass-Fraction Burn Rate and the lower is the average-pressure trace. Both of these traces were taken from the Continental Aircraft engine. The horizontal resolution is now half that in the single channel mode of one part in 1024. Despite this decrease in resolution the curves still appear smooth. The vertical resolution remains the same despite the change in horizontal resolution.

## CONCLUSIONS

A 100-sample instrument has been produced which will generate the average curve, over 100 consecutive cycles, of as many as four independent engine parameters. This calculation is performed in real time, which makes the average curve available immediately after the conclusion of the 100th cycle. The average is compiled point by point

with 204 800 points being accumulated over 100 samples.

Inputs to the 100-sample module can be virtually any engine parameter which can be expressed as an electrical signal between + and - 10 volts, at speeds between 100 and 6000 rpm.

This instrument has been successfully used to average parameters on a 1975 Chevrolet V8 and on a Continental 6-cylinder aircraft engine.

While this instrument was designed for use on an internal combustion engine, with some simple modifications to the timing logic it could be used to generate the average curve of any function that occurs as a time-varying electrical signal.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, June 10, 1977,
505-03.

TABLE I. - COMPONENT LIST

| Designation | Description |
|---|---|
| D1, D2 | 33-V, 5-W Zener |
| D3 | Light Emitting Diode |
| IC1-IC4 | 74LS283 Full 4 Bit Adder with Carry |
| IC5-IC8 | 74LS32 Quad OR Gate |
| IC9 | 74LS221 Dual Monostable Multivibrator |
| IC10 | 74LS02 Quad NOR Gate |
| IC11 | 74LS86 Quad Exclusive OR |
| IC12, IC13, IC15 | 74LS74 Dual Data Flip Flop |
| IC14 | 74LS139 Dual 2 to 4 Demultiplexer |
| IC16, IC17 | 74LS190 Presetable 4 bit Decade Counter |
| C1, C2, C3 | 470 pF |
| C4, C5, C6, C7, C8 | 0.01 $\mu$F |
| C9, C10, C11, C17 | 0.1 $\mu$F |
| C12 | 1 $\mu$F |
| C13 | 50 $\mu$F |
| C14, C15, C16 | 4.7 $\mu$F |
| R1 | 10 K Trimpot |
| R2, R3 | 120 $\Omega$ |
| R4, R5 | 2.2 K |
| R6, R7, R12, R13, R14, R15 | 10 K |
| R8, R9, R10, R11 | 1 K |
| R19 | 470 $\Omega$ |
| R16, R17 | 33 $\Omega$, 2 W |
| R18 | 47 $\Omega$, 1/4 W |
| VR1 | LM340T-15 |
| VR2 | LM320T-15 |
| VR3 | LM320T-12 |
| VR4 | LM340T+5 |
| SH1 - SH4 | AD583 Sample and Hold |
| M1 | AD7502 Analog Multiplexer |
| DR1 | $\mu$a9624 Mos Driver |
| J1-J8 | Isolated BNC Connectors |
| S1 | DPDT Center Off |
| S2 | SPST Momentary, Normally Open |
| T1, T2 | 2N3053 |
| T3, T4 | 2N2222 |
| SR1 - SR16 | MM 5027N Shift Register |
| AD1 | ADC-HY12BC A/D Converter |
| DAC1 | DAC-HY12BC D/A Converter |

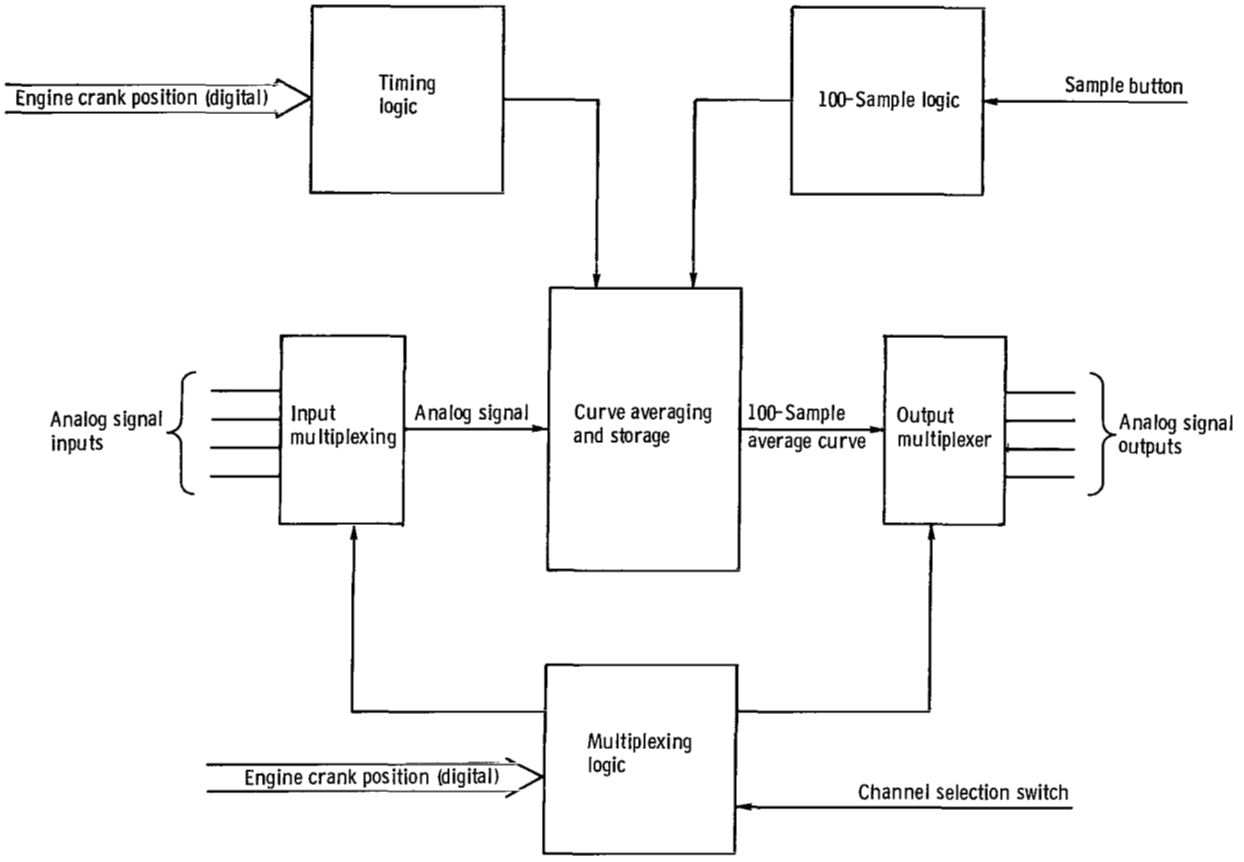



Figure 1. - Curve averaging module block diagram.

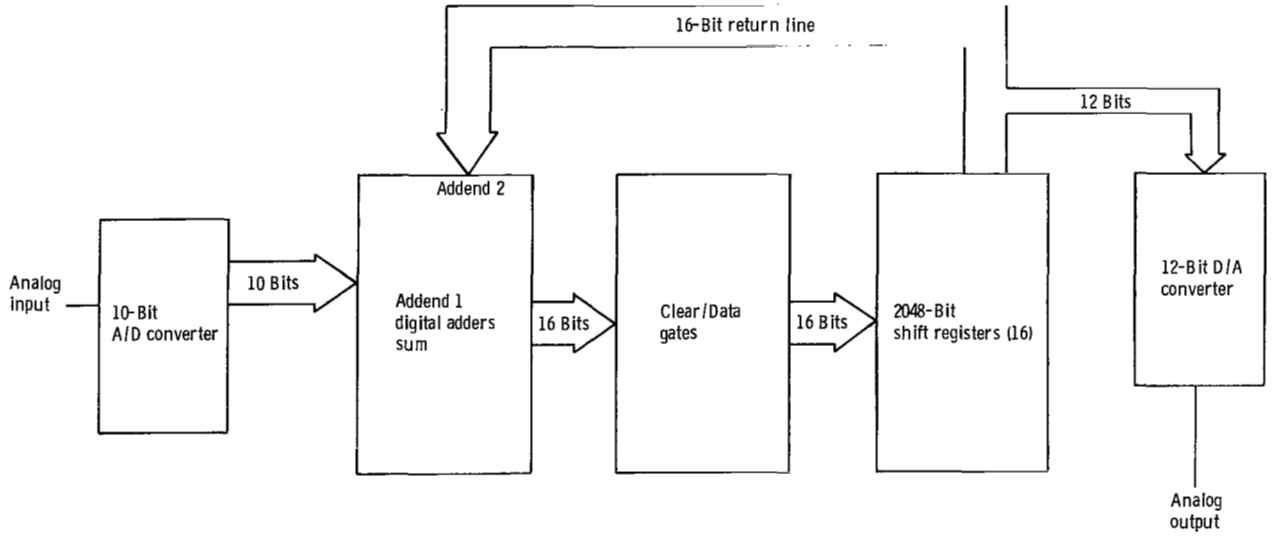



Figure 2. - Averaging and storage block diagram.

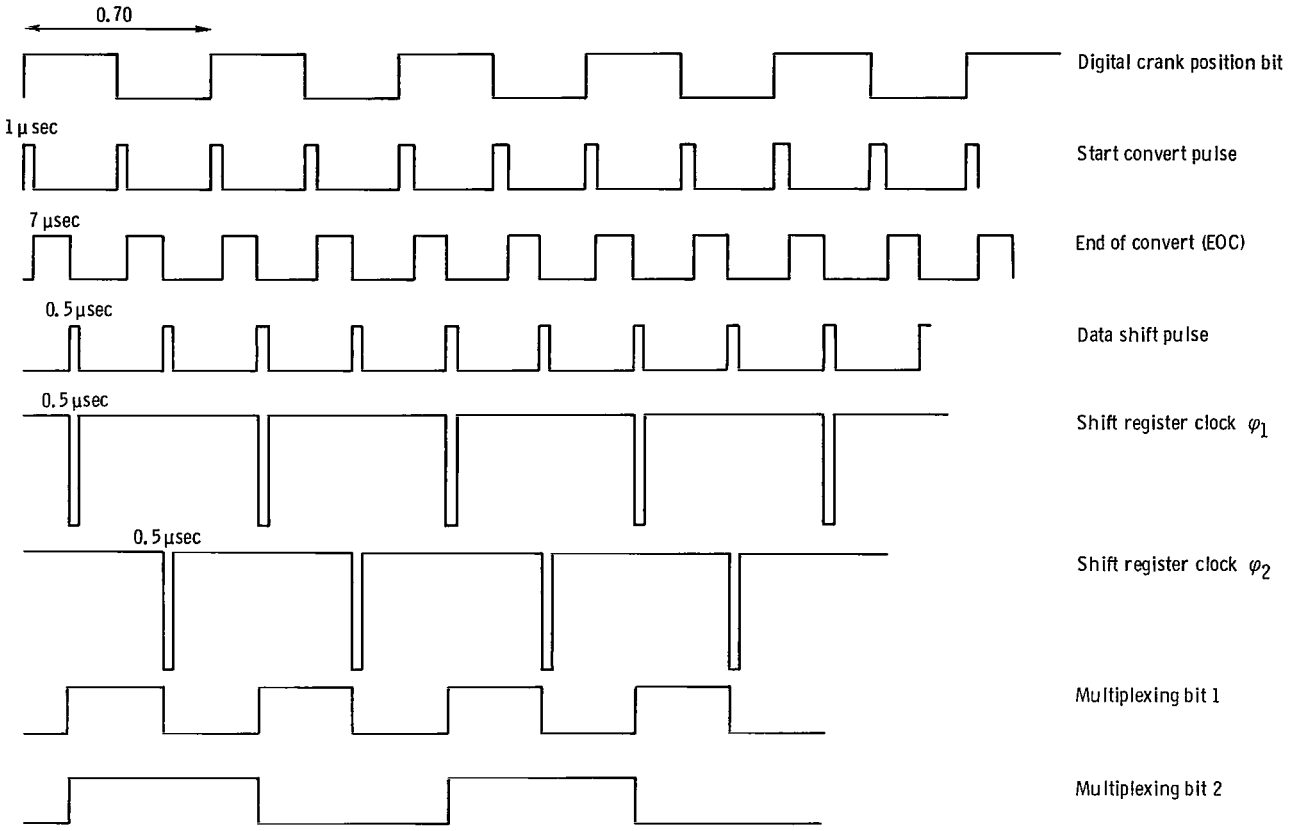
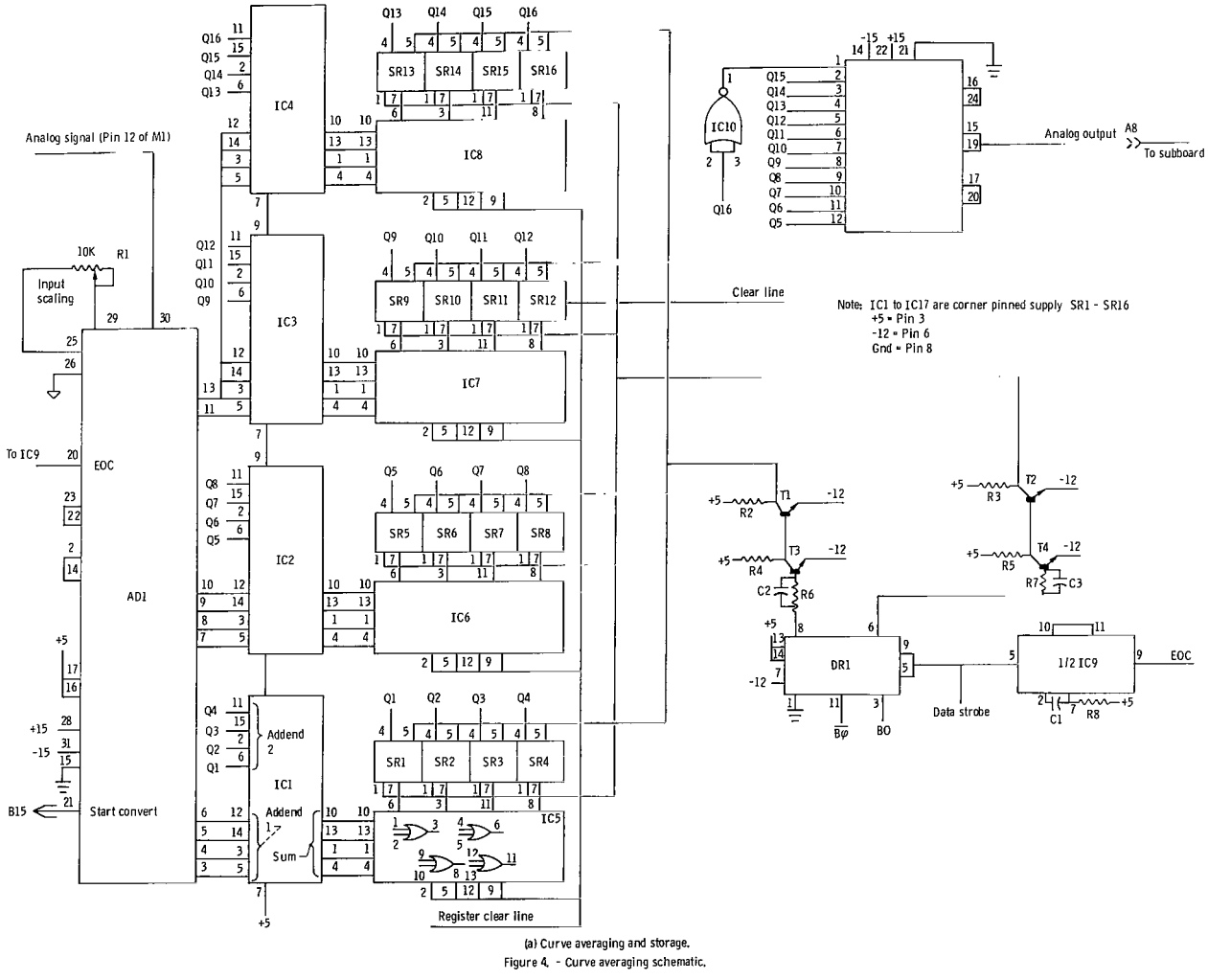
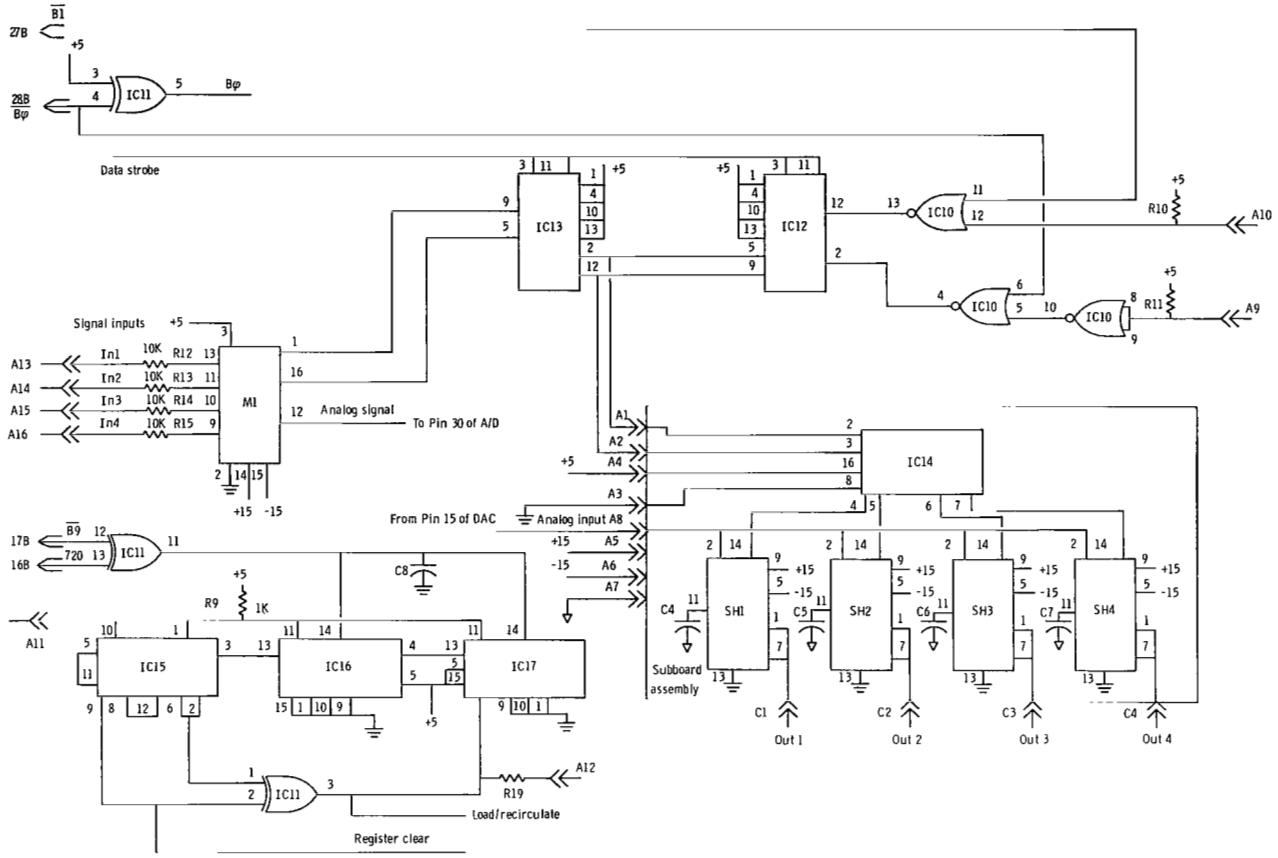



Figure 3. - Timing diagram.



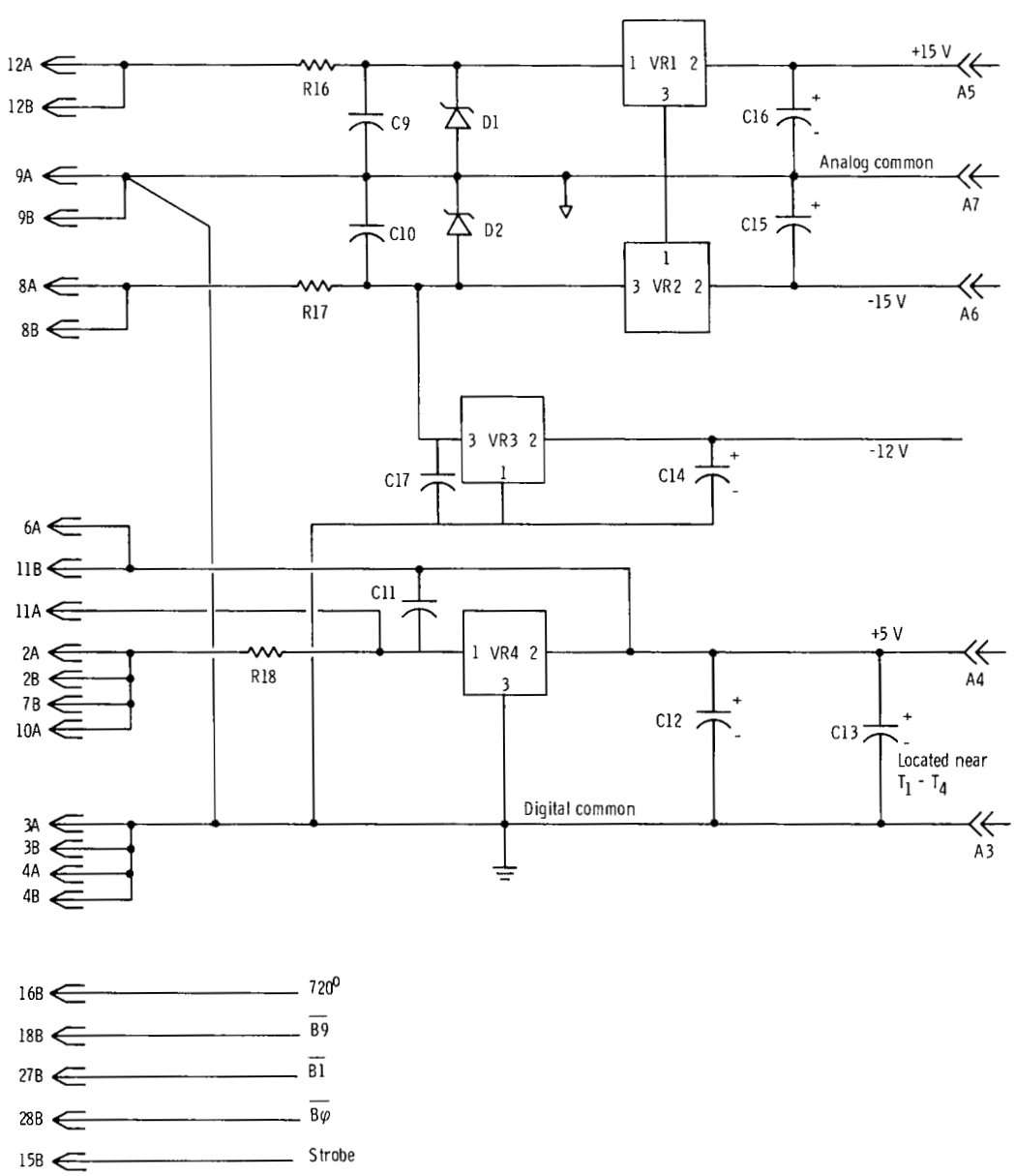

(a) Curve averaging and storage.

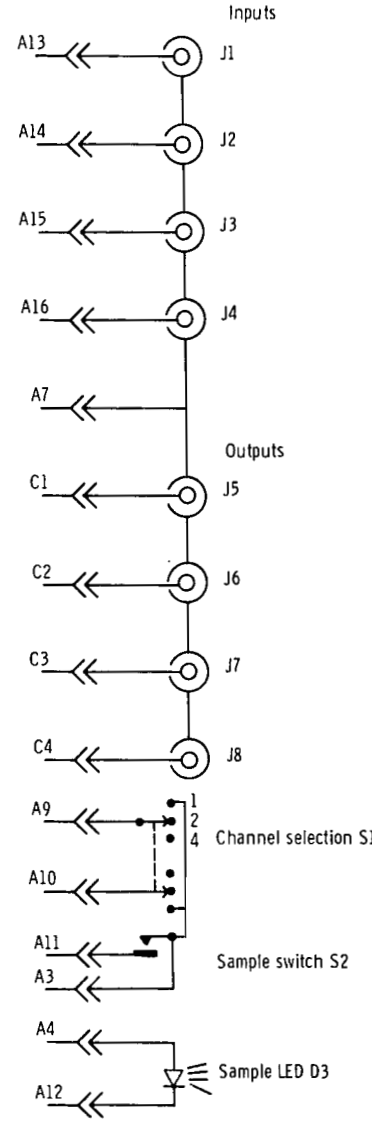
Figure 4. - Curve averaging schematic.




(b) Multiplexer.

Figure 4. - Continued.




(c) Power supply and front panel.

Figure 4. - Concluded.

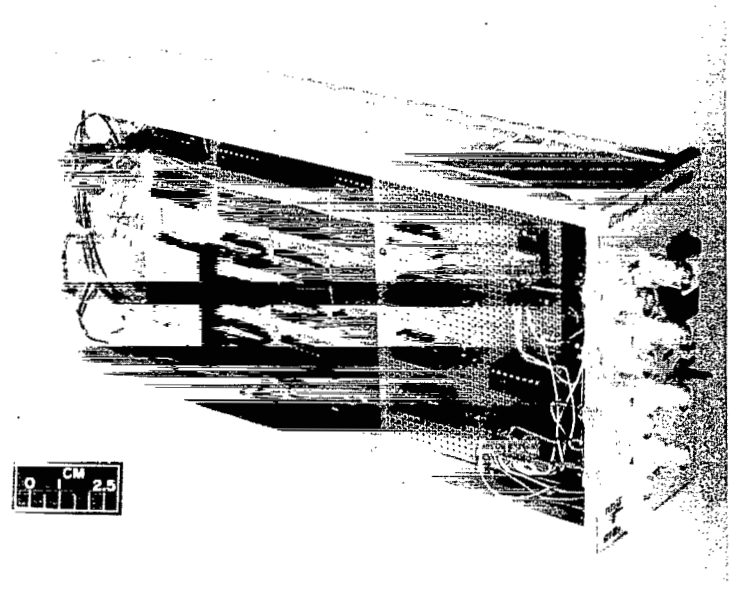



Figure 5. - Curve-averaging module.

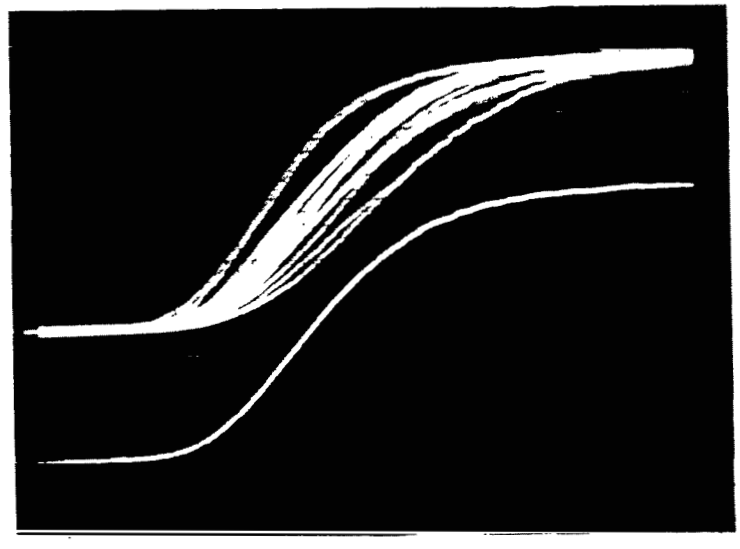



Figure 6. - Typical input-output curves.

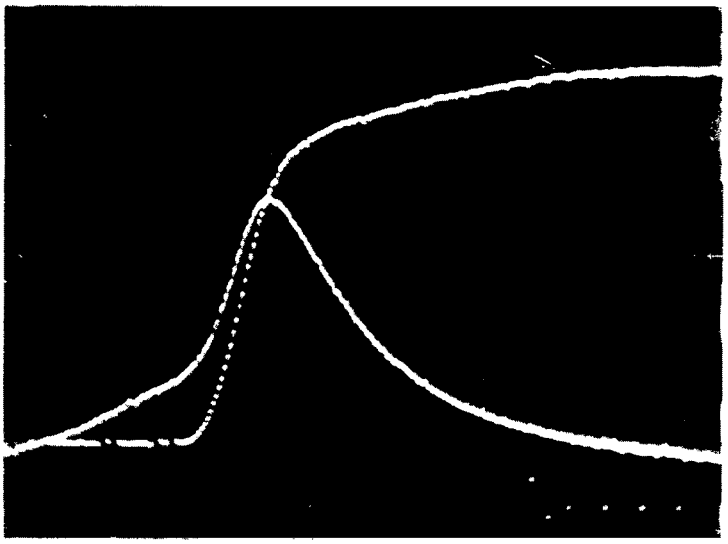



Figure 7. - Two-channel mode.

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16. Abstract

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