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A digital instrumentation system for electric vehicle data acquisition.

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A DIGITAL INSTRUMENTATION SYSTEM FOR ELECTRIC VEHICLE DATA ACQUISITION

by

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Professor in Charge

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ABSTRACT

A microprocessor controlled data acquisition system has been developed for electric vehicle use on a Battronics Minivan at Lehigh University. The system acquires data from numerous sensors, records it on digital cassette tapes, and the same hardware is reconfigured to play back the data to the Lehigh University CDC 6400 computer for data reduction and storage. Sensed quantities include battery voltage, current, and electrolyte temperatures, motor armature and field voltages, controller duty cycle, drive line torque, distance travelled, speed, acceleration, and vehicle inclination. Data taken on various vehicle runs has been successfully processed and used by The Pennsylvania State University for vehicle model synthesis and verification.

I. Introduction

Electric Vehicle Fundamentals

Over the past few years, battery powered Electric Vehicles (EV's) have come under extensive research and development as an alternative to conventional internal combustion engine vehicles. This is due to the significant advantages which electric vehicles can offer [1]: reduction of present dependence on fossil fuels, specifically oil, essential elimination of exhaust pollutants from the vehicle, lower primary energy costs, higher reliability through use of solid state components replacing mechanical ones, reduction of noise generated by the vehicle, reduced engine vibration, and lower overall maintenance costs.

However, the present state of electric vehicle technology does not allow the EV to compete favorably with the internal combustion engine vehicle in terms of speed, range, rate of refuelling and overall vehicle flexibility [2]. These limitations restrict the type of service the electric vehicle can effectively provide. Morris [2] and others have studied the possible classes of service and determined that the "programmed vehicle", i.e., the vehicle making the same type of relatively short journey each day, offers the most promise with present EV technology. The electric vehicle is not new to this type of operation, for over 35,000 electric vans have been used for milk delivery in England for many years [2] and the U.S. Postal service has had electric postal delivery trucks in service for over three years with cost effective results [4] and good driver acceptance [5].

Since the van configuration offers a great deal of promise with available EV technology, several firms researched and produced electric vans, among them Lucas [6], [7] and Copper Development [8] of England, Volkswagen and Daimler-Benz [9] of Germany, Fiat [10] of Italy and Battronics [3] of the United States. While these electric vans perform satisfactorily, the limitations noted previously become apparent when the electric vans' performance is compared with conventionally powered vehicles. Present EV technology must be examined to improve vehicle performance limitations and user acceptance.

Vehicle Limitations

The electric vehicles now in use have five interrelated areas which limit their overall performance:

1) Vehicle range is restricted. The vans discussed in [3], [6]-[10] all have a range under 80 miles when loaded, restricting them to use on in-city or short suburban delivery routes. This is directly related to battery energy storage capacity which, if increased, extends vehicle range. 2) The "refuelling time", i.e. time needed to recharge the vehicle batteries, is long (typically 6-16 hours for the lead-acid batteries presently used in most electric vehicles) compared with the time to refuel a gasoline powered vehicle. This refuelling restriction coupled with the range restriction means vehicles must stand idle for long periods during recharging, or extra sets of batteries must be purchased to have fully charged batteries available whenever and wherever they are needed. This in turn requires garage facilities at several places, as battery pack weight necessitates use of a fork lift or special jack for removal and replacement. Due to high battery cost, this is not usually feasible unless a large fleet operation is maintained. 3) Present lead-acid batteries have fairly short cycle lives. According to battery manufacturers, available batteries for propulsion systems yield between 250 and 800

charge-discharge cycles before the end of their useful life [11]. Using the higher figure and considering an 80 mile range, this means that under ideal conditions batteries must be replaced at 64,000 mile intervals. More typically, an electric van travels 40 miles between recharges and lead-acid batteries realistically have 400 charge-discharge cycle lives, yielding only 16,000 miles per battery set. The expense of replacing batteries can be compared with the cost of rebuilding an internal combustion engine, since the electric propulsion system components rarely require major maintenance [4]. Internal combustion engines usually require major overhaul at intervals between 50,000 and 100,000 miles and this typically costs $1000, but battery packs cost $2000-$4000 and must be replaced more frequently as previously indicated. Battery improvements are needed to increase cycle life, thereby making EV's more economically attractive. 4) Available electric vans are quite heavy. The vehicles described in [3], [6]-[10] weigh between 4000 and 7000 pounds. A large portion of this weight is due to the lead-acid battery pack, which is typically 2500 pounds and leads to slower acceleration and shorter vehicle range. As new materials and technologies are incorporated in vehicle construction, overall weight will be reduced and performance improved. 5) Vehicle cost is high. Due to limited production of EV's and their components, currently available electric vans cost from $6000 for small passenger vans [12] to $15,000 for larger delivery vans [13]. These costs could be reduced significantly by mass production, which will occur thru larger demand by vehicle users. This will most likely be triggered by better performance and improved range resulting from further electric vehicle research and development.

Need for Data Acquisition and Vehicle Simulation

EV improvements can be accomplished in many interrelated ways, three of which are advanced technology subsystems, vehicle simulation,and data acquisition on present vehicles. Advanced technology improves the efficiency of each vehicle component, e.g. battery improvements could immediately improve vehicle performance in terms of range, speed, and battery cycle life. Other components, such as motor, controller, charger, and auxiliary systems also offer possible improvement. However, development of advanced subsystems requires considerable time and capital before production, thus it is desirable to know what improvements can be expected from a specific subsystem before developing it.

Estimates of performance improvements can be made using computer vehicle simulation models. These models, once synthesized and verified, are used to calculate performance gains resulting from new components without actually constructing and testing them. This type of simulation can result in great savings, through development of only the most promising new components, and in reduced road testing [14]. However, synthesis and verification of a vehicle model requires a data base from an existing vehicle in order to show that model predictions follow test results under varying vehicle operating conditions.

Collection of data from an existing electric vehicle requires development of a data acquisition system. The work here, supported by a contract from the Pennsylvania Science and Engineering Foundation (PSEF) [15] to Lehigh University, describes the development of a data acquisition system and data collecting method used on a Battronics Minivan. This data was used as an aid in synthesis and verification of a vehicle simulation model being developed by The Pennsylvania State University, under subcontract to Lehigh University.

II. EV Data Acquisition System

Design Constraints and System Selection

The data acquisition system for the Battronics electric vehicle was chosen subject to physical, electrical and budgetary constraints. For example, all the vehicle borne instrumentation must be extremely rugged for reliable service, and since an electric vehicle is an electrically noisy environment, suppression of ever present large voltage spikes and transient signals as well as proper signal conditioning of the many simultaneous inputs is essential.

A microprocessor based digital data acquisition system was selected, since it is relatively inexpensive (less than $4000) and offers other advantages compared to an analog recording or telemetry system. The analog recording system used by Menga [17] involves an expensive multi-channel analog tape recorder with subsequent data digitization for computer reduction. The telemetry system used by NASA [13] is also relatively expensive and must be operated near a base location if good communications are to be achieved. The microprocessor controlled digital data system selected here can service many data channels quickly, store the data in memory, and then record it on an inexpensive digital cassette recorder. Later, this data is played back to a central data processing computer using the same hardware system with different software. This scheme avoids hardware duplication, allows software changes in data acquisition and playback methods, consumes little power compared with analog recording systems, and if desired allows simple expansion of the number of data input channels. The system block diagram, cf. Fig. 1, illustrates the microprocessor's central role in both data collection and output processes.

System Operating Modes - Data Acquisition and Recording

The microprocessor shown in Fig. 1 is the system controller which determines the timing of data acquisition and recording, as illustrated in greater detail in Fig. 2. Signals from various sensors installed on the vehicle are continuously processed and conditioned to be acceptable to the input multiplexer and analog to digital converter (ADC). When a measurement is desired, as determined by the microprocessor software, the microprocessor selects the proper input channel using the input multiplexer and signals the ADC to begin conversion. Upon completion, the microprocessor collects the digitized data and stores it in memory. After all desired data for a given measurement set has been taken, the microprocessor transfers them and other pertinent data items (e.g. data set, time, checksum) to the tape unit through appropriate communications hardware. The tape unit records the measurement set on a Philips digital cassette. This process is continued until all the desired measurement sets have been recorded for a given vehicle data run.

Data Playback and Processing

The data stored on the cassette is recovered using the equipment of Fig. 3. The microprocessor begins the operation by starting the tape unit and examining the data for a start word. Once this is found, the microprocessor transfers an entire measurement set from the tape unit through the communications interface into memory. The tape unit is stopped after all data words in the set have been transferred and the microprocessor checks the data (parity, checksum, start and stop words) to insure that valid data has been received. After verification, the microprocessor transfers each data word using a second communications link to a computer terminal and onto a phone line link to a central computing facility. After transmission of all data words, the microprocessor starts the tape recorder again and repeats the entire procedure until all desired data has been transferred and stored in the main computer. This data is then reduced, printed out and stored on magnetic tape for future studies and model verification by The Pennsylvania State University personnel.

III. Digital Hardware and Power Supplies

Design Concepts

The digital hardware, cf. Figs. 2, 3, consisting of the microprocessor system, cassette tape unit, analog to digital converter, input multiplexer, and associated interfaces, forms the heart of the data logging system. These components were selected with overall system automation, component modularity and availability, and total system expense in mind. Based on these criteria, the data logging system was constructed using three plug-in circuit cards: microprocessor system, analog input and communications. These cards are installed in a rack mounted chassis along with part of the associated signal conditioning electronics, cf. Fig. 4.

Microprocessor System

The KIM-1 microprocessor system, manufactured by MOS Technology, Norristown, Pa. [18], cf. Fig. 5, consists of an 8 bit microprocessor (6502 MPU) with a 16 line address bus and an 8 line data bus connected to two interface devices, the 6530-002 and 6530-003. The 6530-002 and associated components interface the system to various peripheral units: a teletype (TTY), and audio tape unit for program storage and a small keyboard and display. The 6530-003 has 15 bidirectional input/output lines under software control, thru which the microprocessor controls external devices by toggling the states of these lines. Finally, 1024 (1K) 8 bit bytes of random access memory (RAM) are used for program and data storage. Hardware details and complete equipment schematics are provided in [18], [19].

Connections to the unit are made through two 44 pin edge connectors: the application connector, which provides routing to software development and storage devices and to the 15 bidirectional input/output lines used to interface microprocessor and communications hardware, and the expansion connector, which provides access to unused memory locations through the address and data buses, cf. Fig. 5. The expansion connector is used to interface the analog input system to the microprocessor.

The 15 bidirectional input/output lines control various devices in data acquisition and data playback modes. These lines are split into the A data register, consisting of lines 0 through 7, and the B data register, consisting of lines 0 through 5 and 7 (line 6 is used by the microprocessor and is not externally available). Line assignments in both operating modes are shown in Fig. 6. Register A is used to output or input 8 bits of data from the digital tape unit, while register B is used for communication and tape unit control, cf. Section III. Difficulties encountered with register B, when line 3 failed due to excessive loading by the tape recorder start/stop lines, were eliminated by buffering the signal, cf. Fig. A1(b)*, and moving it to line 4 on the B data register.

A Perkin-Elmer Model 1100 video computer terminal, used to develop the microprocessor software, allowed

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*Fig. A1(b) indicates Fig. 1(b) of App. A, etc.

easy entry, display and control for quick debugging. Required interfacing circuitry for the terminal (RS-232 interface standard) to the KIM-1 teletype outputs (TTL compatible) uses MC1488 quad TTL to RS-232 line drivers and MC1489 quad RS-232 to TTL line receivers, cf. Fig. A1(a).

Programs developed were stored on tapes for later use with an inexpensive audio cassette recorder, using the interconnections shown in Fig. A2 and standard KIM-1 procedures for recording and reading data on tape [18]. This technique eliminates the need for a programmable read only memory (PROM).

Tape Recording Unit

A Philips Compact Digital Cassette Recorder, whose specifications are given in Fig. 7, was chosen for storing data. The associated control box of the rack mounted recorder unit, cf. Fig. 8, has status lights for beginning or end of tape, A/B side of cassette, cassette in position, unit ready to proceed and cassette write enable plug. Switches are provided for manual control of fast or slow tape speed, reverse or forward direction, lock cassette in place, enable cassette read, and enable cassette write. Control box details are shown in Fig. A3. Note the forward control line is also under microprocessor control through the tape unit connector (pin 4) and buffer, cf. Fig. A1(b).

Communications Interfacing

Microprocessor to Tape Unit

A conversion must be made from the microprocessor's parallel data format to a serial format before the data stored in its memory can be transferred to the digital tape unit. This is accomplished using a Universal Asynchronous Receiver/Transmitter (UART), the Western Digital TR1863B [20], chosen due to its single power supply requirement (+5 Vdc), cf. Fig. A4.

The UART's transmitter portion, used during data acquisition, converts the 8 parallel data bits provided by the microprocessor at data register A, cf. Fig. 6, to serial data with a start bit, two stop bits and a parity bit, cf. Fig. 9. The data transfer rate was experimentally chosen at 1200 bits per second for maximum recording reliability consistent with acceptable data measurement intervals. To transmit each character, the microprocessor pauses until the 'transmitter register empty' line, cf. Figs. 6 and A4, has gone from the low (OV) to high (+5V) state, transfers a valid data word to data register A, loads the UART data word register by momentarily bringing the 'transmitter register load' line to a high state, and again pauses until the 'transmitter register empty' line indicates that character transmission is complete. This process is repeated until all data words are transferred to the tape unit.

The receiver portion of the UART, pins 4 through 20, cf. Fig. A4, is used during data playback. Serial data in the format shown in Fig. 9 is transferred from the tape unit to pin 20 of the UART. When a complete character has been received and the UART has verified that a proper word has been received by checking parity and stop bits, the converted parallel data is placed in a holding register and the 'character received' line, cf. Figs. 6 and A4, is set to a low value. The microprocessor then transfers the data values from the receiver holding register through data port A and stores the data word in memory. The UART is reset by a low level signal applied to the 'data received reset' line by the microprocessor through data register B, and the process continues for each word sent to the UART.

If bad parity or stop bits are detected, a visual indication is provided by the parity and framing error light, cf. Fig. A5. The SN7402 NOR gate is configured as a latch to hold the light emitting diode on when a bad bit is detected. The SN7400 NAND gate is used as an inverter for light reset once the error condition has been acknowledged by the operator. Errors of this type are rare, since the cassette tapes are certified by the manufacturer to be free of "bit drops", i.e., areas of tape which do not permit proper recording.

Since the UART does not have an internal clock to provide bit rate information, an external clock at a frequency 16 times that of the bit transfer rate is required. Data transfer rate is 1200 bits per second which corresponds to a clock rate of 19.2 kHz, generated by the circuit shown in Fig. A6. The voltage controlled oscillator (VCO) portion of a Western Electric phase locked loop, the 502EP (R3221), is used to provide an extremely stable 76.8 kHz square wave signal [21], [22], which is divided by 4 with a SN7493 binary counter to obtain the 19.2 kHz square wave (Clock A) for the tape-microprocessor communication UART. Further division by 4 generates a 4.8 kHz square wave (Clock B), which is used in the microprocessor-main computer interface.

Microprocessor to Main Computer

Data stored on cassette tape is transferred to the Control Data Corporation (CDC) 6400 main computer facility at Lehigh University via a 300 bit per second phone line link. Since the phone line is a serial data channel, the microprocessor's parallel data format is again converted using a Western Digital TR1863B UART. Connections to the transmitter portion of the UART (the receiver is not used) are shown in Fig. A7. The CDC 6400 computer requires even parity, generation of two stop bits, standard ASCII characters and hence 7 bit UART operation, which in turn necessitates breaking the 8 bit data word into two hexadecimal characters before transmission, cf. Section V.

Microprocessor operation of the UART for character transmission is identical in form to the tape communication UART, cf. Section III. The 16 times clock frequency, 4.8 kHz, is generated by the circuit previously described, cf. Fig. A6. Serial output data is shifted from the UART, pin 25, through a TTL to RS-232 level converting integrated circuit (MC1488), cf. Fig. A1(a), directly into the modulator/demodulator (MODEM) portion of the Perkin-Elmer computer terminal for transmission to the CDC 6400 main computer.

Analog Input System

Interfacing the microprocessor to several inputs requires an input multiplexer, analog to digital converter and appropriate control circuitry. The Burr-Brown MP-21 analog input system [23], cf. Fig. 10, was chosen to fulfil these requirements on the basis of modularity, compatability with the KIM-1 microprocessor system, and low cost.

The MP-21 system inputs enter a 16 to 1 line multiplexer controlled by the microprocessor's address bus, lines A0 thru A15. Each input channel corresponds to a location in memory of the base address, $1C00_{16}$, plus the input channel number in hexadecimal, e.g. IN-6 corresponds to $1C06_{16}$, IN-10 corresponds to $1C0A_{16}$, etc. The analog input signal selected enters an instrumentation amplifier, which is set so that the analog to digital converter (ADC) spans an input range of -5V to +5V. After appropriate delay for amplifier setting and analog to digital conversion, the 8 bits of data are placed into the tri-state output latch.

In operation, signal conversion begins as the microprocessor places the MP-21 address corresponding to the desired input channel (IN-0 thru IN-15) on to the address bus (data is ignored at this time). The microprocessor delays 40 μs (35 μs settling time and 5 μs ADC time), then places the same address on the address bus. The MP-21 enables data bus drivers and transfers the digitized value over the data bus for storage in the microprocessor's memory.

Detailed connections to the MP-21 module, which is mounted on the analog interface board, cf. Fig. 4, are shown in Fig. A8.

Power Supplies

Regulated dc voltages and currents at +5V at 2.0A, +15V at 0.7A, +24V at 0.6A, +28V at 0.1A, -5V at 1.0A, and -15V at 0.7A are required to operate the data logging apparatus, signal conditioning equipment, and sensors. The scheme adopted which avoids power supply duplication and provides operation both on the vehicle (data acquisition) and in the laboratory (system testing and data playback) is shown in Fig. 11. A 115 Vac operated power supply producing the voltages and currents listed above is operated from the 115 Vac laboratory mains; during vehicle operation the 115 Vac is derived from an EICO Model 1080 Inverter, which provides 60 Hz (nominal) square waves. This inverter, also used to operate other 115 Vac instrumentation, e.g. oscilloscopes, is powered by a 90Ah, 12V storage battery, which requires recharging after continuous data logging of approximately 7 hours. Two other small battery packs are used for sensors, cf. Section IV.

A detailed schematic of the 115 Vac input power supply system is shown in Fig. A9. The +24 Vdc and +28 Vdc supplies are commerically available units, whereas the ±5V and ±15V power supplies were specially designed to operate with either sine or square wave inputs. Since the chokes limit the filter capacitor's charge to the average sine wave value, their voltage rating can be low. The solid state regulators for the ±15V supplies are located on the power supply chassis, but the ±5V regulators are in the main equipment rack chassis. Airflow from a small fan in the power supply cools it as well as the main equipment rack.

IV. Vehicle Specifications, Sensors, and Analog Signal Conditioning

Battronics Minivan Specifications

A 1974 Battronics Minivan EV, presently leased to Lehigh University by the Pennsylvania Power and Light Co. (PP&L), was modified from its standard driver, passenger, and cargo format to carry a driver, five passengers and instrumentation for data acquisition while providing a student bus service from campus to a local dormitory. Entrance to the van is through sliding doors on either side, cf. Fig. 12, and a large rear door, cf. Fig. 13. Vehicle propulsion is provided by a 42 hp series wound, direct current (dc) motor, a silicon control rectifier (SCR) chopper type controller with bypass and field weakening contactors, cf. Fig. 14, and two series connected battery modules which yield 112V, cf. Fig. 15. A simplified schematic of this portion of the system is shown in Fig. 16. The main batteries are recharged through an on-board charger which operates from either 115 or 230 Vac; the auxiliary equipment battery is recharged with a dc-to-dc converter.

Mechanically, the vehicle, weighing approximately 6000 pounds, has a solid axle front and rear suspension, with a conventional front engine/rear drive format. Although a transfer case with two speeds is installed in the van, only the low gear ratio (1.96:1) is used over the routes selected. Complete vehicle details are listed in App. B.

Sensor Design Constraints and Signal Conditioning

The following sensor and signal conditioning constraints are due to the Minivan specifications and data acquisition system design:

1. Since measurements are made on the 112V system, which is isolated from the vehicle chassis, the sensors must also be insulated from the vehicle chassis because available differential amplifiers have limited common mode ranges. This in turn implies that the instrumentation system ground must be insulated from the vehicle chassis.
2. Low power consumption by sensors and signal conditioning circuits.
3. Properly shielded cables and connectors must be used to avoid coupling of controller transients onto the signal lines.
4. Where possible measurements must be made differentially to avoid common mode signal difficulties.
5. The sensor signal range must be adjusted to match the analog input system's range, i.e. -5V to +5V, for greatest signal resolution. This implies that gain or attenuating stages are required.
6. Filtering of high frequency components is essential so that the signal's "running average" is recorded.

Points 5 and 6 embody the required signal conditioning. While the reasons for amplifying low or attenuating high level signals is clear, the need for signal filtering is not obvious. For example, during operation, a silicon control rectifier (Main SCR or "5 REC", cf. Fig. 16) and associated circuitry adjusts the average motor current by periodically chopping it to produce a varying

$$\text{duty cycle} = \frac{t_{on}}{t_{on} + t_{off}} = \frac{t_{on}}{T} \quad ,$$

where t_{on} = amount of time current is allowed to flow

t_{off} = amount of time current does not flow

T = period of waveform = $\frac{1}{f}$

f = waveform frequency

which in turn controls the motor speed. The controller is designed so that <u>both</u> duty cycle and waveform frequency vary with throttle opening for smooth acceleration and best performance. The chopping frequency vs. duty cycle graph, cf. Fig. 17, shows that the lowest frequency component generated during controller operation is approximately 65 Hz. Since the data logging system samples the sensor signals only once per second, a signal average must be created to properly represent motor-controller system performance. It is shown in App. C that a one stage low pass filter with a time constant τ = 0.2 seconds provides a reasonable running average while retaining good transient performance.

Similar filters are used on other parameters, e.g. vehicle inclination, acceleration, etc., for recording average parameter behavior rather than momentary fluctuations.

Sensed Quantities and Sensors

A collection of measured variables, sensors and pertinent figures is found in Table 1. These sensed quantities are divided into three groups: electrical (battery-motor-controller parameters), mechanical (drive line torque and vehicle motion parameters), and other (time interval between measurements and battery electrolyte temperatures). Details of sensor functions and circuits involved follow.

Electrical Variables

There are seven different measured electrical quantities: battery voltage and current, armature and field voltage, controller duty cycle, controller bypass, and field weakening, cf. Table I. Proper conditioning of the signals involved in data logging is achieved through individually designed and constructed circuits.

The battery voltage conditioning circuit, cf. Fig. A10, consists of operational amplifier OA-1 and an input resistive divider which attenuates and level shifts the battery voltage so that zero and 150V corresponds to an output voltage of ∓5V respectively. Battery voltage fluctuations occurring when the controller interrupts the current are smoothed by the single stage low pass filter consisting of OA-2, 2 μF capacitor, and the 50K and 100K resistors, cf. App. C.

Battery current sensing apparatus, cf. Fig. A11, consists of a 200 mV at 600A current shunt (installed in the negative lead to the 112V battery pack, cf. Fig. 16), an input stage (LM725) with a gain of 25, and a unity gain network with differential resistor ladder and OA-1. The unity gain network is included because it was originally thought that the current shunt was installed in the positive lead of the 112V battery system. Since the battery pack negative side is also instrumentation ground, a current shunt installed in the positive lead will cause an excessive common mode voltage to appear at the first stage operational amplifier's input. Thus, the first stage is powered from a separate battery to isolate it from the rest of the system, and its output is delivered to the resistive divider network, which reduces the common mode voltage to a reasonable value for the second stage (OA-1) to reject. Amplifier OA-1 also compensates for the signal attenuation by the divider, and OA-2 provides the required signal conditioning.

The circuit sensing the armature and field voltages is shown in Fig. A12. The armature voltage is sensed at the motor armature terminals through an input resistor/capacitor network which filters high voltage spikes, caused by motor inductance, and reduces the common mode voltage to a level which OA-1 can handle. Stage OA-1 level shifts and reduces the ±100V input to ∓10V at its output. Low pass filtering and further attenuation of the signal by a factor of 2, to produce an output voltage range of ±5V, occurs through OA-2.

The field voltage is sensed at the motor field terminals, using essentially the same circuit as the armature voltage sensing circuitry, cf. Fig. A12, except that the second operational amplifier stage provides a gain of 2, which shifts the field voltage range $V_{in} = \pm 25V$ to $V_{out} = \pm 5V$.

The duty cycle is measured using the circuit shown in Fig. A13. The main SCR ("5 REC", cf. Fig. 16) trigger signal, which is turned on and off as the battery current is pulsed, is applied to the input of this unit consisting of a comparator (LM301 operational amplifier), OA-1, OA-2, the voltage references and their associated resistors and diodes. The output of this precision comparator (pin #6 of LM301) is high (+5V)/low (-5V) if the input signal is greater/less than the threshold (set at pin 2 of LM301). The average value (i.e., the dc level) of this waveform represents the duty cycle of the input waveform and is obtained using two identical cascaded low pass filter stages, cf. App. C, having overall time constant 0.2 seconds. The input threshold level, approximately 0.25V, is set to yield representative duty cycles based on comparison of trigger and battery current waveforms.

In addition to duty cycle variation, the controller has both bypass and field weakening features for higher vehicle speed operation. In the bypass mode the motor is connected directly to the battery through the 1A contactor, cf. Fig. 16. The output voltage of the bypass monitor circuit, cf. Fig. A14, is at a low level (0V) during controller bypass (microswitch closed) and high level (+5V) during normal operation. If higher vehicle speeds are desired during the bypass mode, field weakening is introduced using the field weakening (FW) contactor, cf. Fig. 16, by placing a 0.008Ω resistance in shunt with the motor field which decreases its current and increases motor speed. The field weakening monitor circuit is identical to the bypass monitor circuit and is in the high state (+5V) only during the field weakening mode.

Mechanical Quantities

To properly characterize the motion of the van and its driveline, the propeller shaft torque, distance travelled, vehicle speed, acceleration and inclination are sensed using ancilliary transducer units, cf. Table 1.

Propeller shaft torque is measured with a Lebow model 1228H-10K strain gauge shaft torque sensor consisting of a strain gauge bridge which produces an output linearly related to the torque transmitted through the propeller shaft. The low level bridge output signal (77.75 mV at 10,000 in-lb) is applied to a low drift, low level amplifier, cf. Fig. A15. The amplifier is designed to account for the 350.7Ω (nominal) bridge impedance at signal nodes (B and D) and has first stage gain 64.57 to provide full scale output range ±10,000 in-lb over the ±5V output range. The first stage output voltage is conditioned by a single stage low pass filter with time constant 0.2 seconds and sent to the analog input system.

The distance travelled and vehicle speed are sensed with a Nucleus Corporation Model NC-7 fifth wheel and associated apparatus, cf. Fig. 18, whose speed output from a precision tachometer generator is 88.6 mV per mile per hour of vehicle speed. This signal appears at IN-1 of the analog input system after conditioning in the low pass filter, cf. Fig. A16. A Nucleus Model RSA retentive speedometer is installed to assist the driver in observing vehicle speed.

Distance information is available in visual and digital forms at the Nucleus model PTA pulse totalizer outputs, cf. Fig. 18. Digital pulses (one pulse per foot travelled) produce an analog output signal proportional to distance travelled from an 8 bit up counter consisting of two 74193 synchronous 4 bit counters and a Hybrid Systems digital to analog converter, cf. Fig. A17. The counter's sequence 0,1,2,...,254,255,0,1,2,... combined with vehicle top speed of about 70 ft/s is used to determine how far the vehicle has gone in the past several seconds: each time the counter system resets to zero, 256 ft are added to the distance travelled using system software.

Vehicle acceleration is measured using a Kistler Instrument Model 303T102 servo accelerometer. The sensor, mounted in the foreward center of the van in a one inch thick aluminum plate and steel frame bolted to the vehicle floor, has its sensitive axis pointed to the front of the van and level with the horizon. Foreward acceleration is calculated, cf. Section V, by eliminating the component due to gravity using terrain data from the gyroscope (discussed below).

The accelerometer unit requires regulated 28 Vdc, 25.69K accelerometer range and 120K accelerometer gain resistors to yield an output range of ±1g (g = acceleration due to gravity), cf. Fig. A18. The 25.69K resistor in conjunction with an 8 μF capacitor and 500Ω resistor form a lead-lag low pass signal conditioning filter while maintaining reasonable servo stability.

Inclination is measured using an Electronic Specialty Co. Model N3200 vertical gyroscope which has an internal motor and blower for gyro erection, instead of requiring an external compressed air source, and is powered by two 12V motorcycle batteries which supply the heavy initial current (3A) on gyro start up. Inclination information is derived from a 2K potentiometer having a ±5V range over its ±55 degree angular span with the connections arranged for positive/negative output corresponding to uphill/downhill respectively. This output, which has a maximum error ±1.5 degrees, appears at IN-4 of the analog input system, cf. Fig. A19.

Other Variables

Important measured quantities which do not fall into mechanical or electrical categories directly are the time interval between measurement sets and battery electrolyte temperatures. The time between measurement sets is generated by the crystal controlled (1 MHz) microprocessor reference. The microprocessor requires approximately 160 milliseconds to acquire, store and transfer data to the cassette tape. It then enters a timing loop, whose length was adjusted by trial and error, and exits this loop one second after initial start of data acquisition thereby generating measurement sets spaced at one second intervals.

Battery efficiency and cycle life both depend upon temperature [24]. Thus, two battery electrolyte temperatures are monitored to determine the extremes which occur during operation. Since the initial thermocouple system was unreliable, due to the low level signal (2 mV) and high common mode voltages, an Analog Devices AD590L two terminal temperature transducer was substituted. This device produces an output current directly proportional to absolute temperature, with 1μA/°K output and overall accuracy of ±1°K. The circuit shown in Fig. A20 provides a constant voltage reference source for these transducers and the operational amplifiers, which level shift the output voltage generated by the AD590L and 10K load resistor over the temperature range -5 to 55°C. The 1μF capacitor in conjunction with the 10K resistor act as a low pass filter to reduce system noise.

Physical construction of the battery temperature probe, cf. Fig. 19, consists of a 4 inch length of 0.25 inch diameter glass tubing cut and sealed at one end. After the temperature sensor is wired and placed in the tube, mineral oil is added to the halfway point, and the tube is placed in a battery cap and held in place with rubber O-rings. The assembly is then placed in the battery, the wires taped to the top of the glass tube, and the tube pressed down until it touches the battery plate protection sheet.

V. Computer Programming

Computers and Tasks Involved

The large quantity of data generated during acquisition is processed, stored, and printed out by computers, which readily provide flexibility and necessary capabilities. As previously indicated, two types of computers are involved: a KIM-1 microprocessor, which forms the heart of the data acquisition system, and a large computing facility, the Control Data Corporation (CDC) 6400 at Lehigh University. Thus, KIM-1 programs were developed for data acquisition and recording with subsequent recovery and transmission to the CDC 6400 facility, where the raw data is reduced to useful results, printed out, and stored on magnetic tape. The tapes are then supplied to The Pennsylvania State University personnel who synthesize and verify the vehicle model being developed. Each of these tasks, which have different programming requirements, are discussed in detail in the following sections.

Microprocessor Programming

Data Acquisition

During data acquisition, the KIM-1 controls both the analog input system and the digital tape unit, cf. Figs. 2, 20. After initializing, the microprocessor starts the ADC on the first information channel, pauses 40 microseconds, directs the data value into memory and adds it to the checksum. This process is repeated until all 16 channels have been sampled and the data stored in memory. The tape unit is then started foreward (in record mode) and the start word, which is the time increment counter, is sent to the UART, followed by the sixteen data samples, the checksum and the stop word, which is the data run number assigned by the operator, cf. Fig. 21(a). Between each item sent to the UART, the microprocessor waits one character space to avoid framing and overrun errors on data playback. The microprocessor stops the tape unit, waits approximately 840 milliseconds, initiates data taking again, then repeats this entire process until a data run is completed. Each side of a 282 foot digital tape cassette can record 14 minutes of data in this manner.

Data Playback

On playback, the microprocessor must transfer data from the tape unit to memory and output characters representing this data to the CDC 6400 main computer. The transmission format is two hexadecimal ASCII characters representing each 8 bits of data, cf. Fig. 21(b). The program flow chart, cf. Fig. 22, lists the steps followed by the microprocessor for data transfer. After initialization, the tape unit is started foreward (in playback mode), data is examined for a start word which is then stored and added to the checksum. The eighteen remaining data items (checksum, 16 data words, and stop word) are transferred from tape to memory, the tape unit is stopped while the checksum, start and stop words are each tested and verified: if any of these are incorrect, the microprocessor transmits a "00" and selects the next measurement set on the tape, otherwise it transmits the verified set to the CDC 6400. Each data word is split into upper and lower four bits, and these bits are translated into ASCII characters and transmitted, high order bits followed by low order bits. After all 19 fields (38 characters), cf. Fig. 21, and a line feed and carriage return have been sent, the tape unit is restarted and the entire process repeated until all the data from the tape cassette has been transferred.

Main Computer Programs

Data Receiving and Storage

The interactive text editing program SENATOR [25] is used to receive the ASCII characters, sent during data playback, and build a new data file. Automatic line number generation and data file structuring are provided by the input mode, and the paper tape directive prevents the retransmission of characters from the CDC 6400 while the microprocessor is transferring data to it. To transfer the data and build a file, the user prepares the microprocessor system, cf. Fig. 23, types SENATOR, specifies the data file EVDATA and system DATA, then INPUT and %T. Two data transfer switches on the terminal/microprocessor control box are moved from the terminal to microprocessor position, and data playback is initiated by pressing "GO" on the microprocessor keyboard. After data transfer is complete, the playback system is halted by pressing "ST", the data transfer switches are returned to the terminal position, CRTL and S are typed simultaneously followed by a semicolon. The SENATOR holding file containing the entire data file is now ready for use or storage.

Temporary file storage on system disc space is available using the command CATALOG, EVDATA, ID=EV [26]. The file is retained under the name EVDATA and identifier EV for recall by the data reduction and processing program.

Data Reduction and Processing

The raw data is reduced using a CDC 6400 FORTRAN program of approximately 100 executable statements. The program selects the EVDATA file (previously constructed), checks that it is the desired data set, then converts each two character hexadecimal field, cf. Fig. 21(b), into its decimal equivalent and stores them in an array having a range 0 to 255. These values are converted by the program into final form representing each sensed variable, cf. Table 2. When all the data has been converted and reduced, the program prints out several copies, cf. App. D, and stores the file EVOUT using the CATALOG utility [26], for use in magnetic tape generation.

Magnetic Tape Generation

Two magnetic tapes are generated for use by EV personnel: a permanent file copy and a data transfer tape. Permanent file copies containing all reduced data are maintained on tapes EV1 and EV2, stored in the Lehigh University Computing Center tape library. These are created using the COPYBF utility [26] and standard tape handling procedures.

The tape for data transfer to The Pennsylvania State University's IBM computer is created with the CDC utility package FORM in 'SCOPE stranger' writing format, blocked with 80 characters per record and 20 records per block, and a coded tape format. Details on the complete procedure are found in [27].

VI. Results

Vehicle Data Runs

Several types of vehicle runs can be made using the data acquisition system. Each vehicle test requires installing the data logging system on board the van, activating the system power supplies, transcribing the microprocessor program from tape, inserting a digital cassette in the tape unit, resetting various system components, and entering the data set number, cf. Fig. 24. The test is started by pressing "GO" on the microprocessor keyboard, and the data run proceeds automatically until "ST" is pressed. Any number of runs can be made by repeating this procedure.

After preliminary calibrating and debugging runs, vehicle data acquisition commenced over several routes and driving cycles, cf. Fig. 25. Constant speeds, wide open throttle (WOT) accelerations, and coast downs from high speed were conducted on Riverside Drive, a 1.5 mile flat course. Variable terrain is encountered on a 1.2 mile hilly course on the Lehigh University campus, along the 2.5 mile loop to the Bishopthorpe student dormitory, and over the 6 mile South Mountain run to and from SMAGS, a second student dormitory. Data from the campus run and level course tests are presented next.

Campus Run Data

Vehicle data from run number 50, a single loop on the campus route, is presented in App. D. A sketch of the route showing the roads and slopes involved is shown in Fig. 26; the vertically directed streets (North-South) have slopes 2^o to 7^o whereas the horizontal ones are essentially flat ($\pm 1^o$). Maximum observed drive line torque (686 N·m) occurred 194 seconds into the run, after stop number 3, with a correspondingly large battery current (323 A). Total route distance travelled was 2059 m, and maximum speed was 58.8 km/hr, after running with both bypass and field weakening in operation. After field weakening was engaged, battery voltage dropped to 89.6V, 254 seconds after start, and increased as the current drawn decreased (from 254 to 266 seconds). Electrolyte temperature rose 1.3°C and 1.0°C in the outer and center cells respectively over the total run time of 412 seconds.

Level Course Data

Average vehicle velocity versus time for wide open throttle acceleration is presented in Fig. 27. The averaged acceleration data yields a 0-30 km/hr time of 5.8 seconds and a 0-50 km/hr time of 16.5 seconds, in good agreement with the results obtained by Dustin, et al [13]. Top speed of approximately 67 km/hr was reached after 60 seconds.

Coast down data was taken by accelerating the vehicle to approximately 65 km/hr, releasing the throttle and allowing the vehicle to roll freely to a stop, cf. Fig. 28. An almost constant deceleration occurred during the 92 seconds required for the vehicle to stop.

Reduced data from constant speed data runs 30-33 are presented in Table 3. As speed increases, duty cycle also increases, cf. Fig. 29. While the drive shaft torque and battery voltage do not change much, power drawn from the battery increases: battery current rises by a factor of 3 as speed changes from

8.2 to 47.7 km/hr. Correspondingly, battery energy expended per kilometer drops as vehicle speed increases: at 40 km/hr 1.31 megajoules is required to travel one kilometer. This agrees with the results of Dustin, et al [13] (1.5 MJ/km) when the charger efficiency of about 0.9 is accounted for.

Vehicle range at each speed was calculated using battery ampere-hour capacity, measured speed and battery current, and assuming an 80% battery discharge. These results, cf. Fig. 30, along with the NASA experimental results [13], indicate that vehicle range increases up to 40-50 km/hr, where 80-100 km ranges may be expected.

Preliminary Model Results

Although model synthesis and parameter adjustment is still ongoing, preliminary results from The Pennsylvania State University vehicle simulation are shown in Figs. 31-34 for a wide open throttle and coasting run. The simulation models the battery performance, motor-controller interactions, and vehicle dynamics using separate FORTRAN subroutines, and both printed and plotted results are generated. Each plot shows both data and simulation results as functions of time, with the experimental results generally somewhat larger than the simulation results. The velocity, cf. Fig. 31, and battery current, cf. Fig. 32, show that the largest discrepancies occur at high speeds. Both drive shaft torque, cf. Fig. 33, and motor armature voltage, cf. Fig. 34, follow the experimental results closely. Further simulation results for these and other parameters are expected as model synthesis proceeds.

VII. Summary

A digital data acquisition system was designed and constructed for data collection on a 1974 Battronics Minivan electric vehicle. This system is microprocessor based and interfaced with various sensors on board the van to measure battery voltage, current, and electrolyte temperatures, motor armature and field voltages, controller duty cycle, bypass, and field weakening, drive line torque, distance travelled, vehicle speed, acceleration, and inclination. Raw data taken over several different routes, with both varied and level terrain, was recorded by the system on digital cassette tapes. These tapes were played back using the same data acquisition hardware and different software to the CDC 6400 main computer at Lehigh University, where the raw data was processed and both hard copy and magnetic tapes generated. The data was then sent to The Pennsylvania State University, where it was used to aid in synthesis and verification of the vehicle model being developed. Experimental and preliminary model results agree to first order, and further model optimization is expected to yield closer correlation.

Table 1 Variables Sensed, Sensors, and Pertinent Figures

Variable	Type	Sensor	Pertinent Figure(s)
Battery Voltage	Electrical	Circuit	Fig. A10
Battery Current	Electrical	Shunt	Fig. A11
Armature Voltage	Electrical	Circuit	Fig. A12
Field Voltage	Electrical	Circuit	
Duty Cycle	Electrical	Circuit	Fig. A13
Controller Bypass	Electrical	Microswitch	Fig. A14
Field Weakening	Electrical	Microswitch	
Drive Line Torque	Mechanical	Strain Gauge Torque Meter	Fig. A15
Distance Travelled	Mechanical	Fifth Wheel System	Fig. 18 Fig. A16 Fig. A17
Speed	Mechanical		
Accleration	Mechanical	Servo Accelerometer	Fig. A18
Vehicle Inclination	Mechanical	Gyroscope	Fig. A19
Time	Other	Microprocessor	———
Battery Electrolyte Temperature	Other	Semiconductor Temperature Transducer	Fig. 19 Fig. A20

Table 2 Sensor Variable Conversions

Variable (unit)	Range	Conversion Procedure
Time (seconds)	0 to ∞	(CHV†)+(No. of Resets)*256
Duty Cycle (unitless)	0 to 1	(CHV)/256; If in bypass, duty cycle = 1.
Inclination (degrees)	±55	(((CHV-128)*0.0391)+0.1231)*11.08
Velocity (km/hr)	0 to 90	(CHV)*0.7097
Acceleration (g)	±1	((CHV-128)*7.483×10^{-3}) - sin(θ) where θ = inclination angle
Distance Travelled (m)	0 to ∞	((CHV)+(No. of Resets)*256)*0.3048
Torque (N·m)	±1130	(((CHV-128)*0.0391)+0.02)*226.53
Battery Voltage (volts)	0 to 150	(CHV)*(150/256)
Battery Current (amps)	±600	(CHV-128)*4.6806
Armature Voltage (volts)	±100	(CHV-128)*(100/128)
Field Voltage (volts)	±25	(CHV-128)*(25/128)
Field Weakening (unitless)	IN or OUT	If CHV > 251, field weakening is IN; otherwise, OUT.
Battery Electrolyte Temperatures (°C)	-5 to 55	((76.7-((CHV)-128)*0.4398)-32)*(5/9)

†: CHV means Converted Hexadecimal Value, Range 0 to 255, cf. Section V.

Table 3 Averaged Constant Speed Results for Runs 30-33

Run #	Speed v (km/hr)	Duty Cycle (unitless)	Torque τ (N·m)	Battery Voltage V_{Batt} (V)	Battery Current I_{Batt} (A)	Battery Power out P_{out} ① (kW)	Battery Energy Expended E_{Batt} ② (MJ/km)	Calculated Vehicle Range d ③ (km)
30	8.2	0.12	63	114	48	5.4	2.37	45
30	15.6	0.23	71	112	68	7.7	1.78	61
31	23.5	0.35	66	110	91	10.0	1.53	69
32	31.9	0.47	71	109	115	12.5	1.41	73
32/33	39.7	0.61	74	107	135	14.5	1.31	78
33	47.7	0.77	83	105	157	16.5	1.25	80

Notes:

① $P_{out}(W) = V_{Batt}(V) \times I_{Batt}(A)$

② $E_{Batt}(MJ/km) = \dfrac{3.6 \times P_{out}(kW)}{v(km/hr)}$

③ $d(km) = \dfrac{v(km/hr) \times 330 A\text{-}H \times 0.8}{I_{Batt}(A)}$

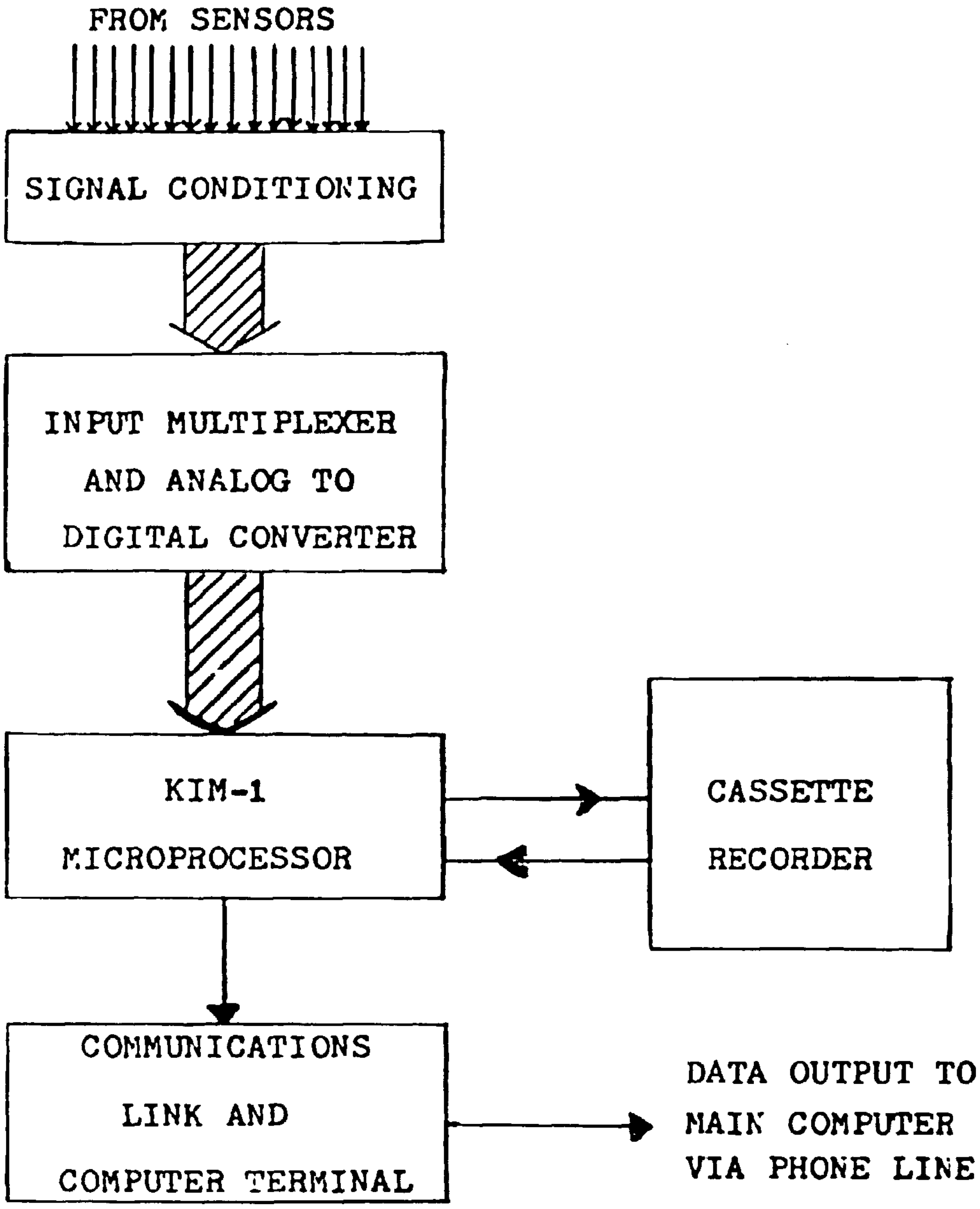


Fig. 1. Block Diagram of Digital Data Acquisition System

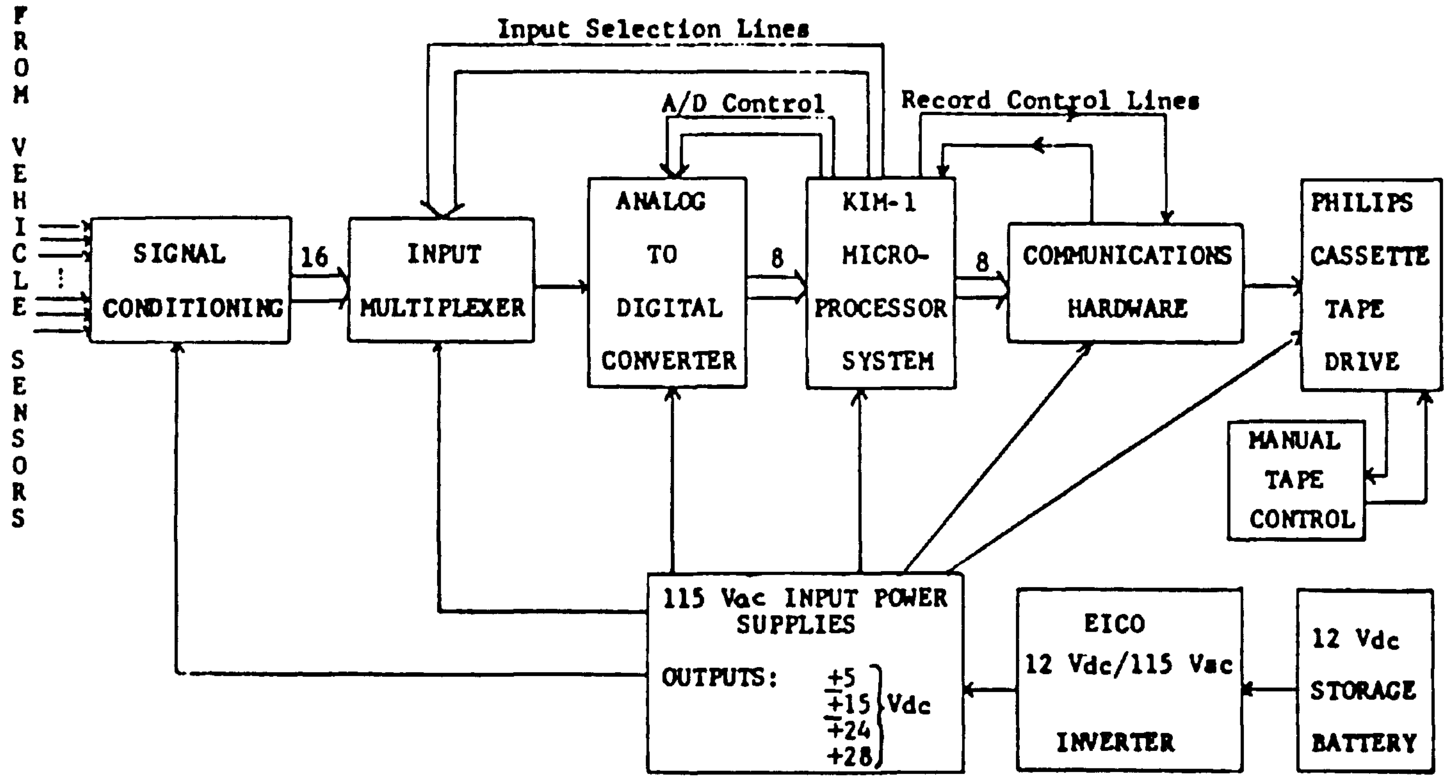


Fig. 2 Block Diagram of Data Acquisition and Recording Operations

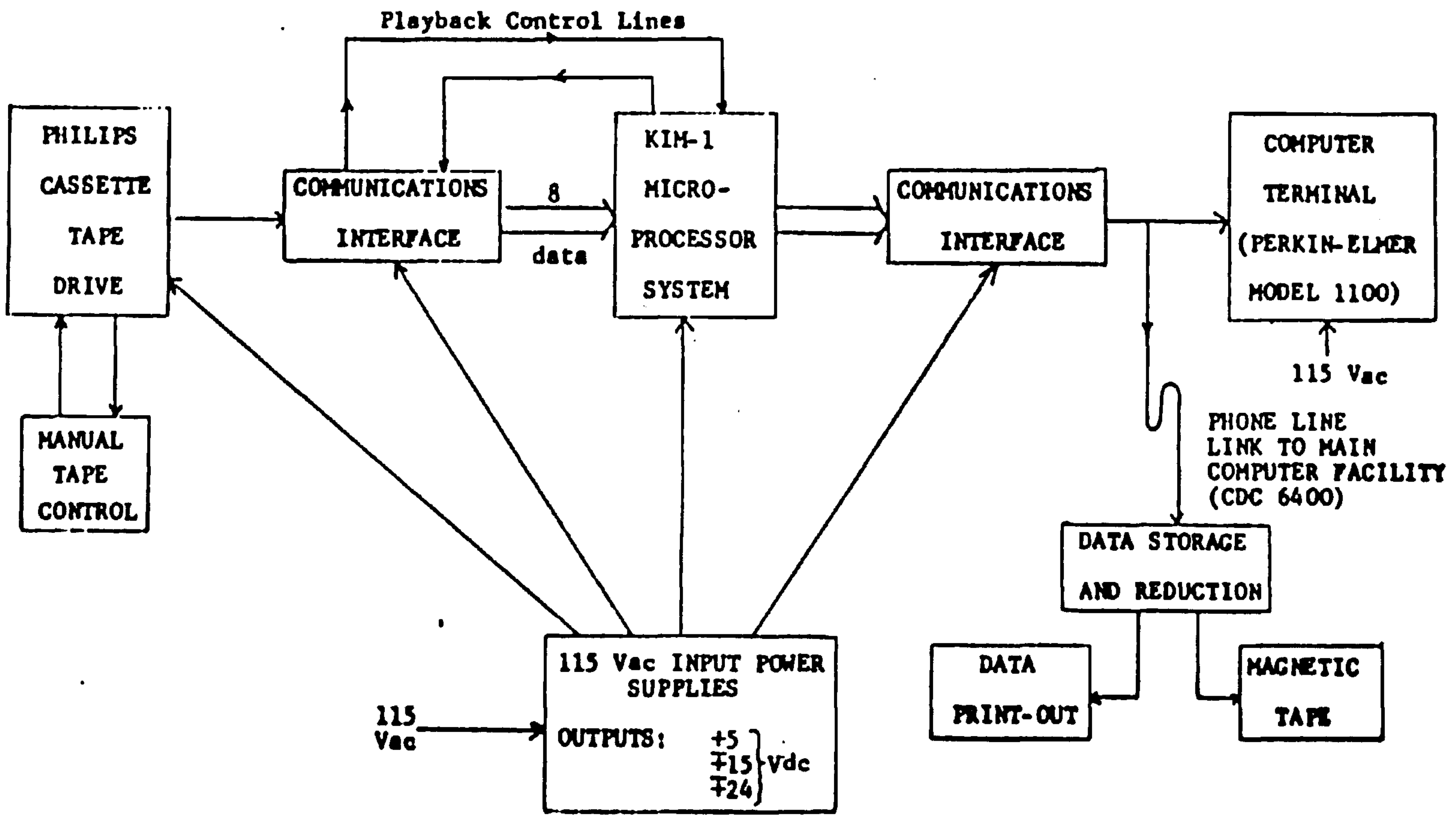


Fig. 3 Block Diagram of Data Playback and Processing System

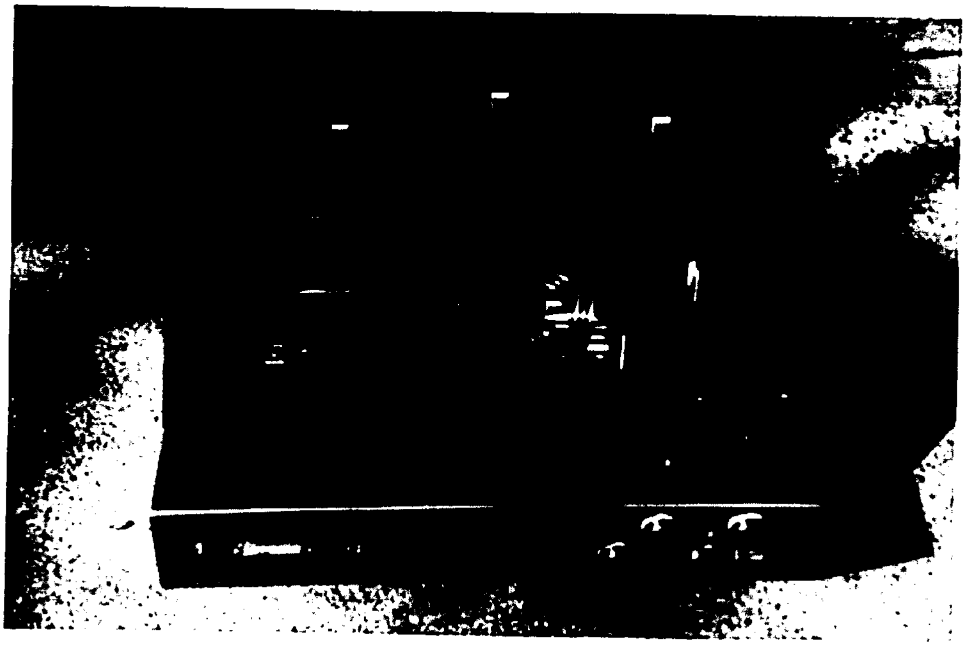


Fig. 4 Data Logging Equipment Rack

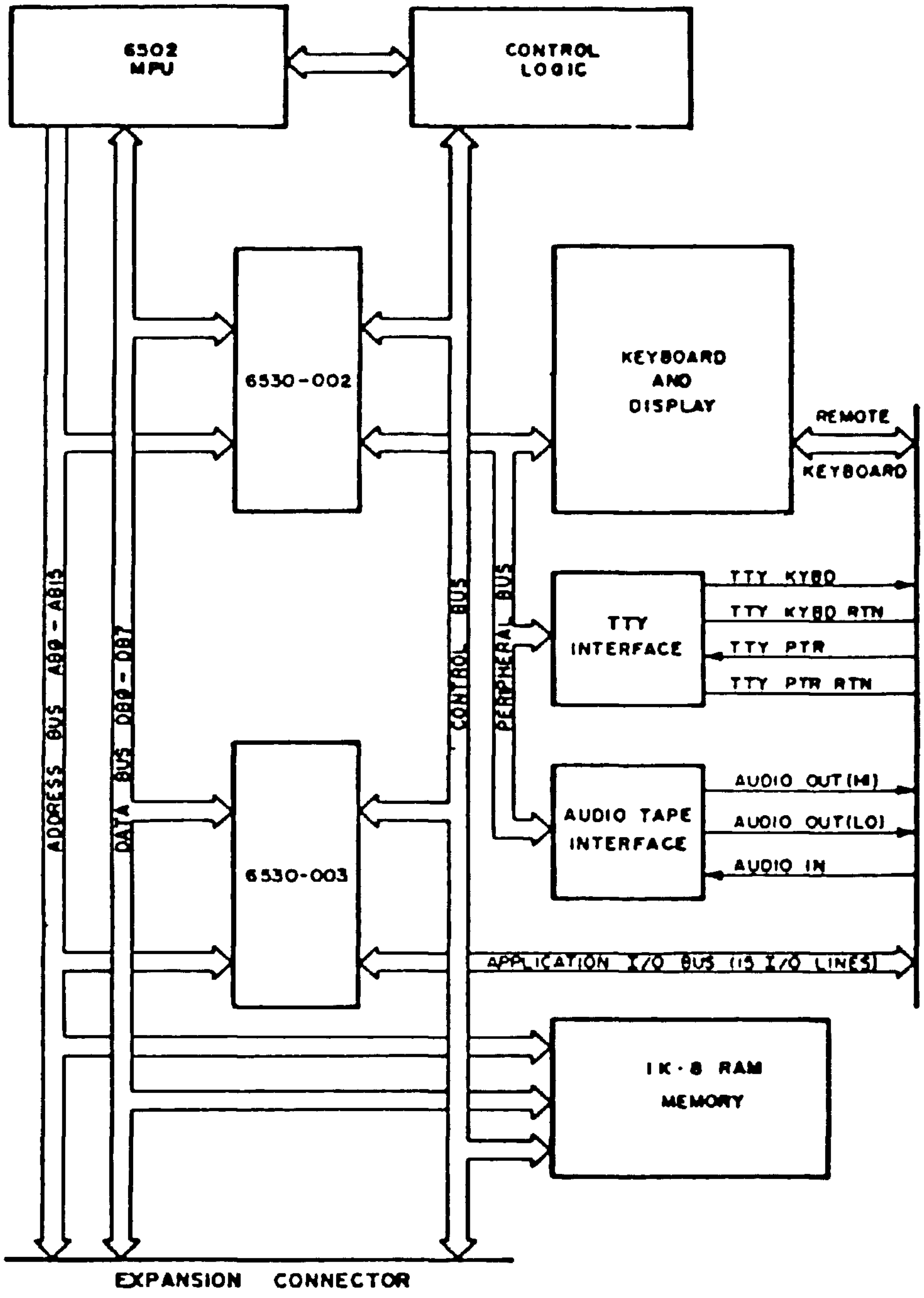


Fig. 5. KIM-1 Microprocessor System Block Diagram

line #	Allocation during: Data Acquisition	Data Playback
A Register		
0	(Output) LSB, tape unit data	(Input)
1	(Output) 2^1, tape unit data	(Input)
2	(Output) 2^2, tape unit data	(Input)
3	(Output) 2^3, tape unit data	(Input)
4	(Output) 2^4, tape unit data	(Input)
5	(Output) 2^5, tape unit data	(Input)
6	(Output) 2^6, tape unit data	(Input)
7	(Output) MSB, tape unit data	(Input)
B Register		
0	Disconnect Receiver data register, Tape (Output)	
1	Load Xmit Register, Tape (Output)	Load Xmit Register, CDC 6400 (Output)
2	Data Received Reset (Output)	
3	Unavailable	
4	Tape Foreward Start/Stop Control (Output)	
5	Transmitter Holding Register Empty, CDC 6400 (Input)	
6	Unavailable	
7	Xmit Register Empty, Tape (Input)	Character Received, Tape (Input)

Note: Output means output from microprocessor to device, Input means input to microprocessor from device.

Fig. 6 Data Register Line Allocations

Type: Philips 40461 digital cassette recorder.

Drive: Uses Philips type cassettes. Three motors (two hub, one capstan), foreward/reverse at 7.5 ips, fast foreward/reverse at 75 ips. Start time 40 ms, start path 7 mm; stop time 30 ms, stop path 2 mm.

Physical: 5" x 5" x 12", 8.3 lb. Metal cased, unit is rack mounted, cf. Fig. 8.

Signals: Control (TTL levels) - fast/slow, foreward, reverse, lock, unit select, read enable,

Status (TTL levels) - begin/end of tape, A/B side, cassette in position, unit ready, cassette write enable plug

Data - read data (TTL level), write data (TTL level), analog read data (for testing).

Power: +5V at 0.5A, +24V at 0.7A

Fig. 7 Digital Cassette Tape Recorder Specifications

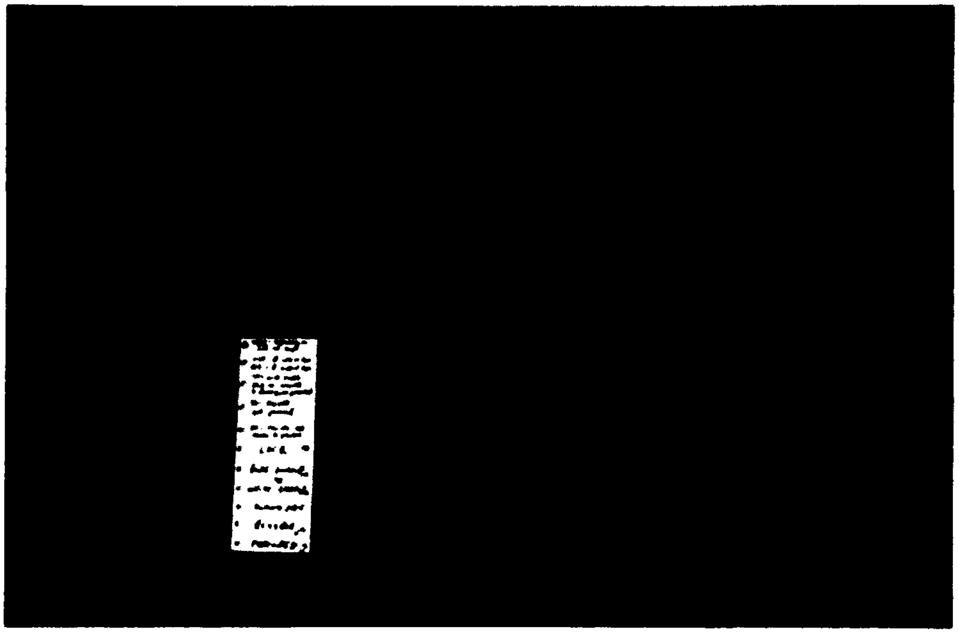
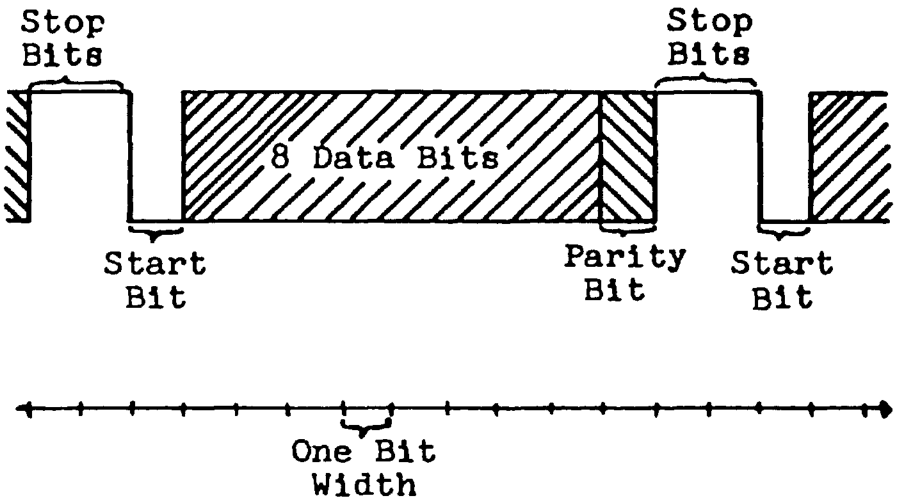


Fig. 8 Rack Mounted Digital Cassette Tape Unit and Control Box



Parameters Selected: Odd Parity

Two Stop Bits

8 Bit Data Word Length

1200 Baud Data Rate

Fig. 9. Digital Cassette Tape Data Format

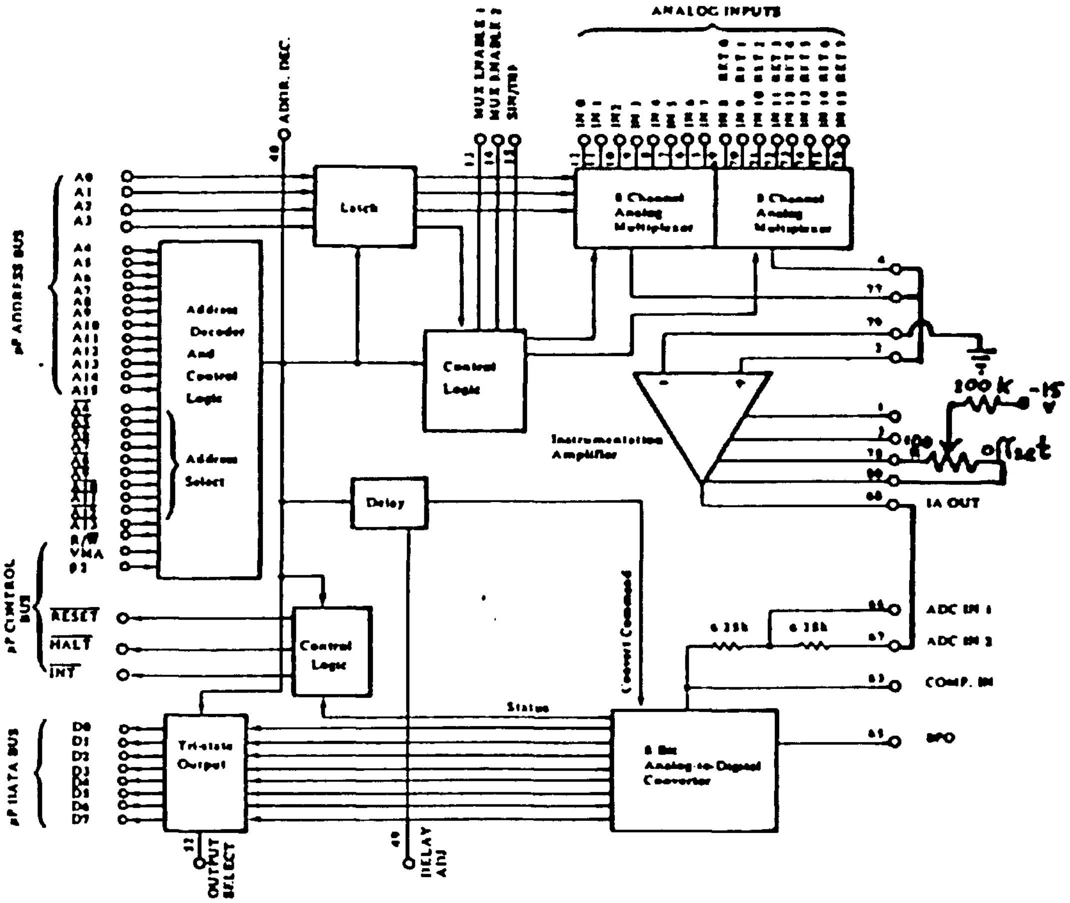
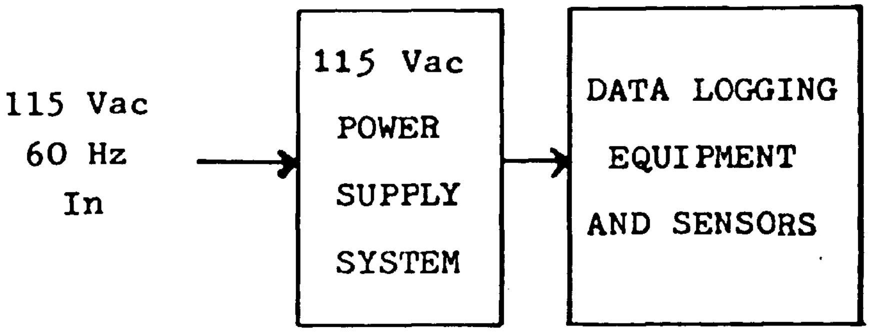
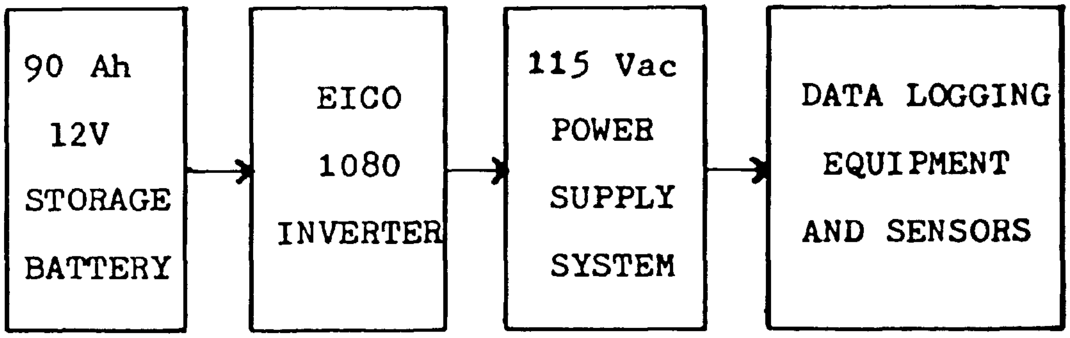


Fig. 10. Block Diagram of
Analog Input System



(a) In Laboratory: Testing and Data Playback



(b) On Board Vehicle: Data Acquisition

Fig. 11. Power Supply Systems

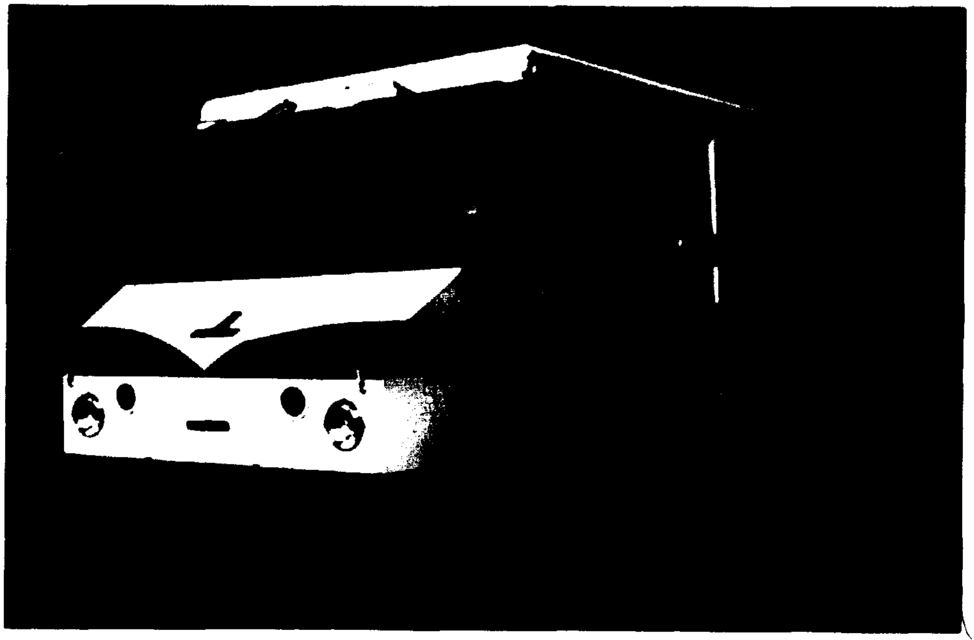


Fig. 12 Battronics Minivan - Front Quarter View

Fig. 13 Battronics Minivan - Rear and Interior View

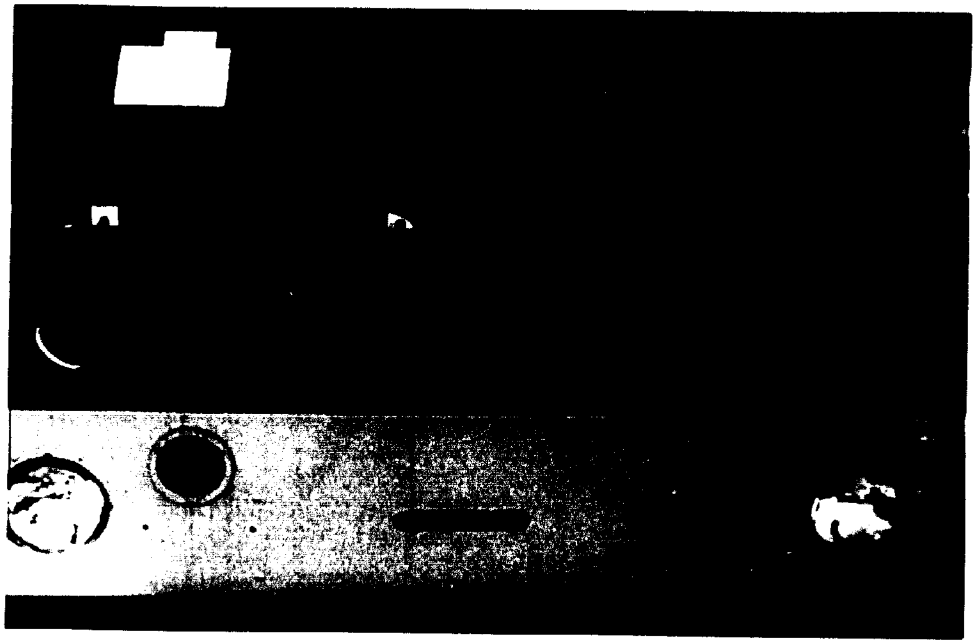


Fig. 14 Underhood Electricals - Battronics Minivan

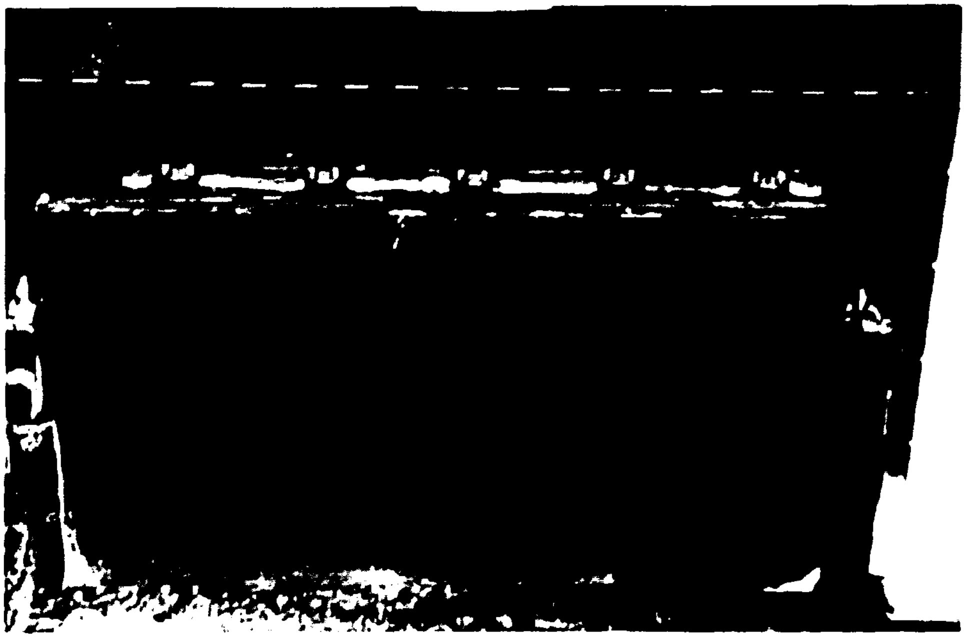


Fig. 15 Right Hand Side Battery Compartment - Battronics Minivan

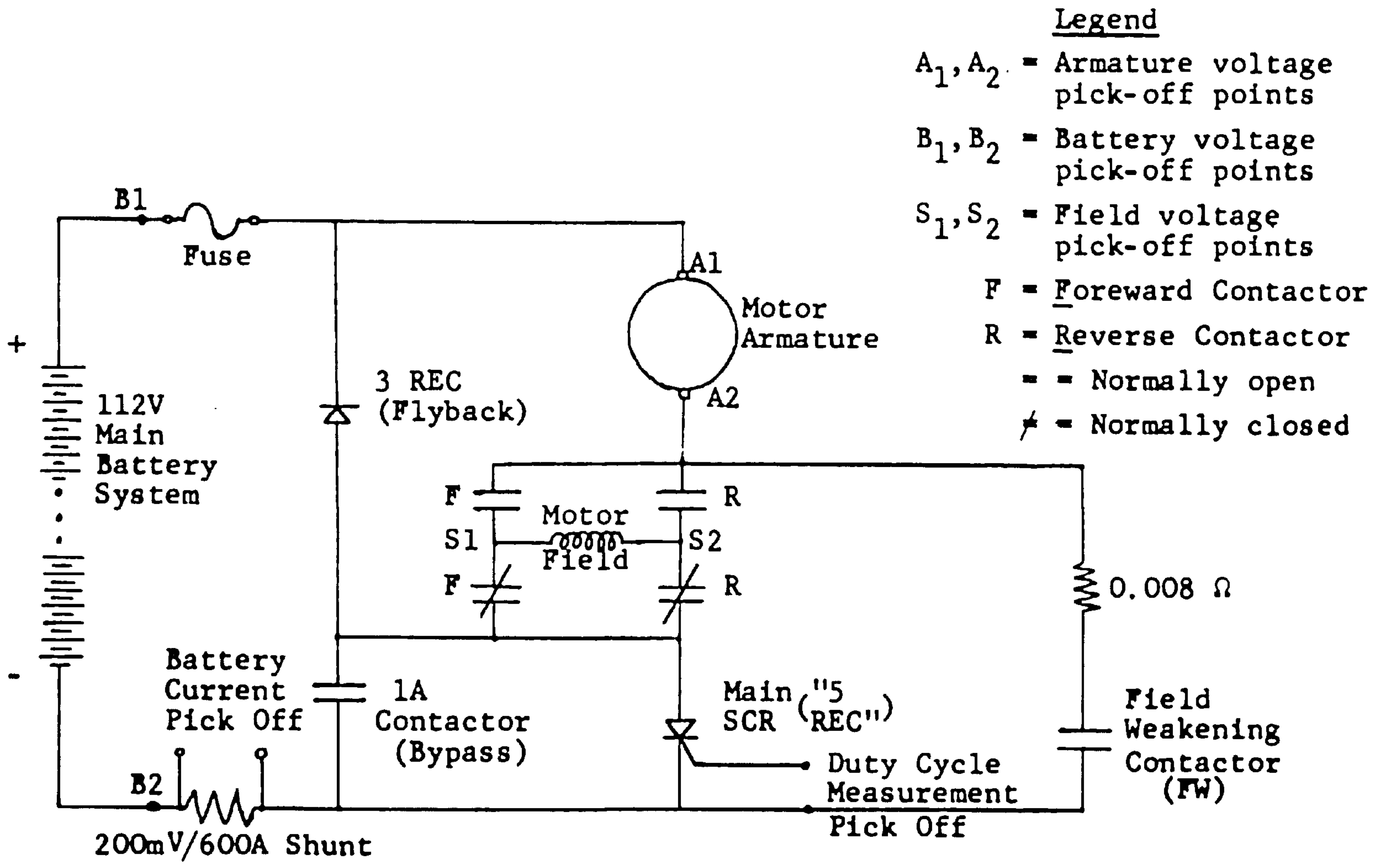


Fig. 16 Simplified Controller Diagram Showing Sensor Pick Off Points

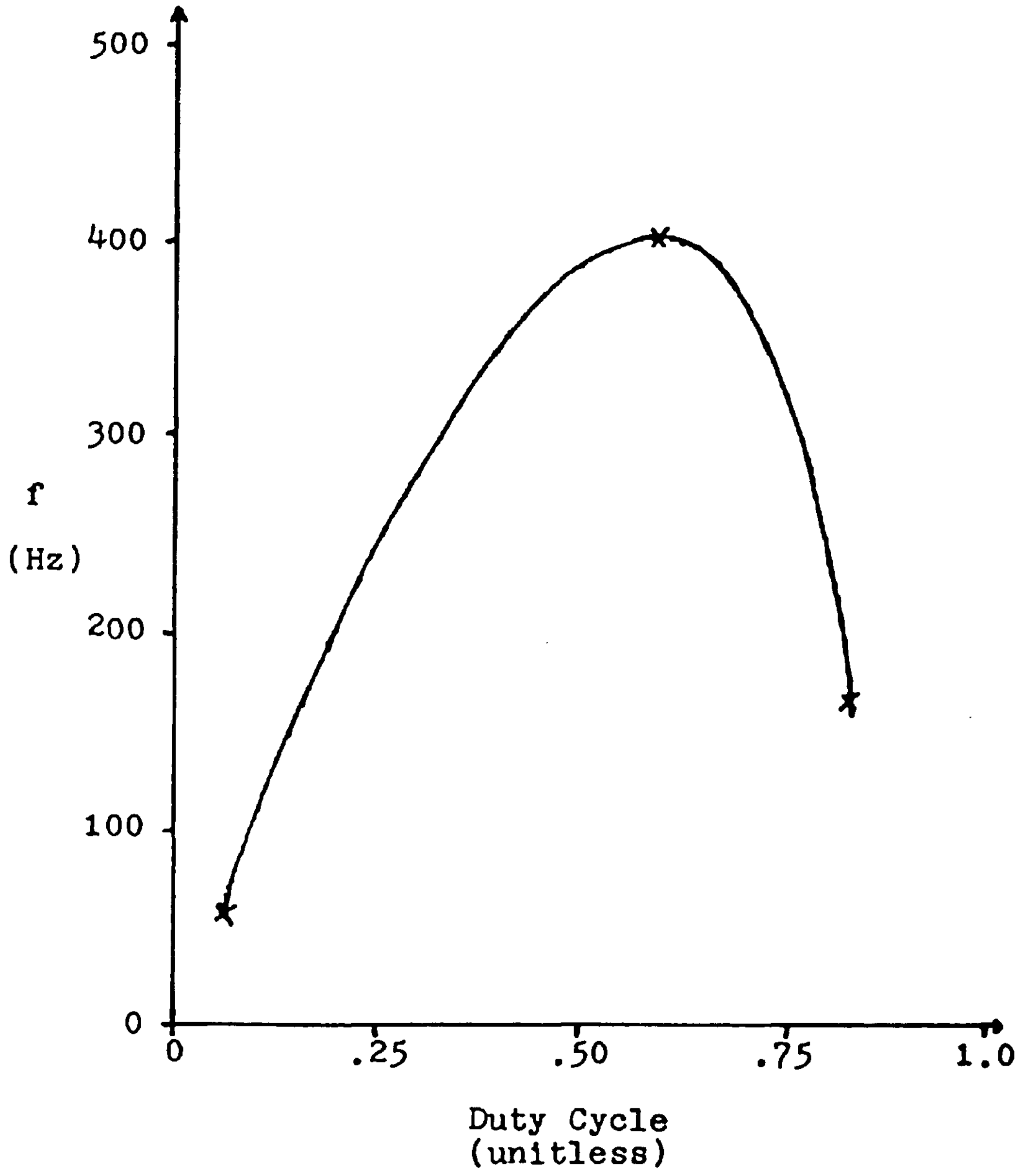


Fig. 17. Measured Controller Chopping Frequency vs. Duty Cycle

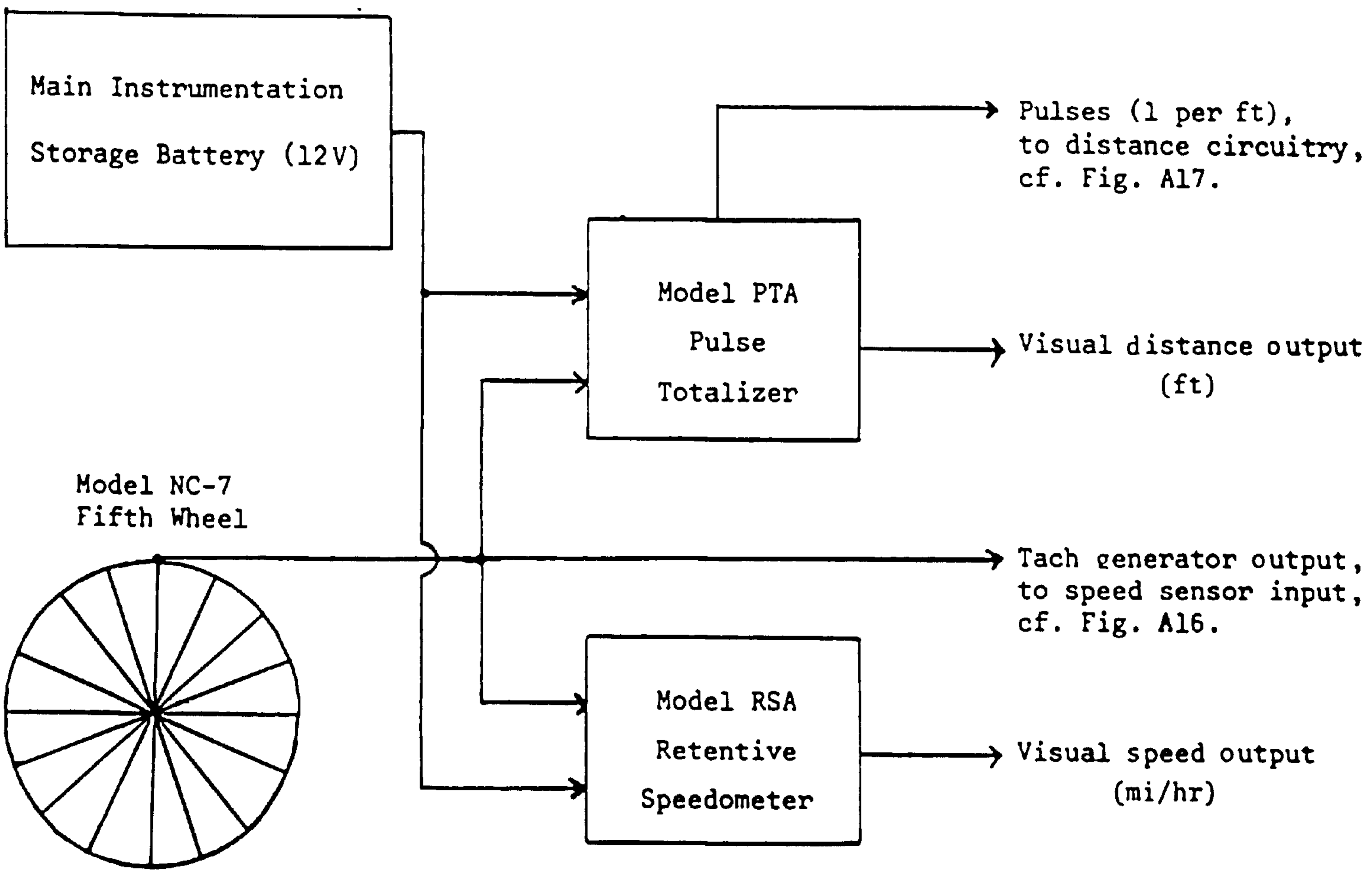


Fig. 18. Nucleus Fifth Wheel Apparatus

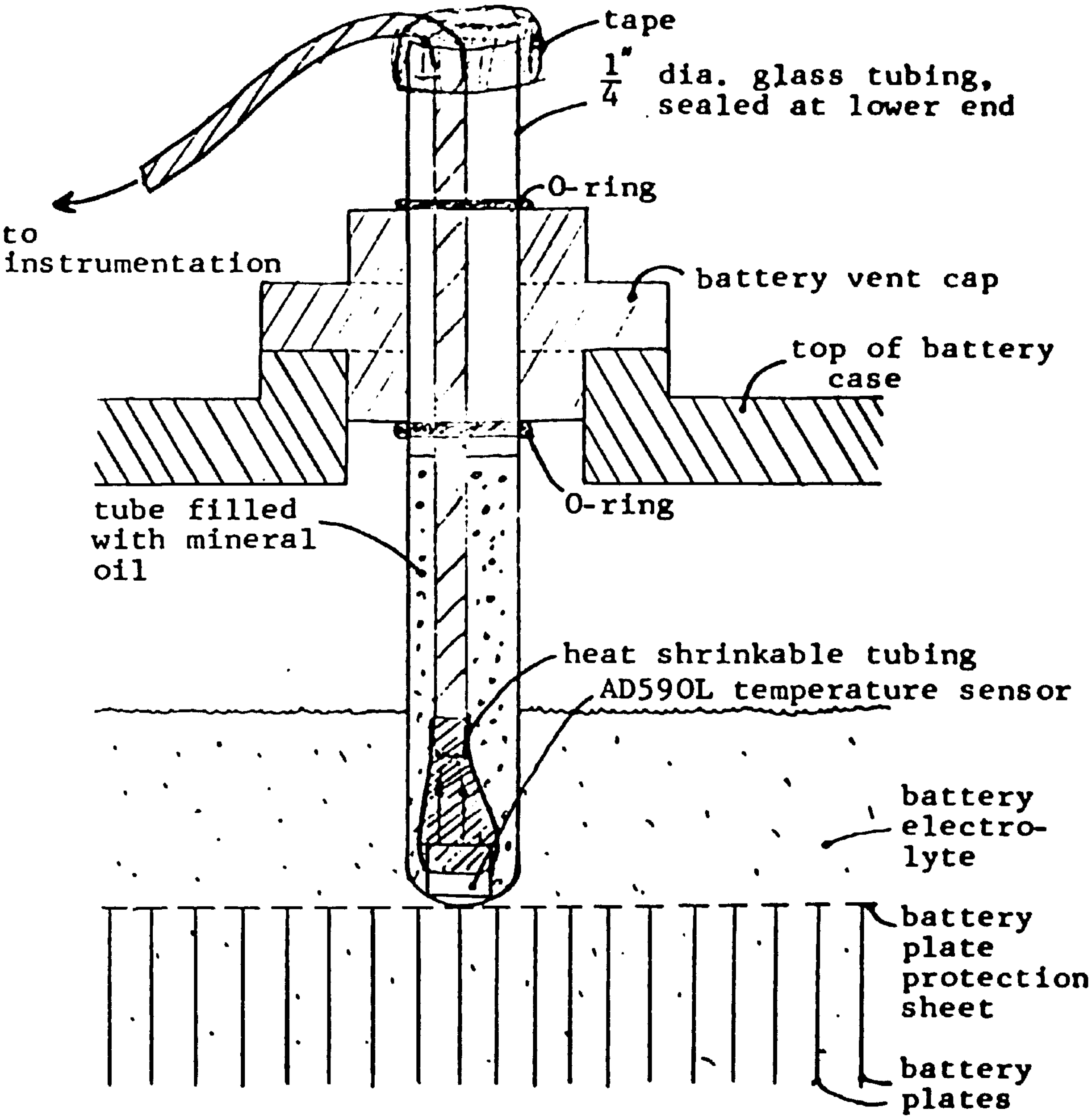


Fig. 19 Cross Section of Battery Temperature Sensor

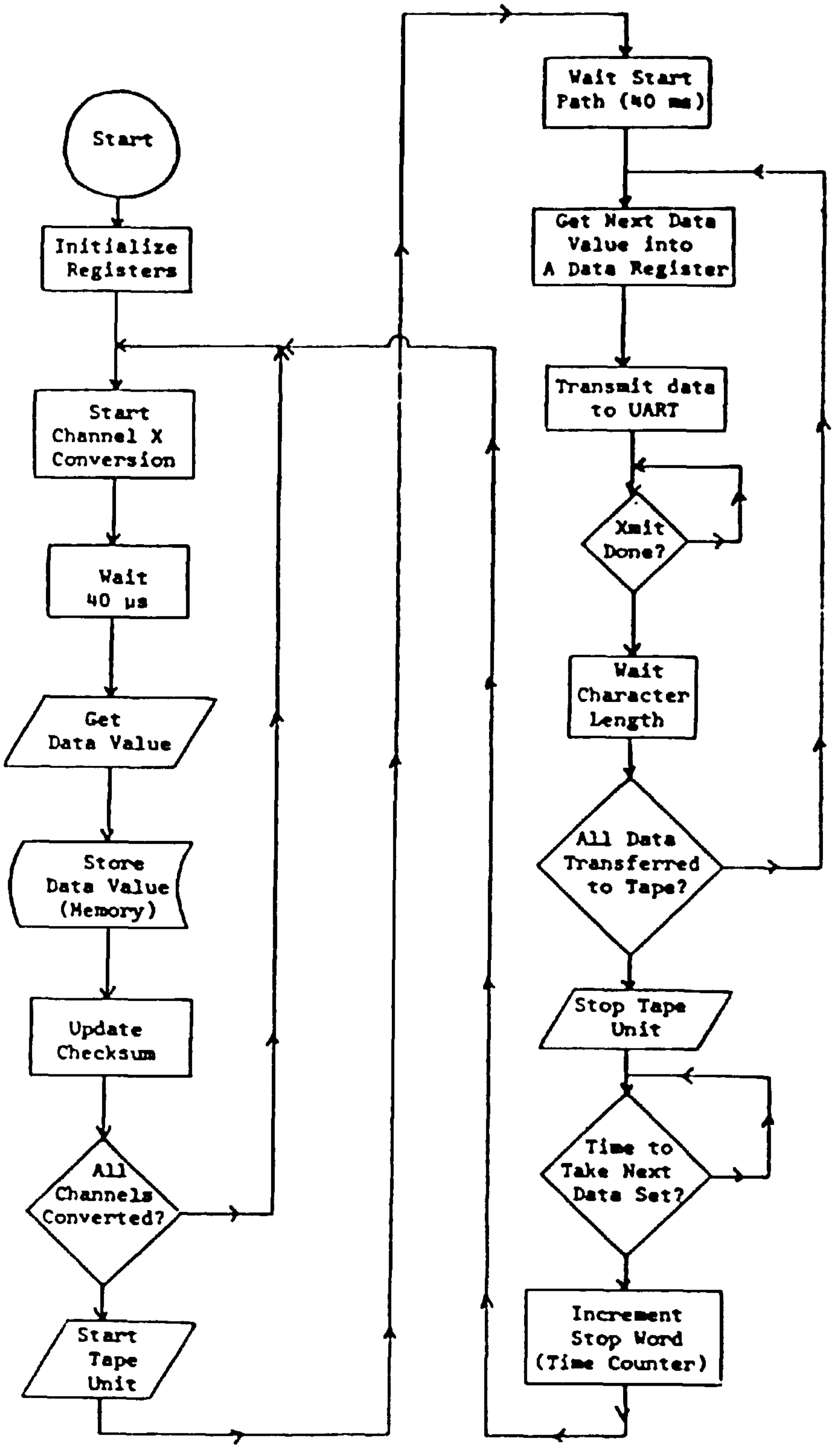
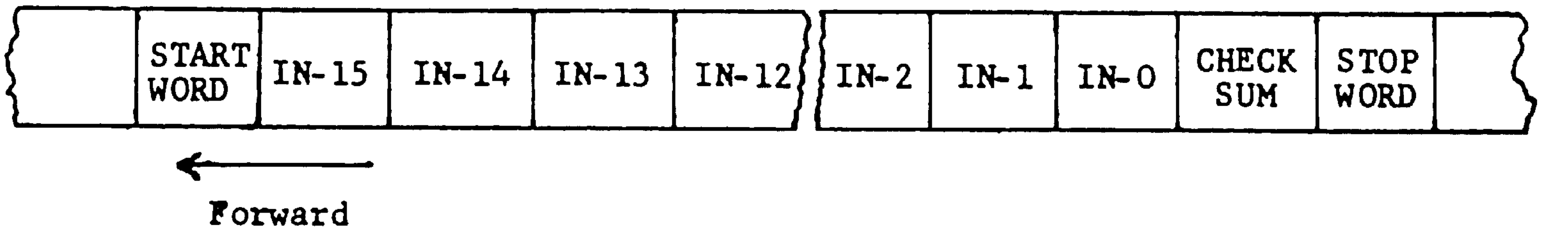


Fig. 20 Data Acquisition Programming



*Stop Word = Data Set Number
*Start Word = Time Counter

(a) Digital Tape Data Format

	DATA SET #	CHECK SUM	IN-15	IN-14	IN-13	IN-12	IN-11	...	IN-1	IN-0	TIME COUNTER
Data:	01	38	80	80	A9	B7	62	...	80	08	00
Field:	1	2	3	4	5	6	7	...	17	18	19

(b) Data Output Format
(Each field represents two hexidecimal characters)

Fig. 21 Tape and Data Output Formats

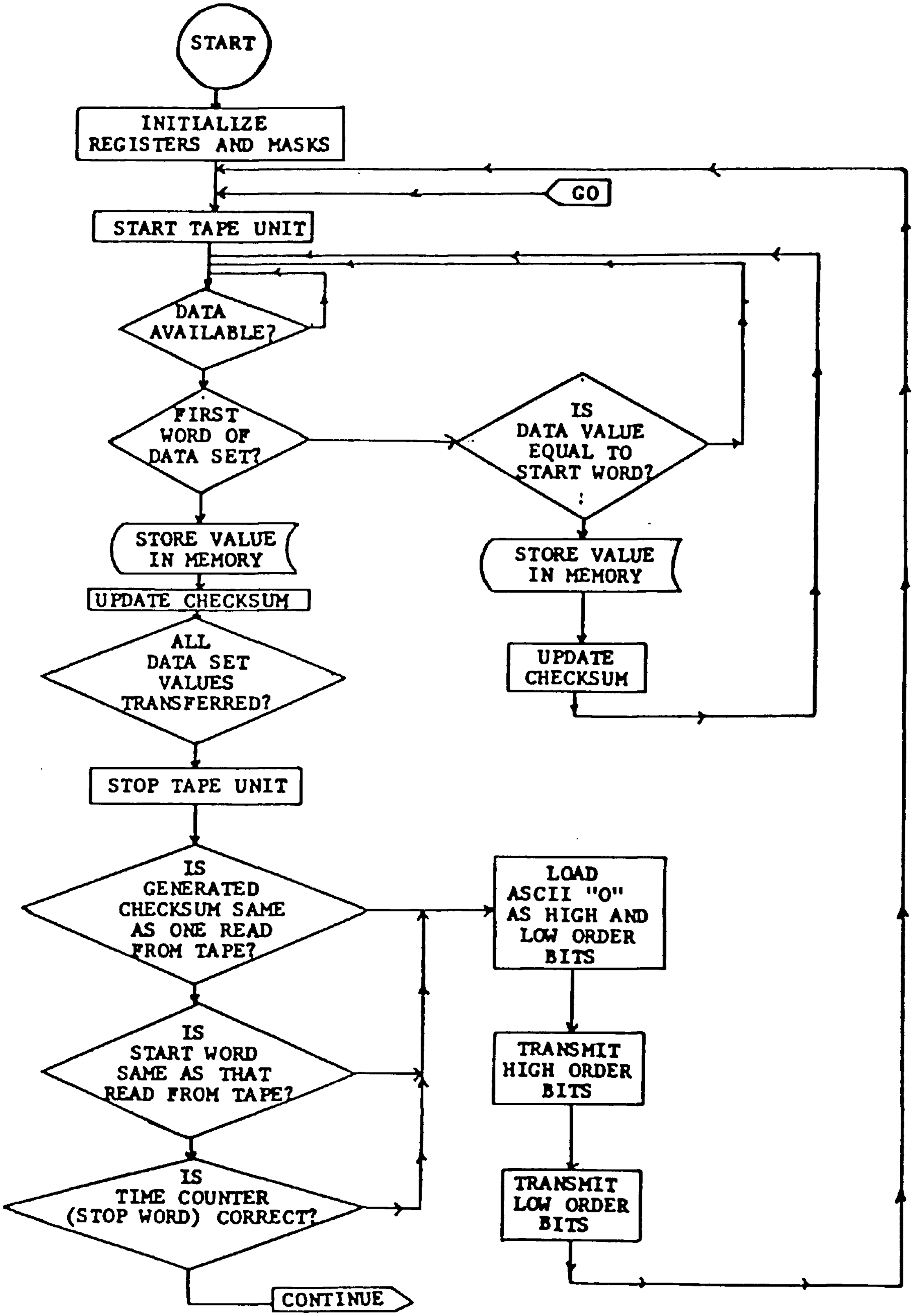


Fig. 22 Data Playback Programming

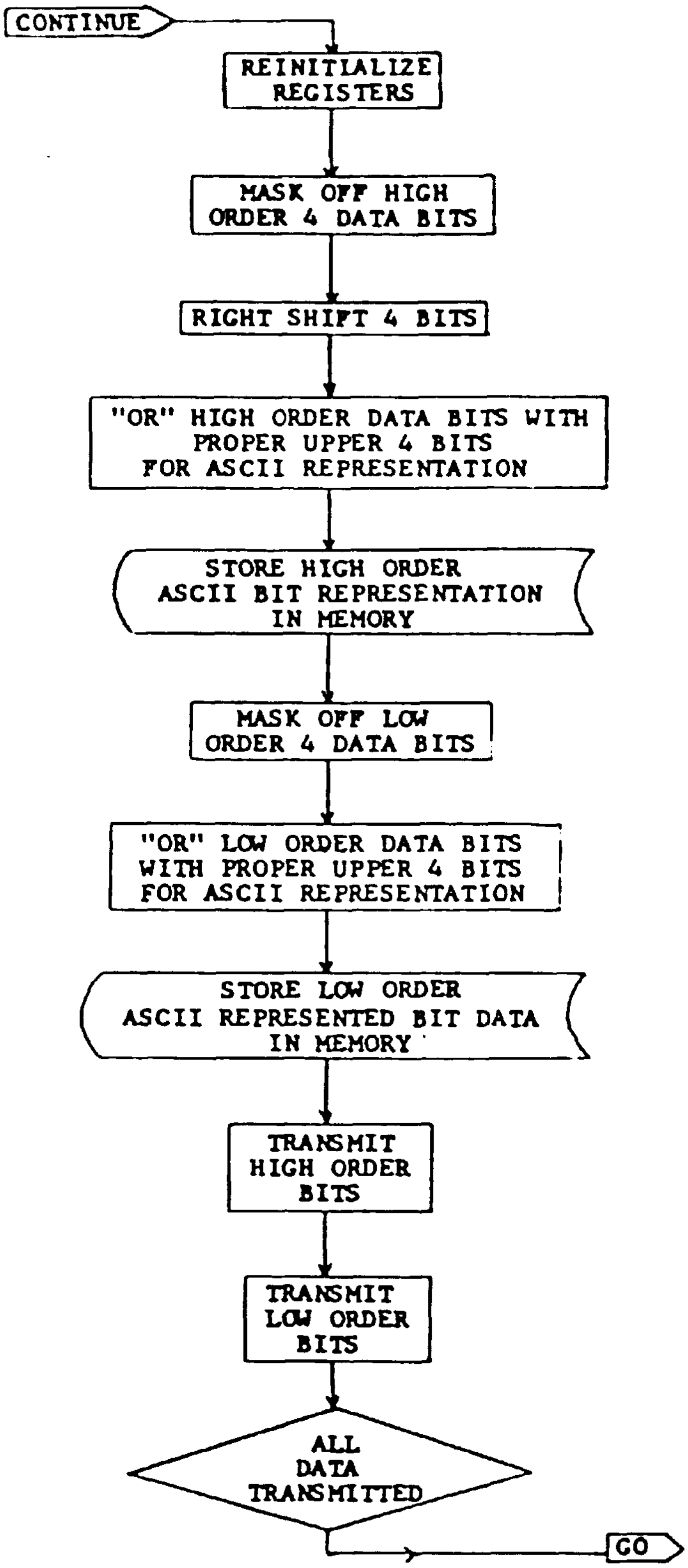


Fig. 22 (Continued) Data Playback Programming

1) Install three rack mounted components (power supply, tape unit, electronics), analog tape unit and digital tape control box.

2) Connect: Digital tape unit plug to electronics
   Analog tape unit to electronics cable
   Power line from electronics to power supply
   110V power line (power supply) to mains
   Data output cable to electronics rack.

3) Turn on power supply.

4) To load program, enter on microprocessor keyboard:

```
"RS"
"AD", 00F1, "DA", 00
"AD", 1703, "DA", 1F
"AD", 17F9, "DA", 01
"AD", 17FA, "DA", 00
   +, 1C
"AD", 1873, "GO" .
```

5) Microprocessor program loading is complete when "0000 xx" appears (x = don't care). If "0000 xx" does not appear, rewind analog tape cassette and repeat step 4. Rewind analog tape cassette after "0000 xx" appears.

6) Set electronics rack switches to "data playback" and "KBD"; reset UART and parity light.

7) Load, lock and rewind desired digital cassette on correct side.

8) Enable data playback (digital tape control box).

9) Login on CDC 6400.

10) Follow procedure of p. 37, main text, for data playback of one or several data sets.

Fig. 23. Data Playback Checklist

1) Reset vehicle trip odometer before starting.

2) Install three rack mounted components (power supply, tape unit, electronics), analog tape unit and digital tape control box.

3) Connect 10 sensor input lines and 4 sensor power lines to electronics rack.

4) Connect: Power line from electronics to power supply
   Main battery ground lead (green) to electronics
   Digital tape unit plug to electronics
   Analog tape unit to electronics cable
   110V power line (power supply) to inverter.

5) Turn on inverter, power supply, and Nucleus equipment power switches.

6) To load program, enter on microprocessor keyboard:
   "RS"
   "AD", 00F1, "DA", 00
   "AD", 1703, "DA", 1F
   "AD", 17F9, "DA", 01
   "AD", 17FA, "DA", 00
   +, 1C
   "AD", 1873, "GO" .

7) Microprocessor program loading is complete when "0000 xx" appears (x = don't care). If "0000 xx" does not appear, rewind analog tape cassette and repeat step 6. Rewind analog tape cassette after "0000 xx" appears.

8) Start gyroscope (switch on gyro frame) - cage for one minute by pressing lever at front of frame to driver's left.

9) Insert, lock, and rewind digital cassette.

10) Remove digital cassette, and wind foreward by hand until tape is visible.

11) Insert and lock cassette; switch on write enable. Insure that top light on control box is lit and bottom three are blank.

(Continued)

Fig. 24 Vehicle Data Run Procedure

12) Place electronics rack switches to "Data Record" and "KBD"; reset UART and parity light.

13) Reset distance (switch on Nucleus equipment).

14) Key in data set number by: "AD", 0012, DA, (data set #).

15) To run, press: "AD", 0200, "GO"; run for no more than 14 minutes per cassette side.

16) For further data runs, repeat steps 9-15.

Fig. 24 (Continued) Vehicle Data Run Procedure

Run #	Date	Route Name	Type of Run	Comments
30	7/26	Riverside Drive	Constant Speed	5 mph, 10 mph
31	7/26	Riverside Drive	Constant Speed	15 mph
32	7/26	Riverside Drive	Constant Speed	20 mph, 25 mph
33	7/26	Riverside Drive	Constant Speed	25 mph 30 mph
34	7/26	Riverside Drive	WOT/Coast	3 runs
40	7/28	Campus	Variable	
41	7/28	Campus	Variable	
42	7/28	Bishopthorpe	Variable	
43	7/28	Bishopthorpe	Variable	
50	8/2	Campus	Variable	
51	8/2	Campus to SMAGS	Mountain	Run over South Mountain - high battery temperatures
52	8/2	SMAGS to Campus	Mountain	

Fig. 25. Data Run Summary

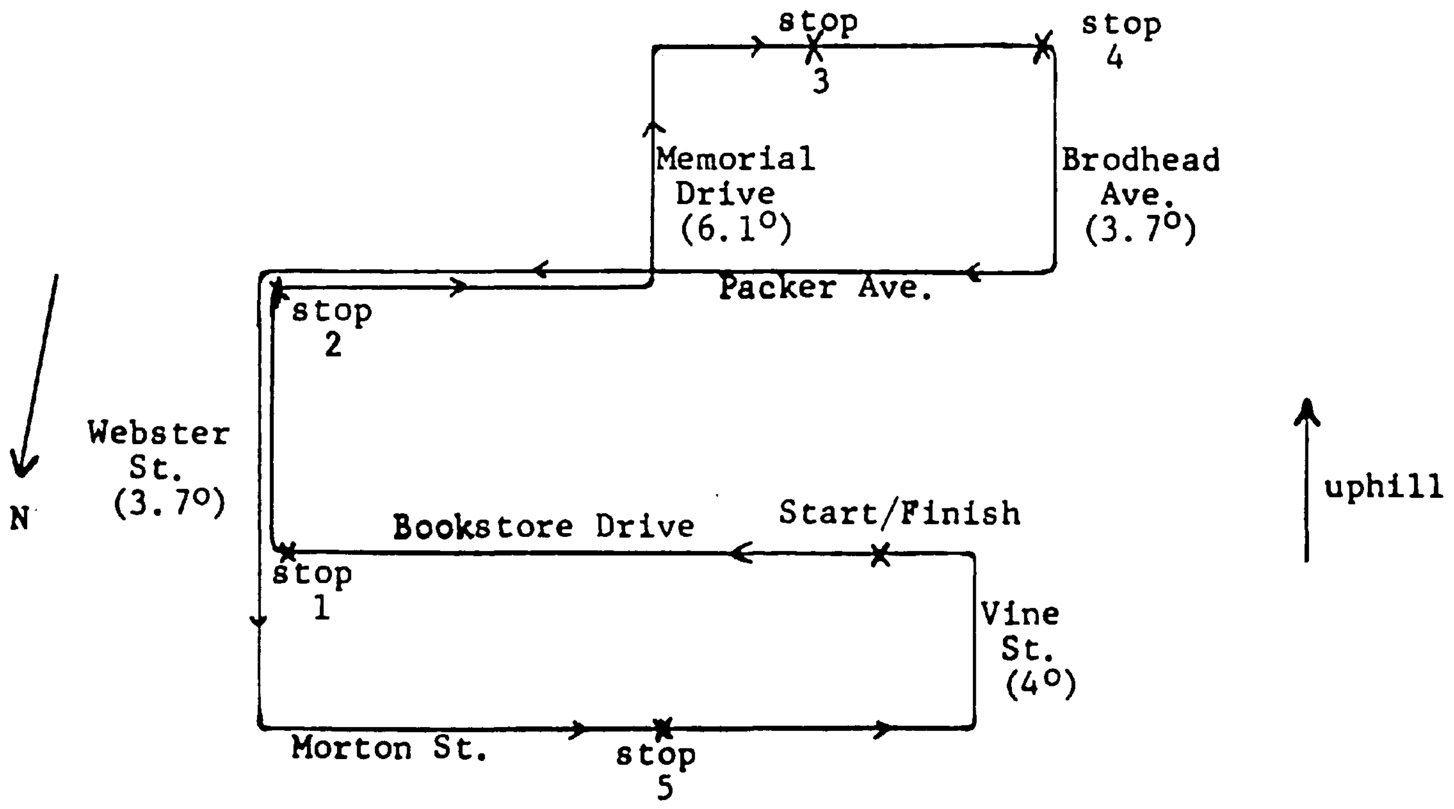


Fig. 26. Campus Run Route

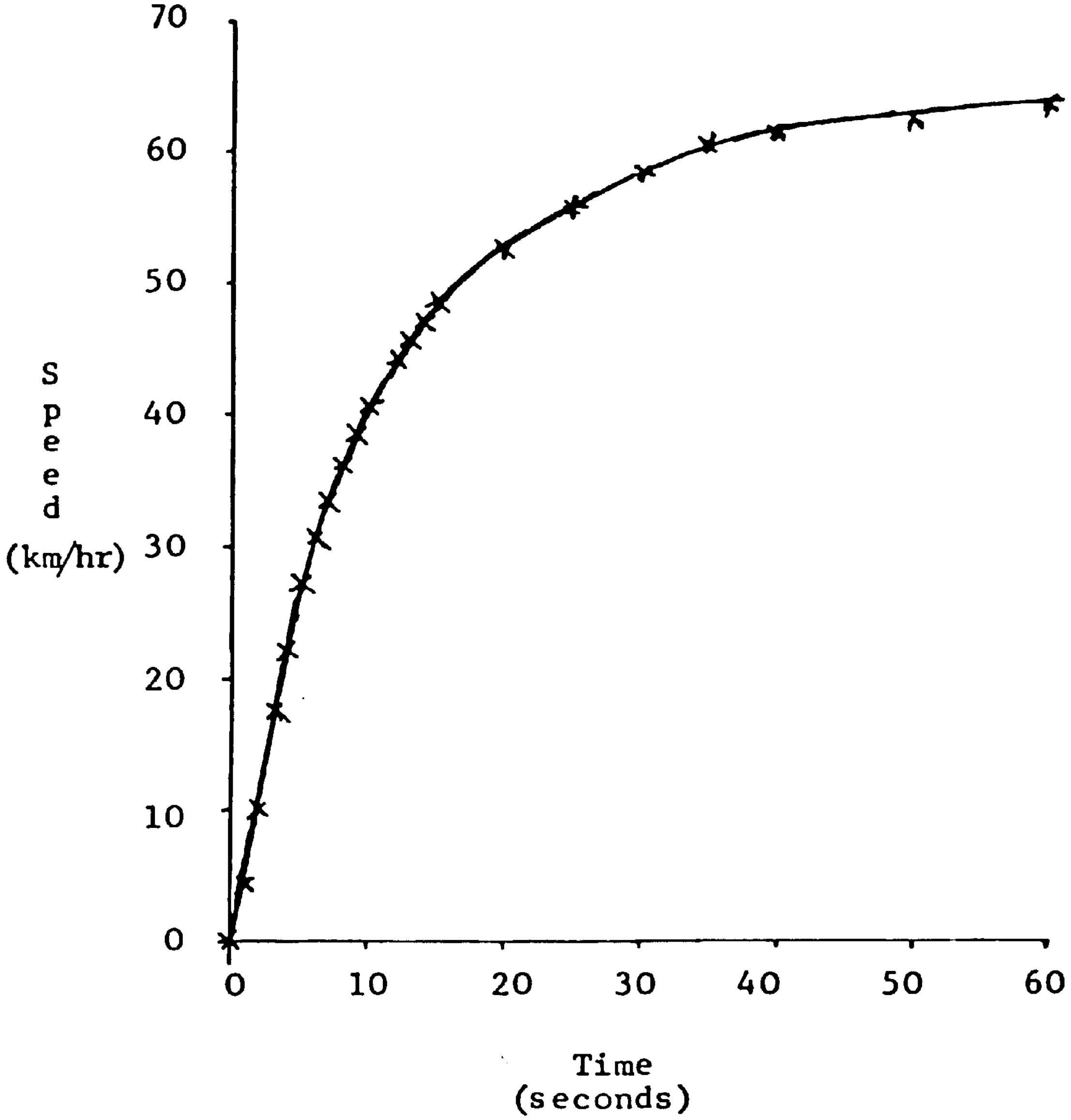


Fig. 27 Average Wide Open Throttle Results (Run 34)

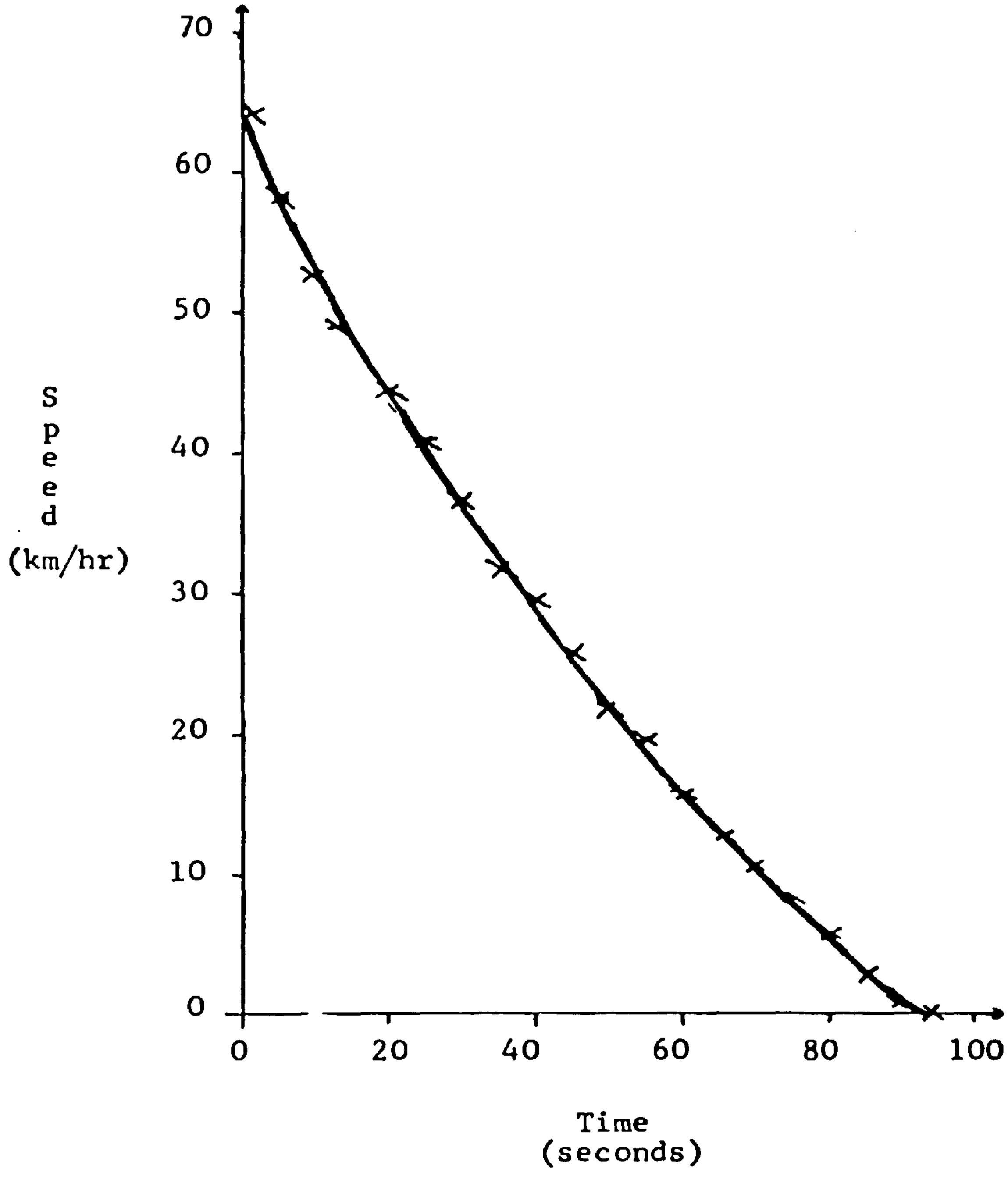


Fig. 28 Average Coast Down Results
(Run 34)

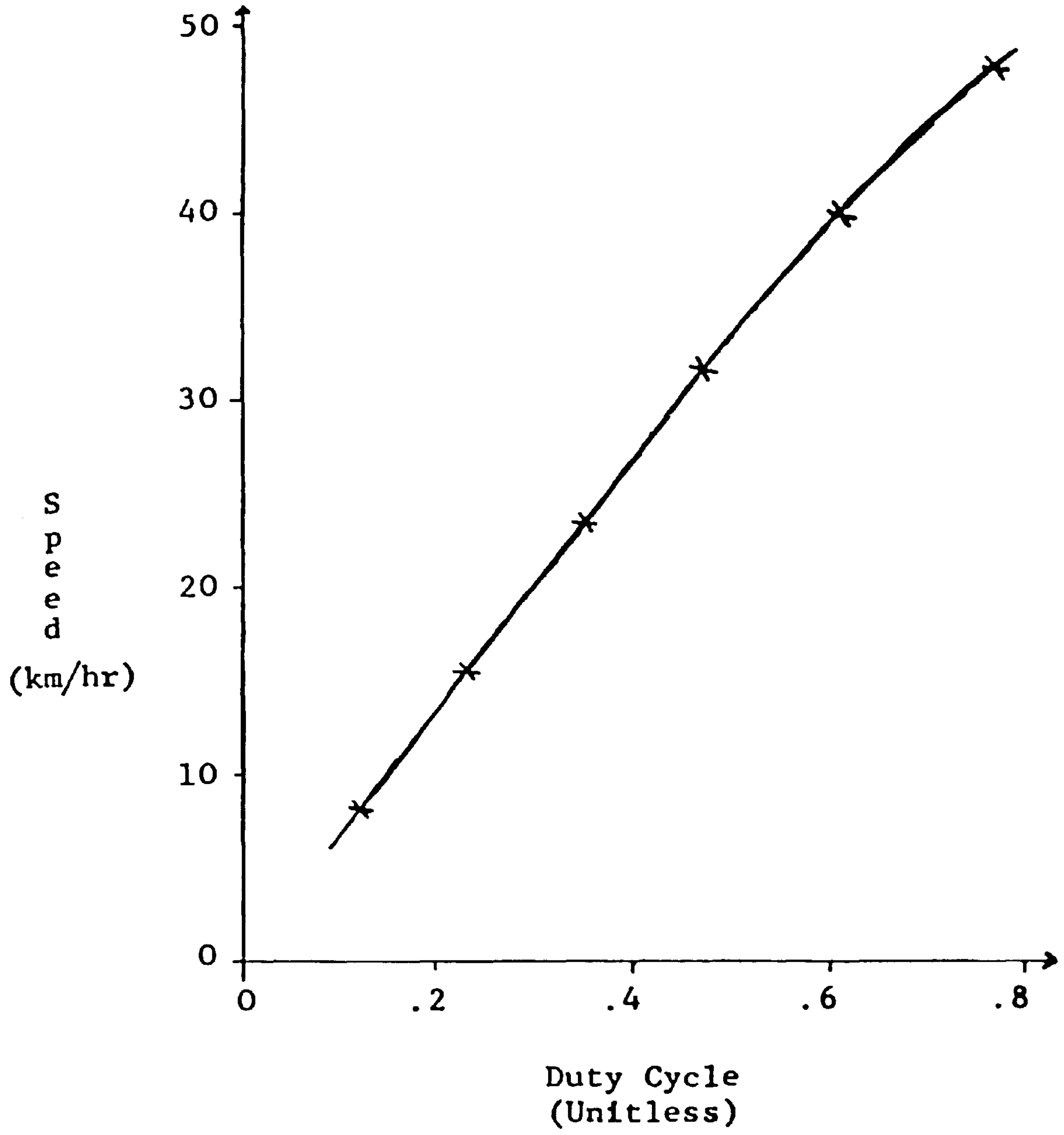


Fig. 29 Constant Speed Results: Speed vs. Duty Cycle

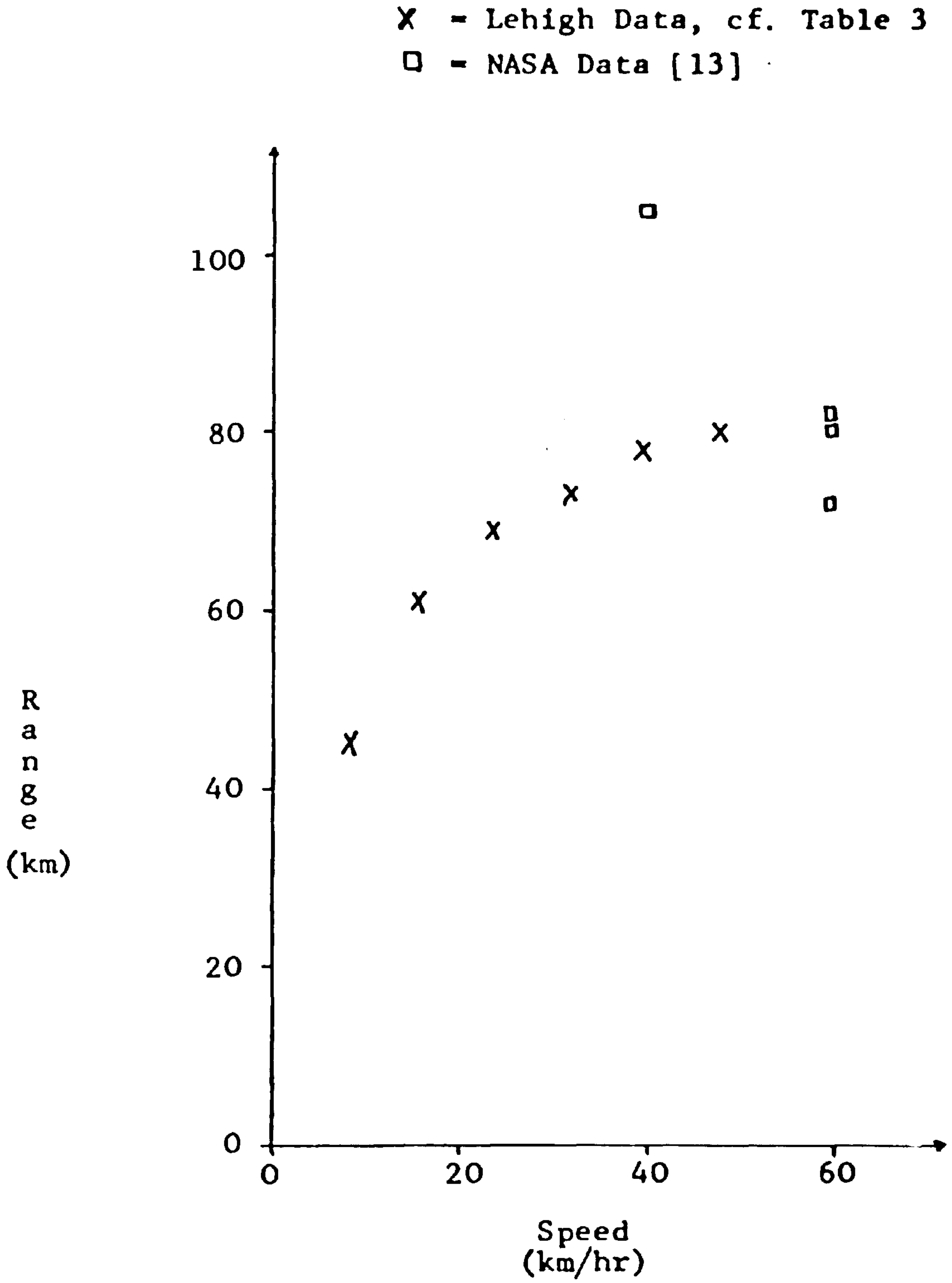


Fig. 30 Constant Speed Vehicle Range Data

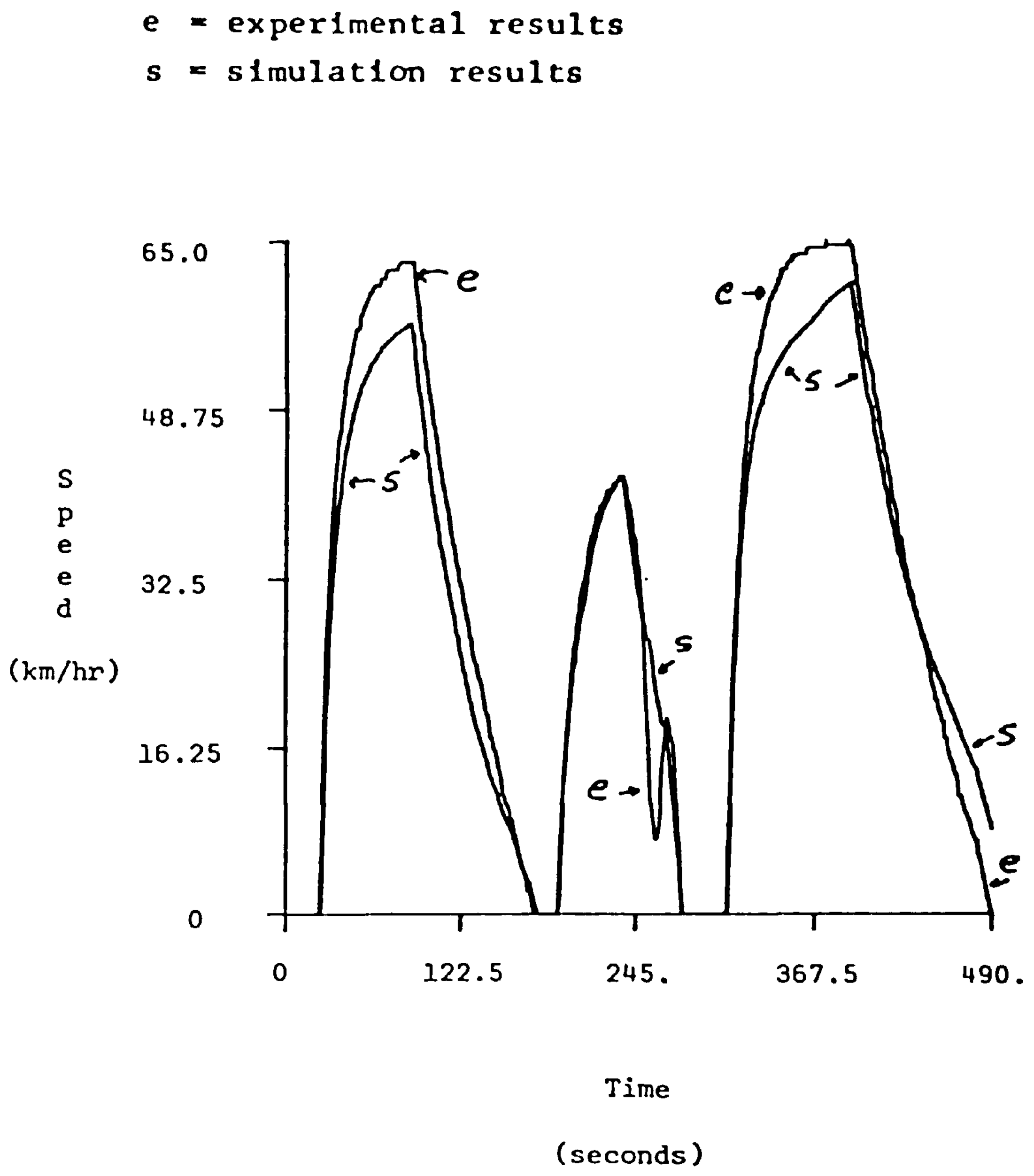


Fig. 31. Simulation Results-
Speed vs. Time

e = experimental results
s = simulation results

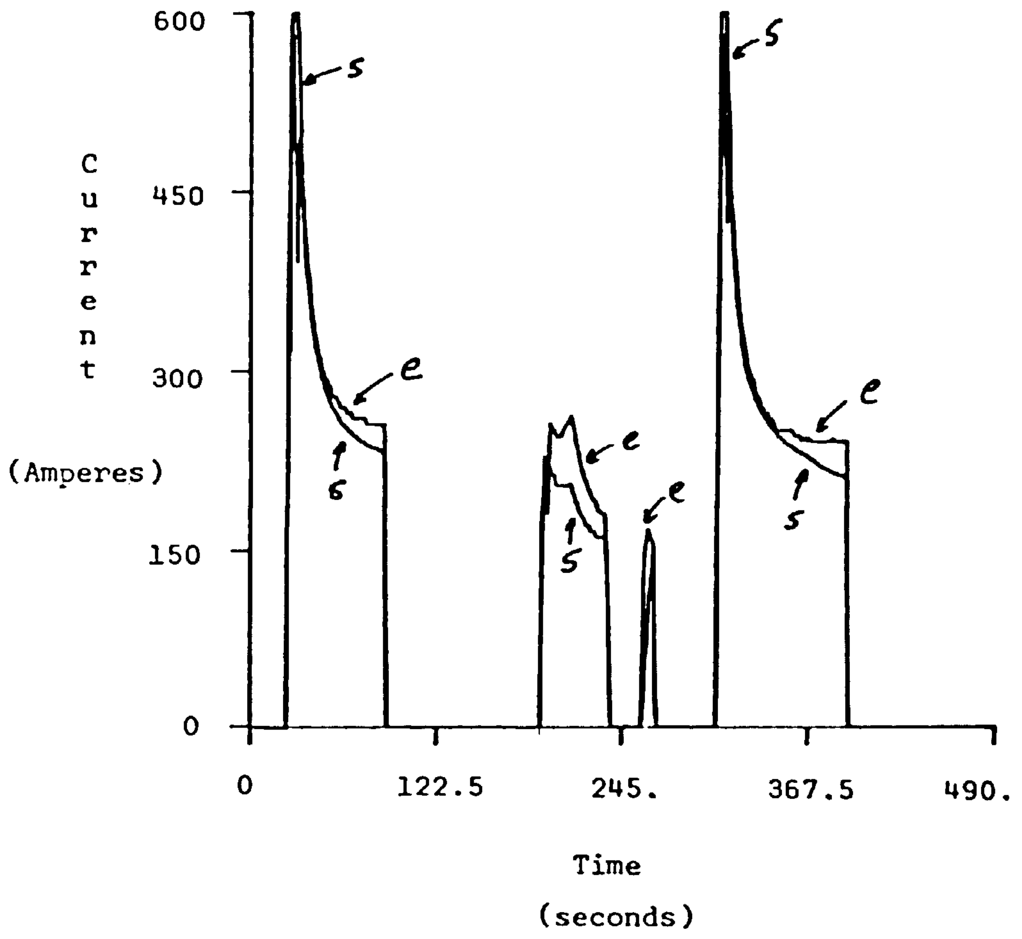


Fig. 32. Simulation Results-

Battery Current vs. Time

e = experimental results
s = simulation results

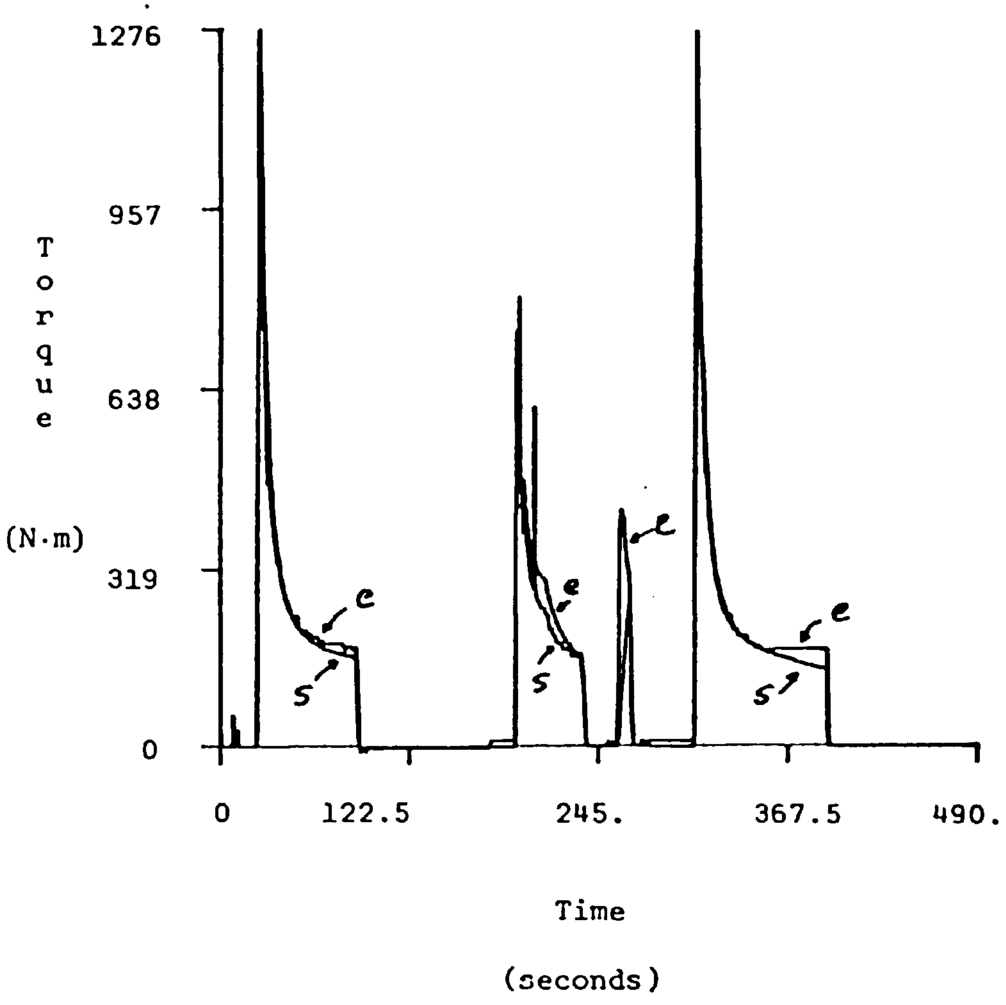


Fig. 33. Simulation Results-
Torque vs. Time

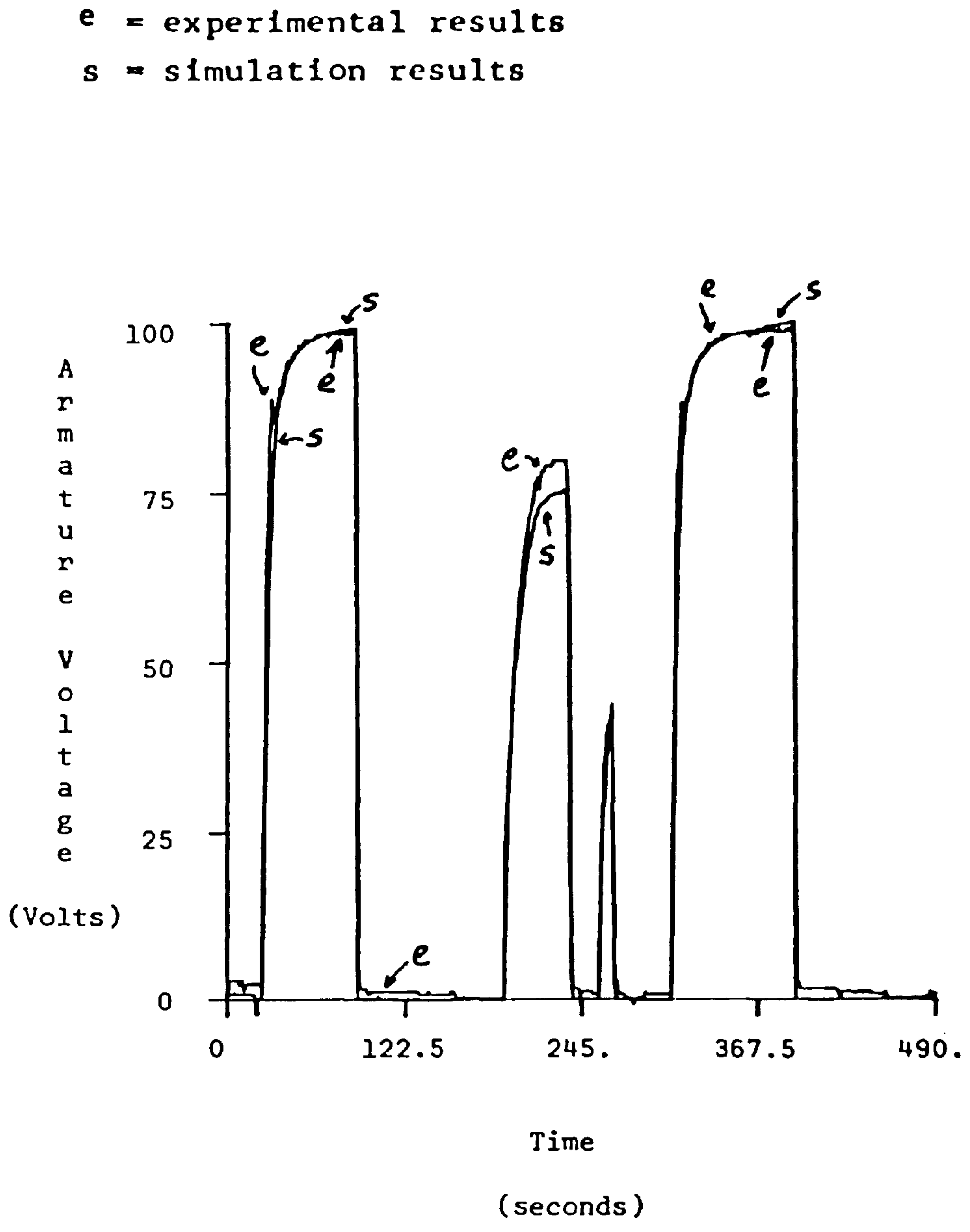


Fig. 34. Simulation Results-
Armature Voltage vs. Time

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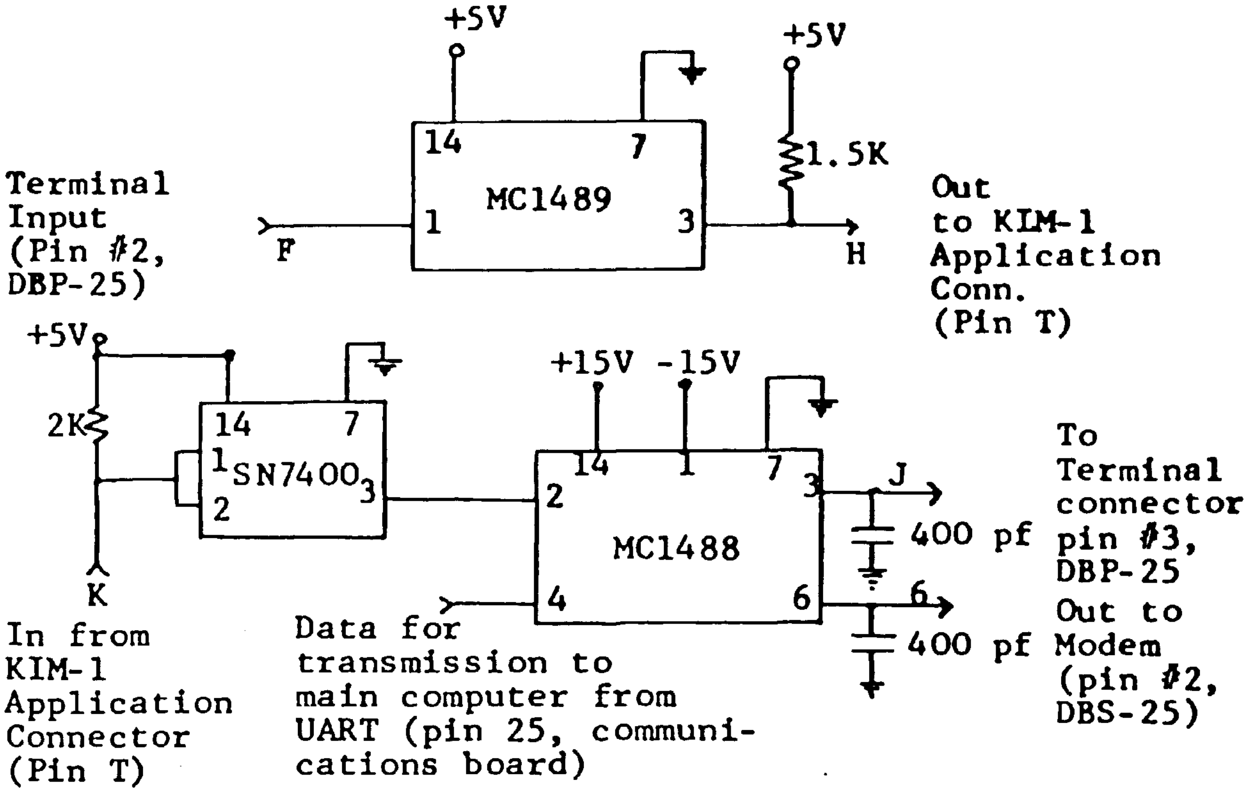
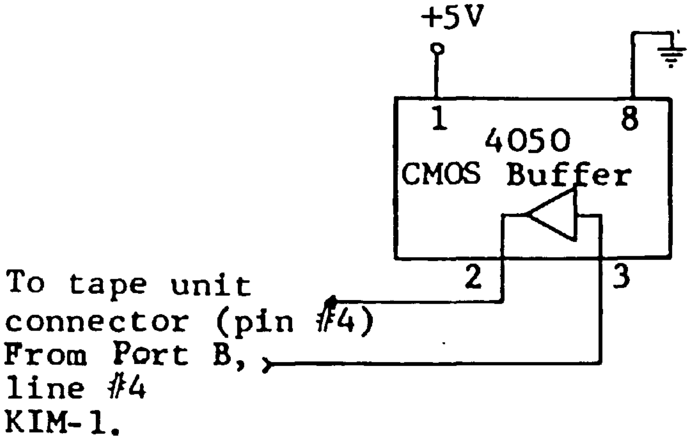
Appendix A - System Schematics

Note: Indicated pin numbers/letters, where not annotated, refer to the board or device in parenthesis below the figure caption.



(a) Terminal Interface



(b) Tape Stop/Start Buffer

Fig. A1 Terminal Interfaces and Tape Stop/Start Foreward Line Buffer (Communications Board)

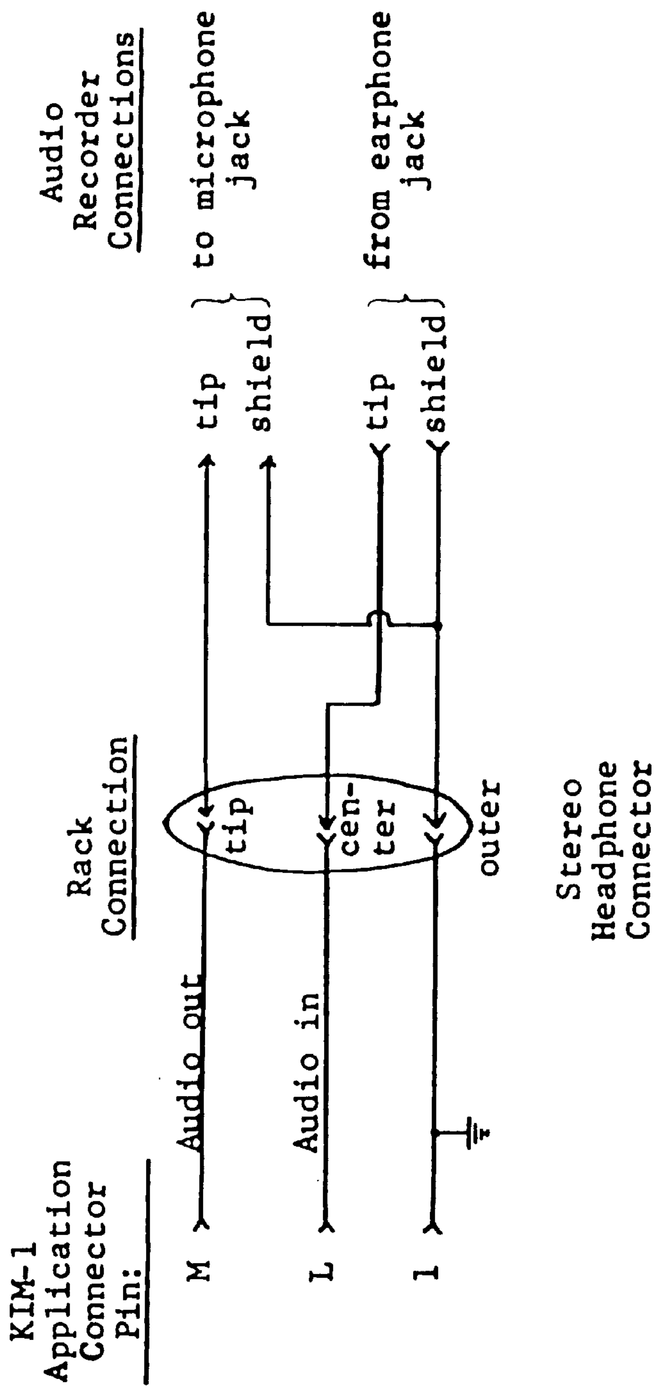


Fig. A2 Audio Cassette Tape Recorder Interface (Microprocessor)

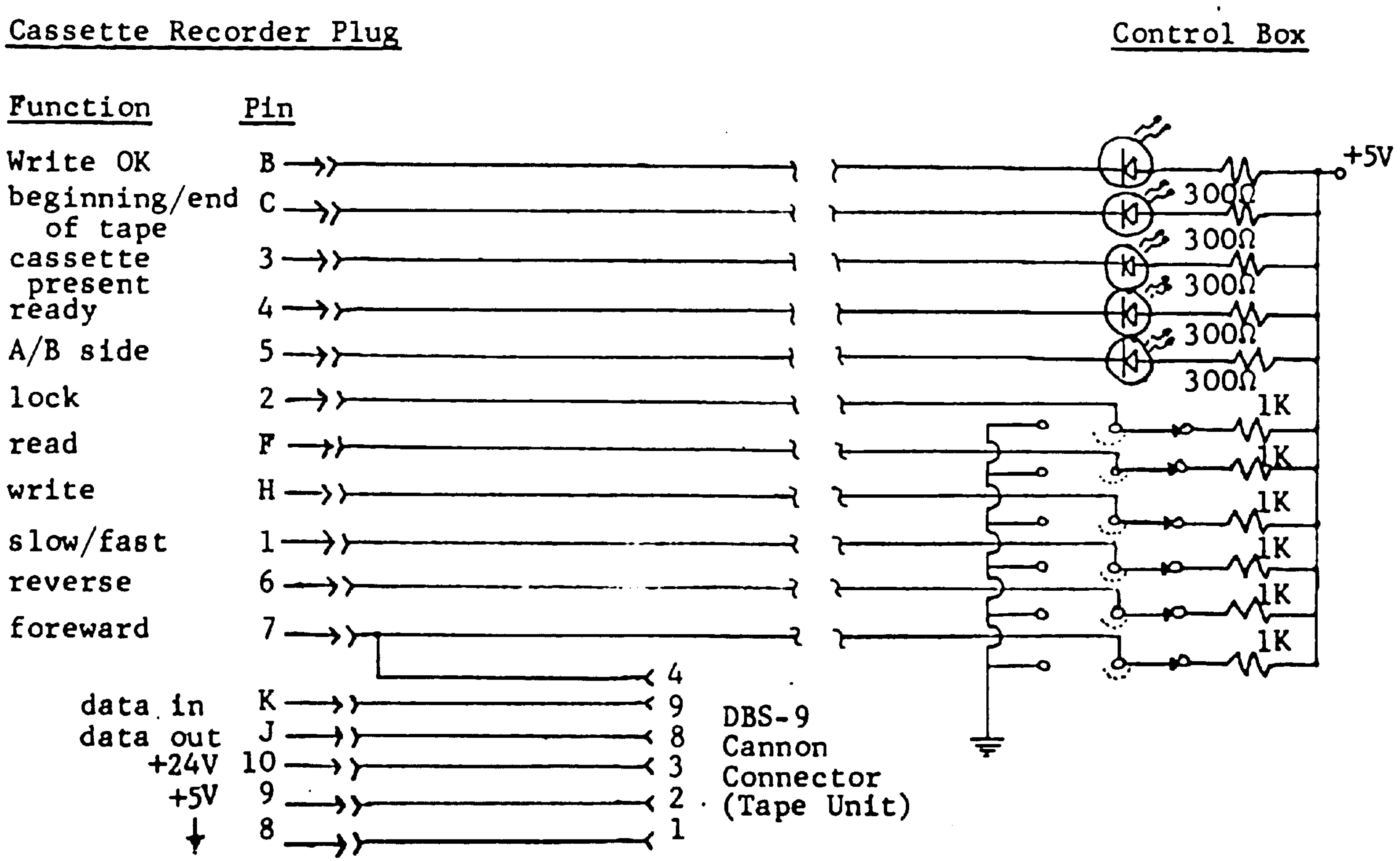


Fig. A3 Digital Cassette Recorder Wiring
(Digital Tape Unit)

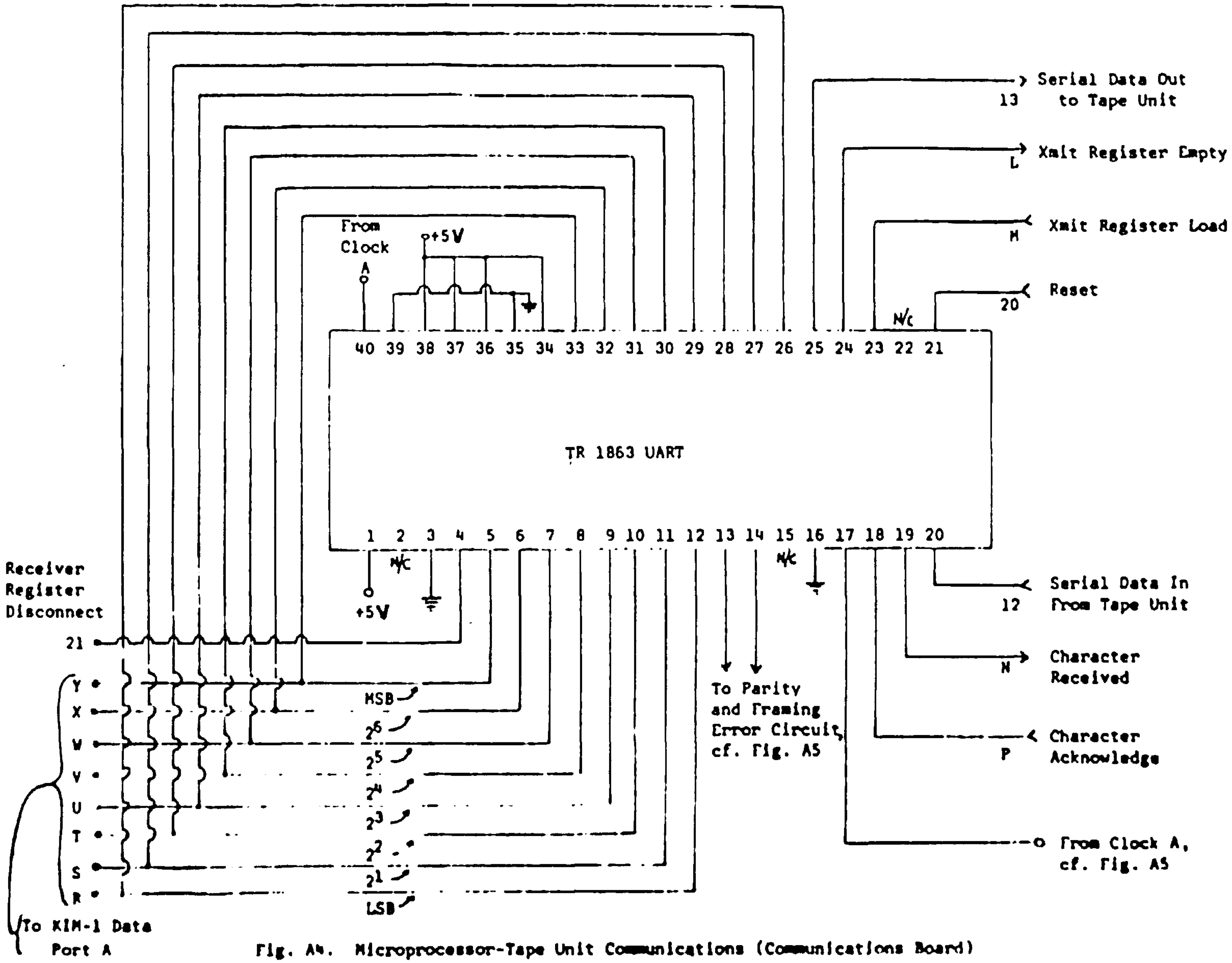


Fig. A4. Microprocessor-Tape Unit Communications (Communications Board)

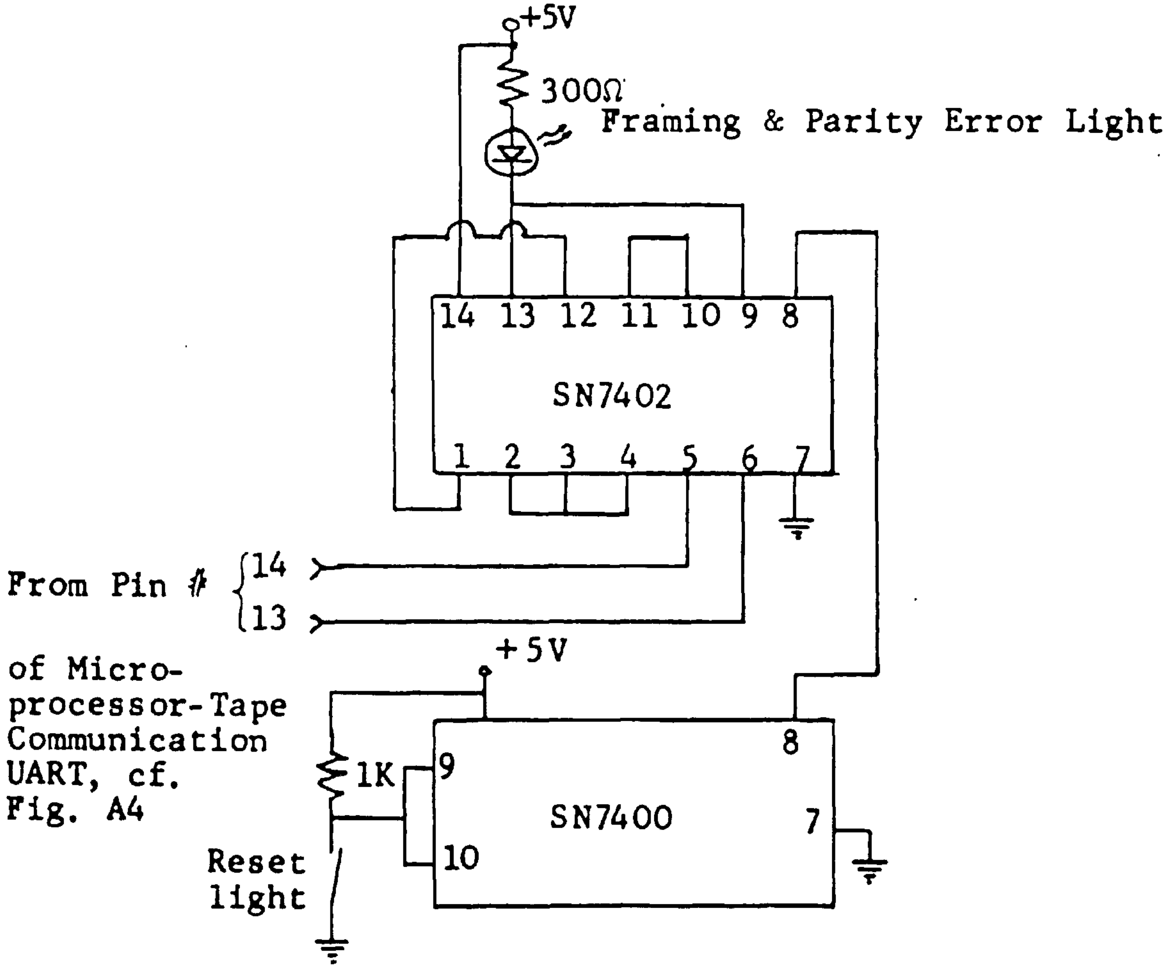


Fig. A5 Parity and Farming Error Latch Hardware (Communications Board)

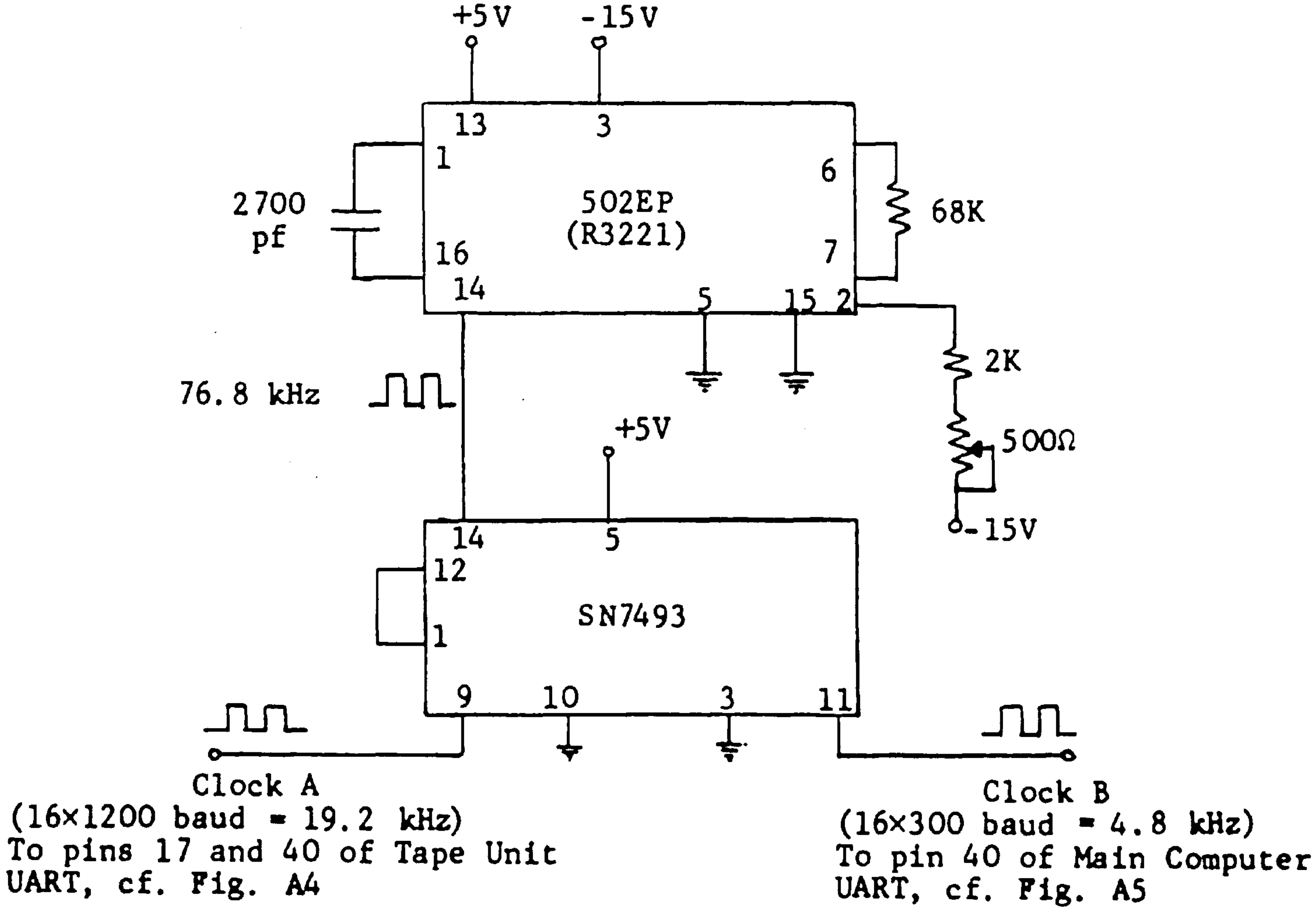


Fig. A6 UART Clock Schematic
(Communication Board)

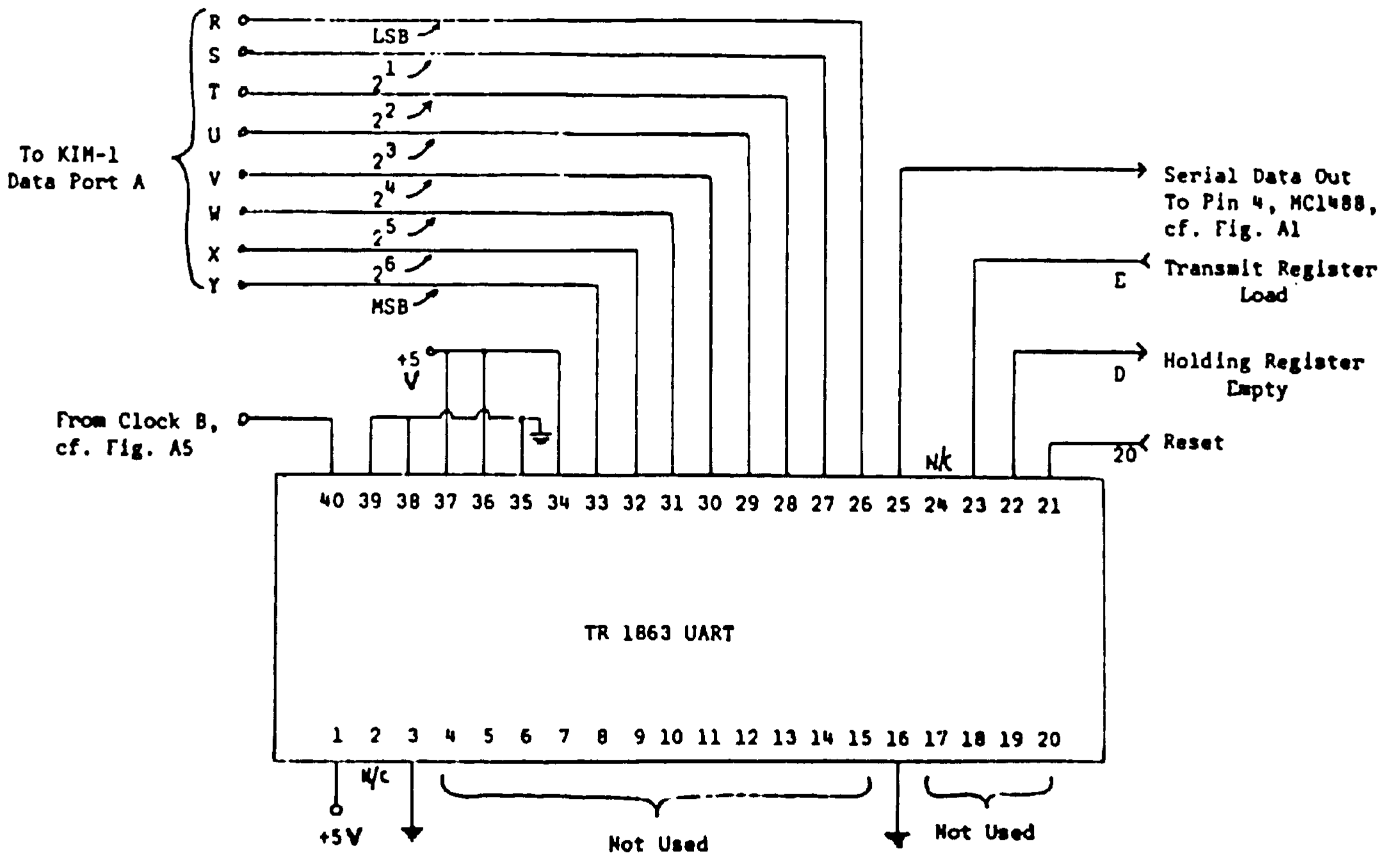


Fig. A7 Microprocessor-Main Computer Communications (Communications Board)

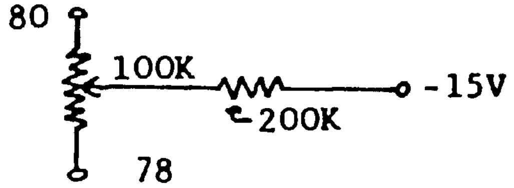
Pin #(s)	Connections to:
Power and Internal Connections	
1, 3, 13, 40, 44, 48, 49, 66	No connection
2	4, 77
14	15
67	68
63	65
51	52, 64, 79
50	+5 Vdc
61	-15 Vdc
62	+15 Vdc
45	+5V thru 1K resistor
80, 78	
Analog Inputs	
5 (IN-0)	Duty Cycle, cf. Fig. A13
6 (IN-1)	Speed, cf. Fig. A17
7 (IN-2)	Accelerometer, cf. Fig. A18
8 (IN-3)	Torque Meter, cf. Fig. A15
9 (IN-4)	Gyroscope, cf. Fig. A19
10 (IN-5)	Field Voltage, cf. Fig. A12
11 (IN-6)	Armature Voltage, cf. Fig. A12
12 (IN-7)	Battery Voltage, cf. Fig. A10
69 (IN-8)	Not Used
70 (IN-9)	Battery Current, cf. Fig. A11
71 (IN-10)	Inner Cell Temperature, cf. Fig. A20
72 (IN-11)	Outer Cell Temperature, cf. Fig. A20
73 (IN-12)	Field Weakening Monitor, cf. Fig. A14
74 (IN-13)	Distance, cf. Fig. A16
75 (IN-14)	Bypass Monitor, cf. Fig. A14
76 (IN-15)	Not Used

Fig. A8 MP-21 Analog Input System Connections

Address Bus and Address Select

16 → 20	A0 → A4	
22	A5	
24	A6	
26	A7	
28	A8	
30	A9	
32	A10	
34	A11	
36	A12	
38	A13	
41	A14	
43	A15	
33	⏚	
21, 23, 25, 27, 29, 31, 35, 37, 39	} +5V thru 1K resistor -	Base Address Selected is $1C00_{16}$

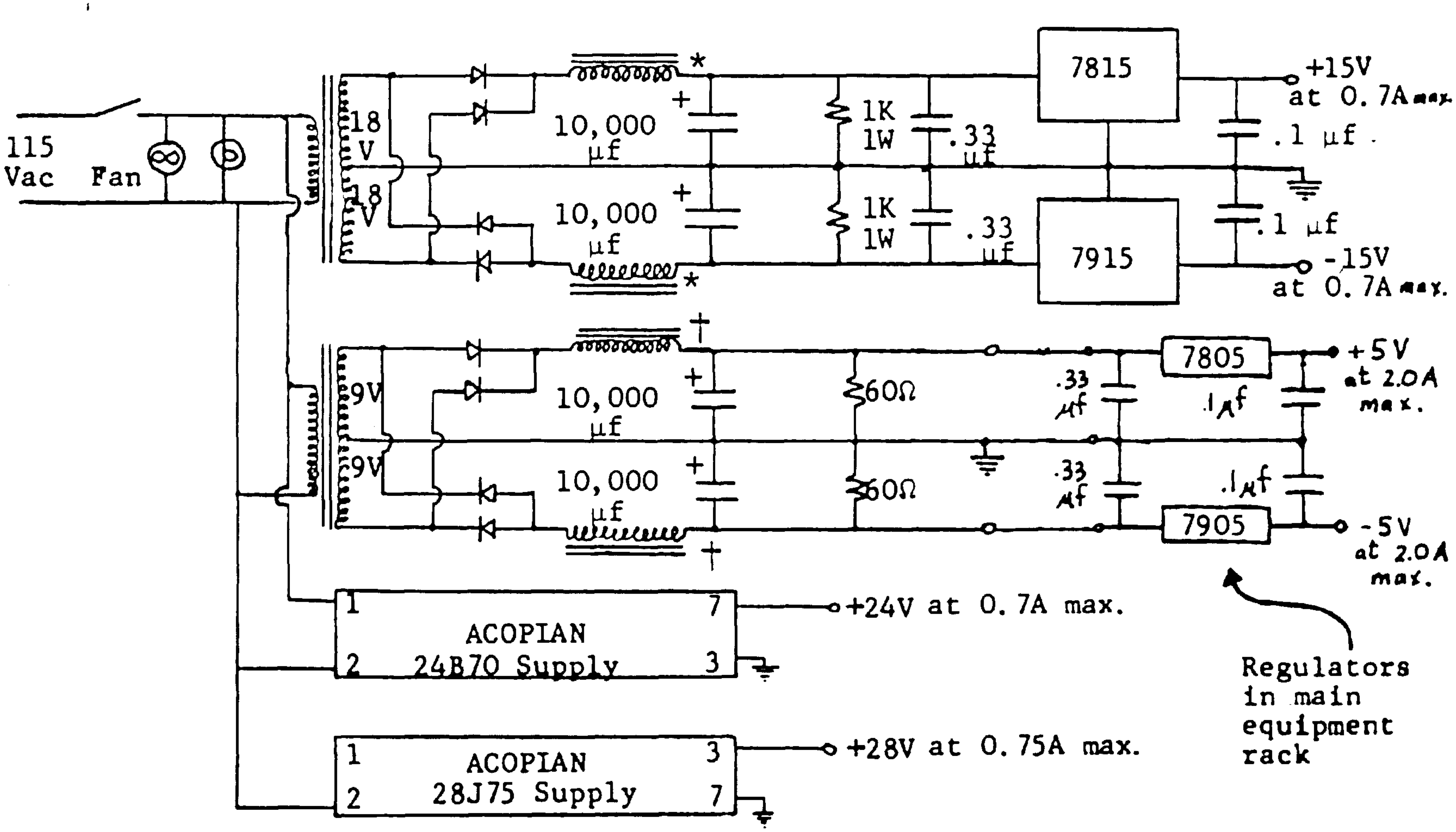
Data Bus

60 → 53	D0 → D7

Microprocessor Signals

42	R/$\overline{W}$
46	ϕ_2 Clock
47	$\overline{\text{Reset}}$

Fig. A8 (Continued) MP-21 Analog Input System Connections



All diodes 5A,100 PIV

* - Each choke is a secondary winding of a 115/25V filament transformer

† - Each choke is a secondary winding of a 115/6.3V filament transformer.

Fig. A9 115 Vac Power Supply System

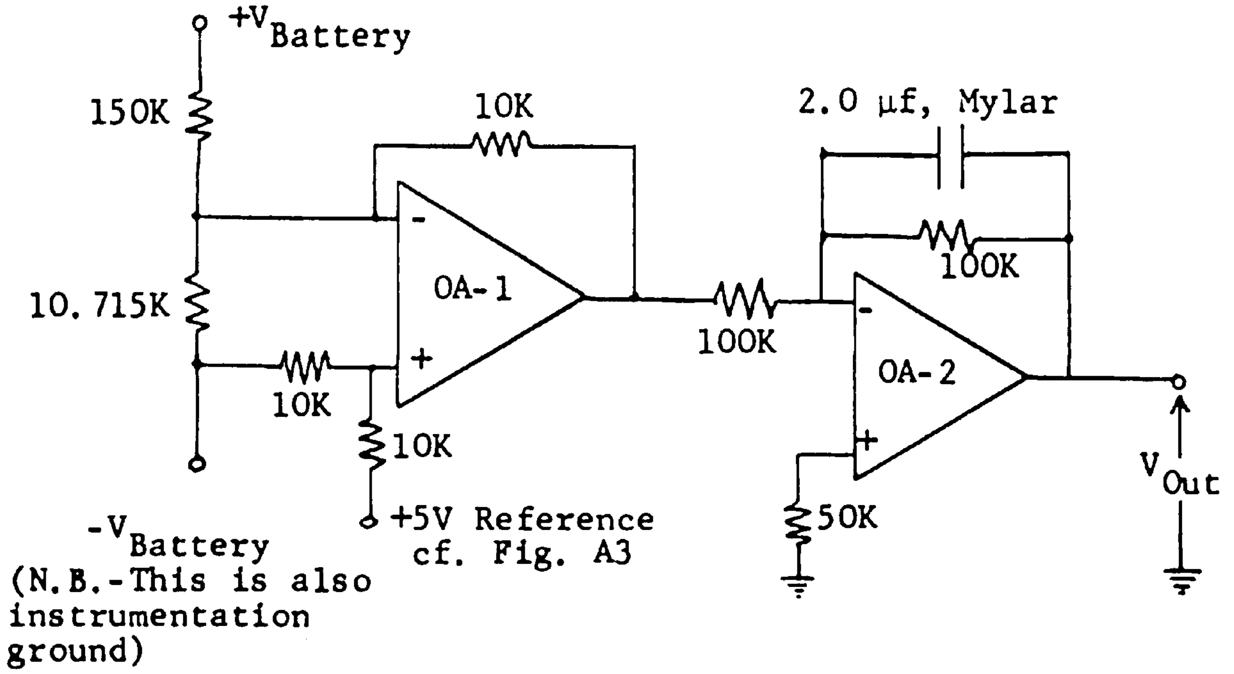


Fig. A10 Battery Voltage Sensing and Conditioning Circuit

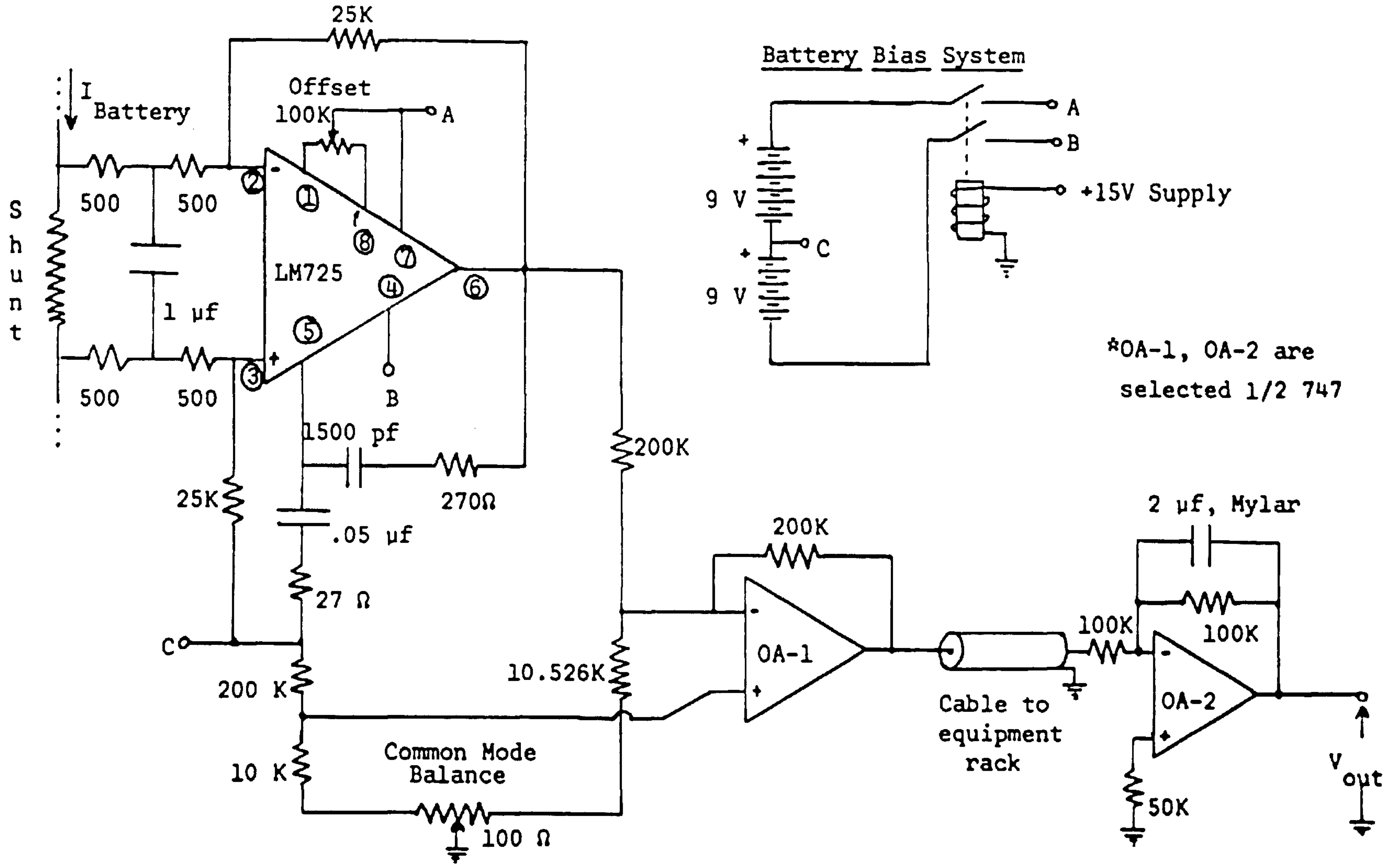


Fig. All Current Shunt and Amplifier System

Measurement	Rx	Ry
Armature	200K	66.6K
Field	50K	33.3K

Op amps are each ½ 747

All resistors are selected (1% precision)

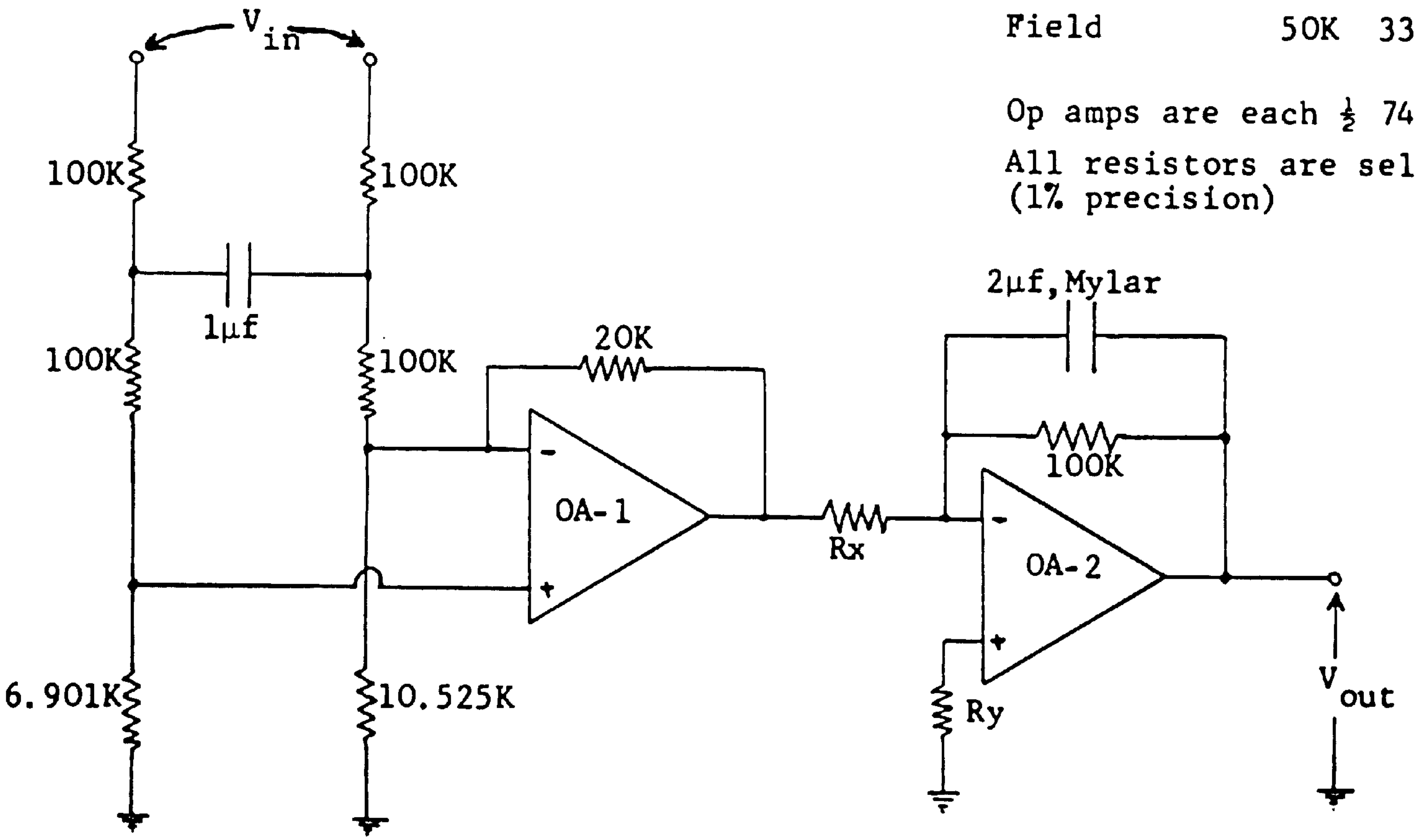
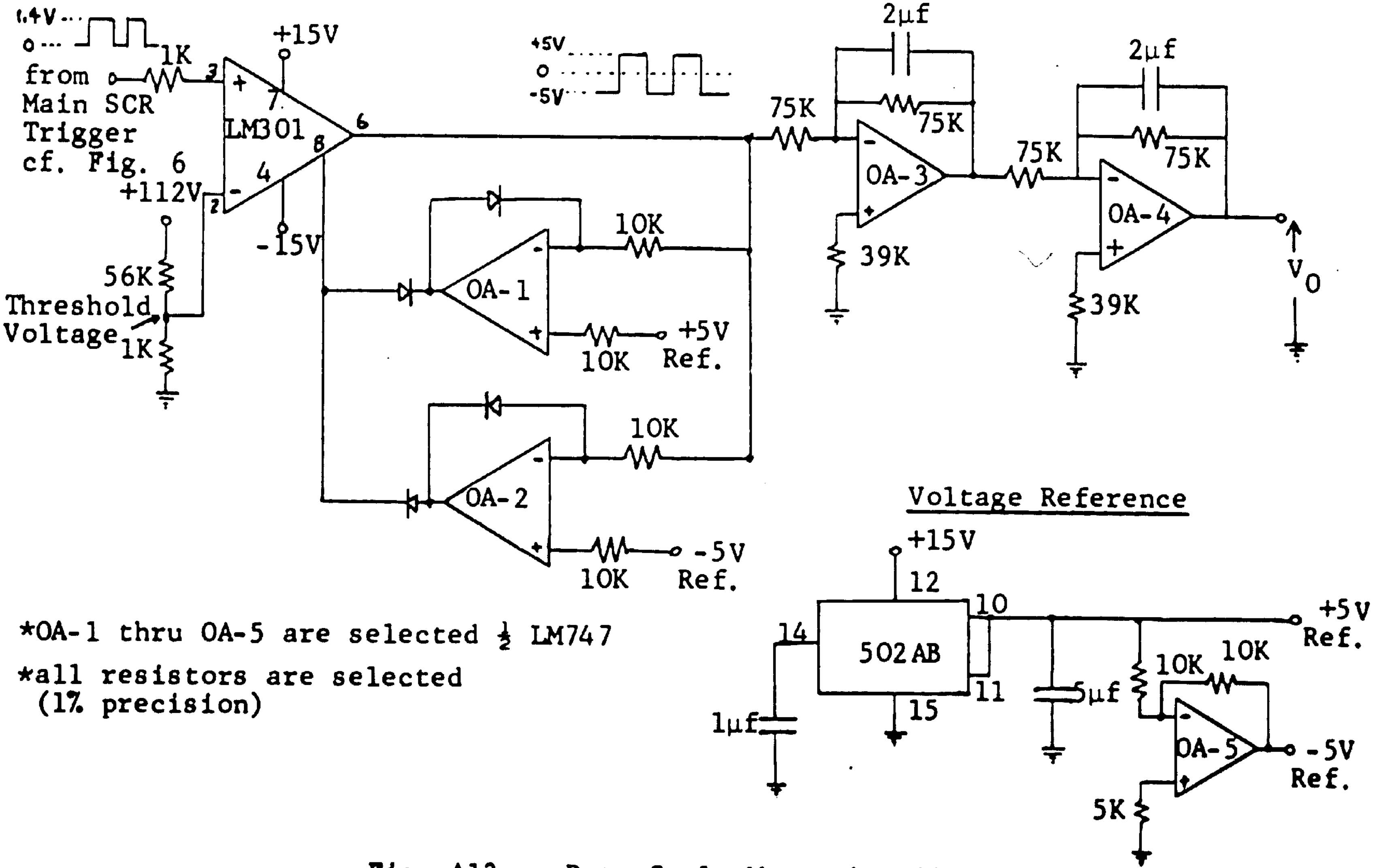


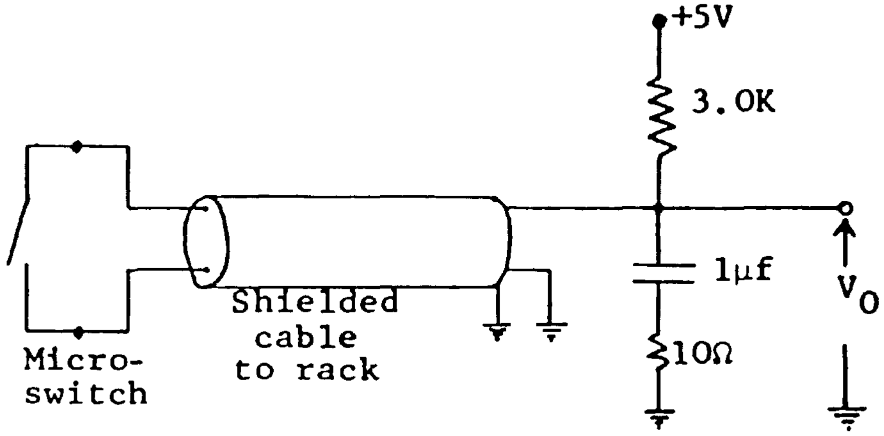
Fig. A12 Armature and Field Voltage Sensing Circuit



*OA-1 thru OA-5 are selected ½ LM747

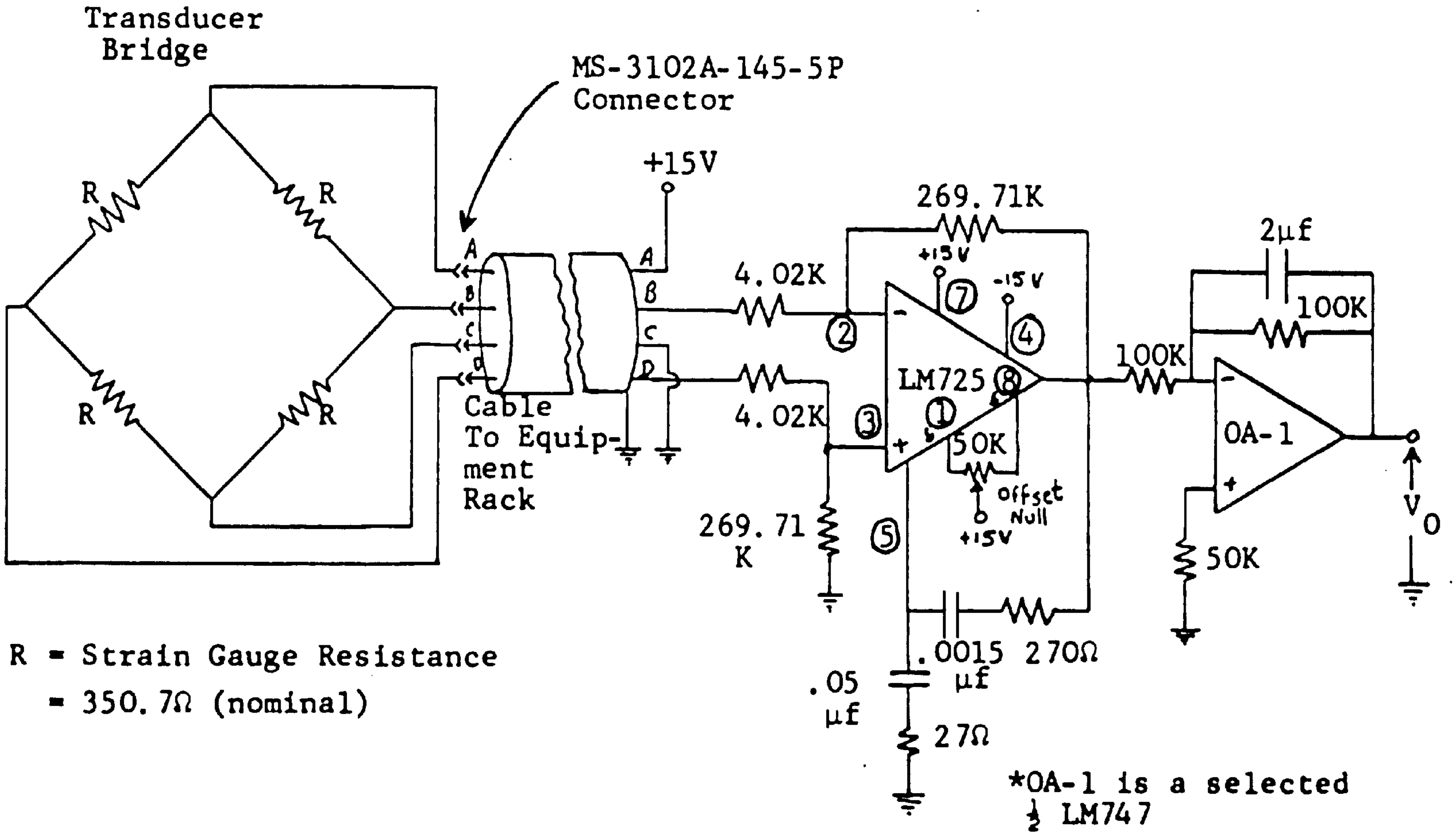
*all resistors are selected
(1% precision)

Fig. A13 Duty Cycle Measuring Circuitry



Contactor Function	Switch State During Function
Bypass	Closed
Field Weakening	Open

Fig. A14 Bypass and Field Weakening Monitor Circuits

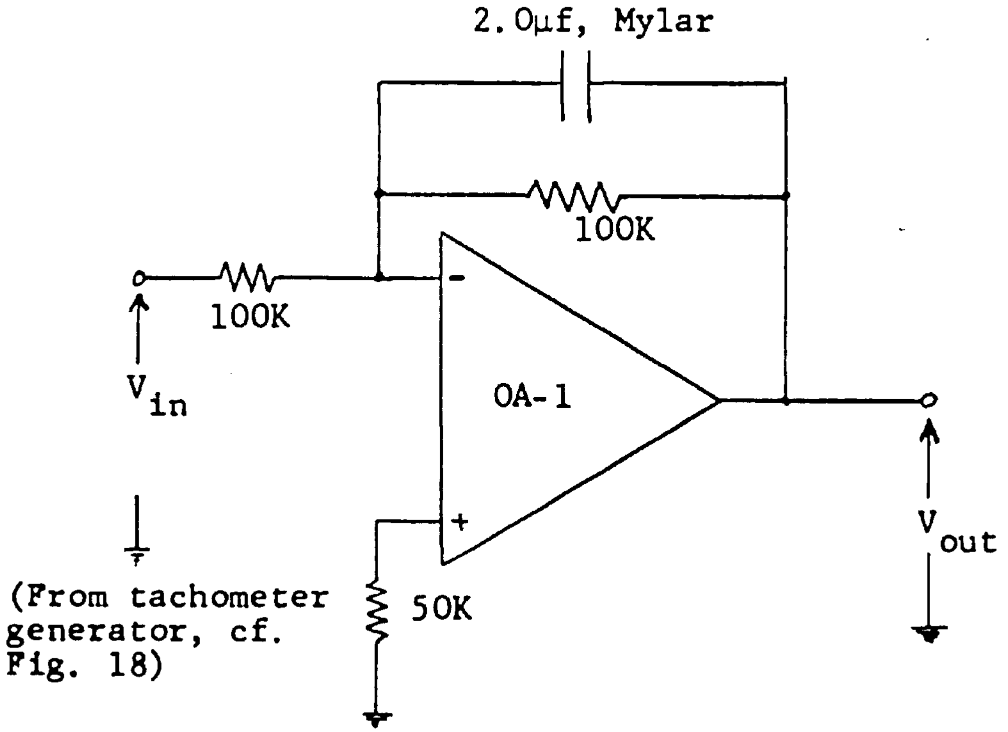


R = Strain Gauge Resistance
= 350.7Ω (nominal)

*OA-1 is a selected
½ LM747

*Resistors are selected
(1% precision)

Fig. A15 Torque Transducer and Amplifier



Op amp is a selected ½ 747

All resistors are selected, 1% tolerance

Fig. A16 Low Pass Filter For Speed Sensor

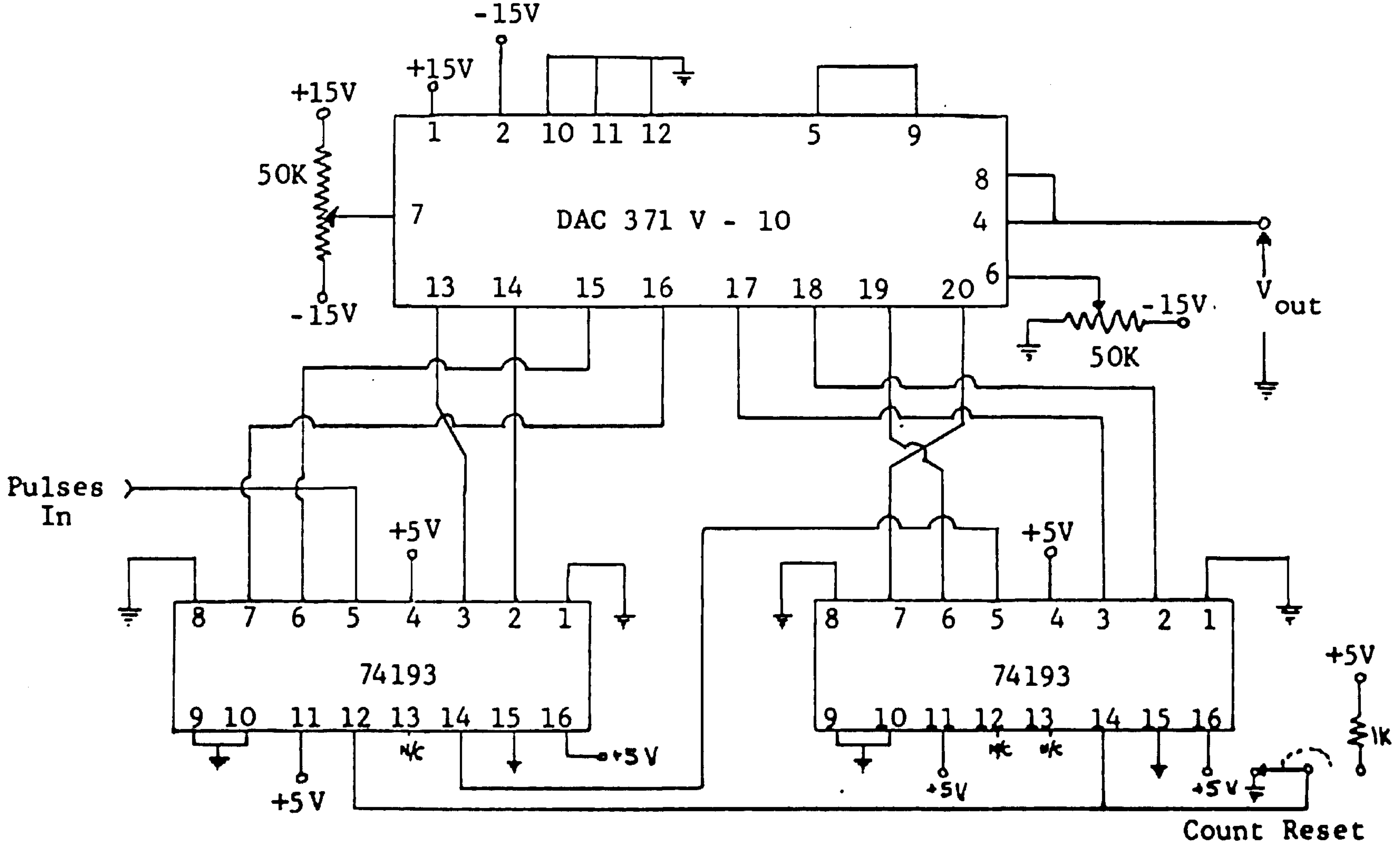


Fig. A17 Distance Pulse Converter Circuitry

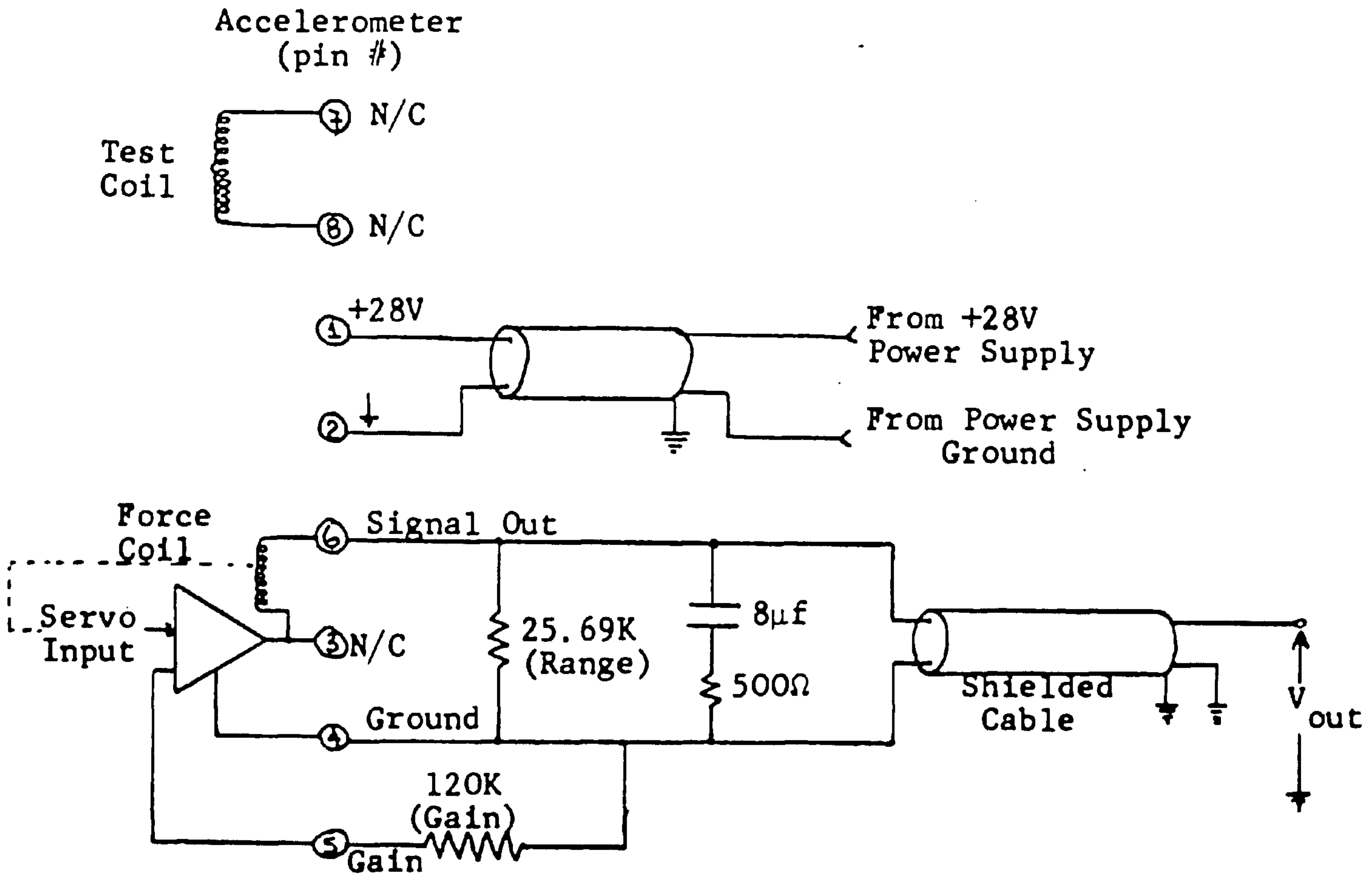


Fig. A18 Accelerometer Circuit Diagram

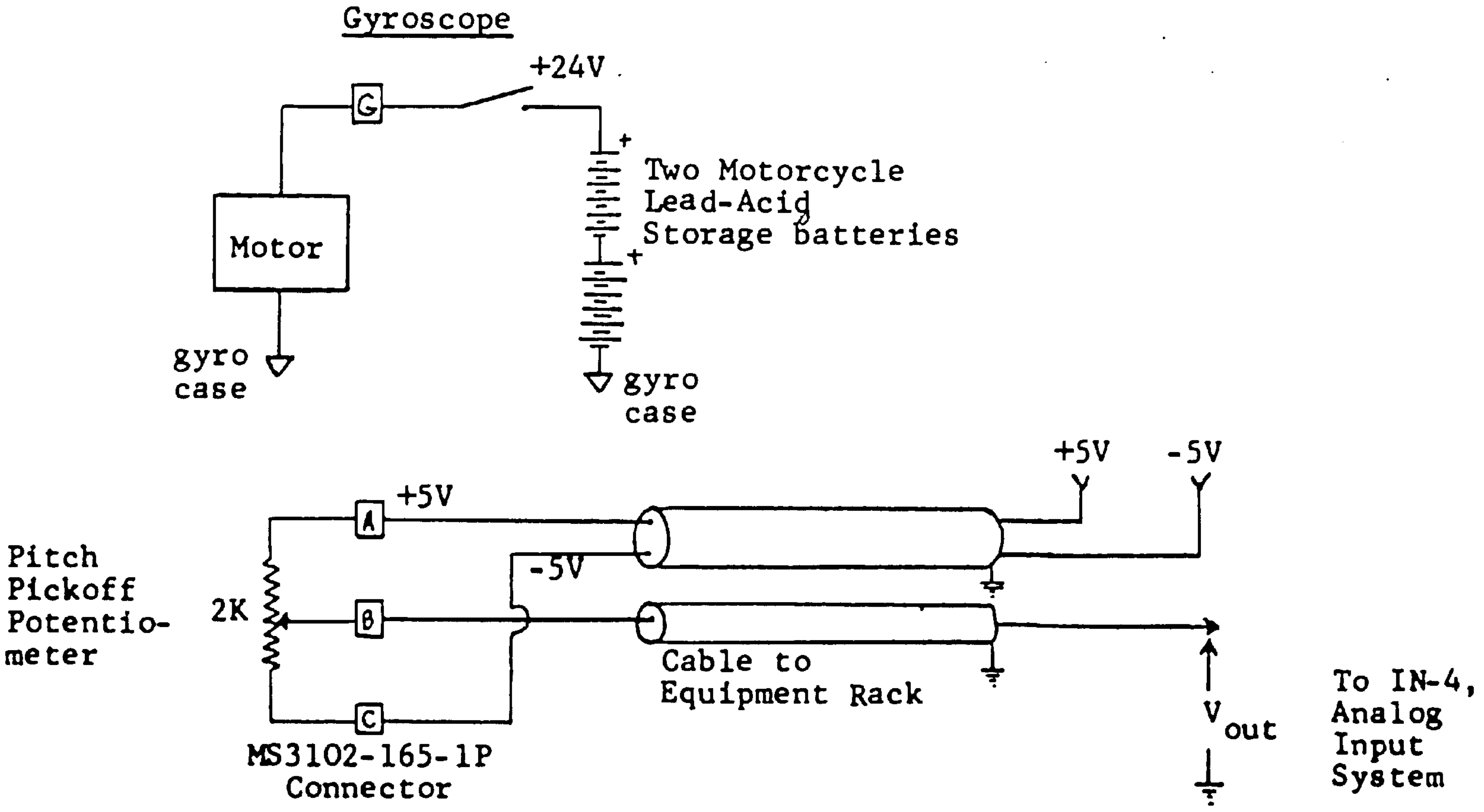


Fig. A19 Gyroscope Connections

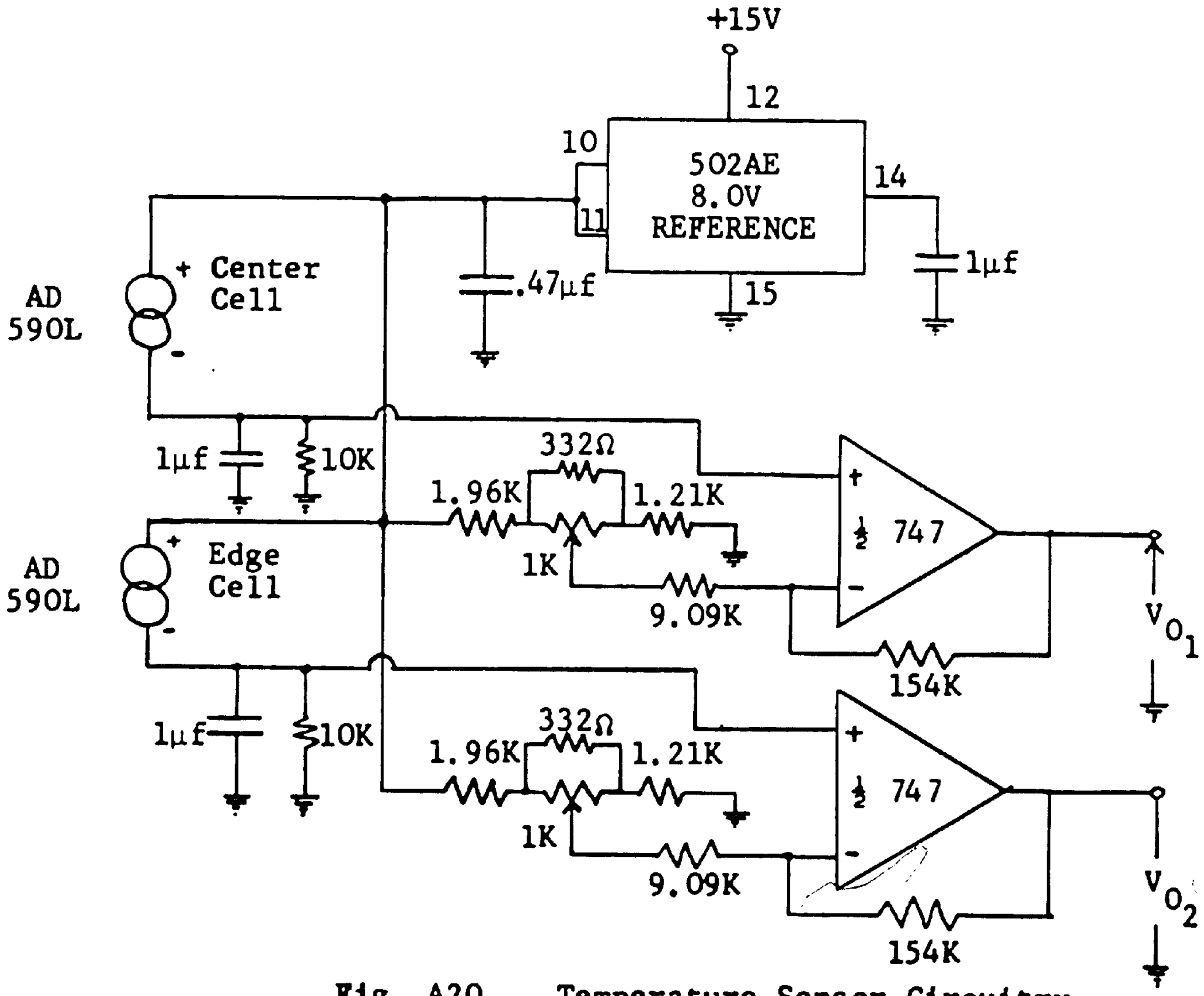


Fig. A20 Temperature Sensor Circuitry

Appendix B

Vehicle Summary Data Sheet

Vehicle manufacturer: Battronic Truck Corp.
Boyertown, Pa.

Vehicle: Battronic Minivan

Price and availability: $15,000; production upon request

Vehicle weight and load

1. Curb weight, kg (lbm): 2690 (5930)
2. Gross vehicle weight, kg (lbm): 2858 (6300)
3. Cargo weight, kg (lbm): 227 (500)
4. Number of passengers: 6
5. Payload, kg (lbm) 363 (800) including driver

Vehicle size

1. Wheelbase, m (in.): 2.40 (94.5)
2. Length, m (in.): 3.69 (145)
3. Width, m (in.): 1.98 (77.9)
4. Height, m (in.): 2.27 (89)
5. Head room, m (in.): 1.10 (43.5)
6. Leg room, m (in.): 0.37 (14.5)
7. Frontal area, m^2 (ft^2): 3.9 (42)
8. Road clearance, cm (in.): 33 (13)
9. Number of seats: 6

Auxiliaries and options

1. Lights (number, type and function): 2 headlamp; 2 park; 2 brake; 1 backup; 2 sidelights at rear; 2 sidelights and directional front and rear
2. Windshield wipers: yes
3. Windshield washers: yes
4. Defroster: yes
5. Heater: yes (Hunter UH-47-6; gasoline, 7.57 liter (2 gal))
6. Radio: No
7. Fuel gauge: yes (Curtis 11611)
8. Amperemeter: armature and 12-volt auxiliary battery
9. Tachometer: no
10. Speedometer: yes

11. Odometer: yes (and trip mileage indicator)
12. Right- or left-hand drive: left
13. Transmission: 2 speed; 1:1 and 1:1.96 ratios
14. Regenerative braking: no
15. Mirrors: left and right outside; interior
16. Power steering: no
17. Power brakes: no

Battery

Propulsion battery

1. Type and manufacturer: General Battery Corp. Type 56-EV-330
2. Number of modules: 2
3. Number of cells: 56 (28 per module)
4. Operating voltage, V: 112
5. Capacity, Ah: 330 (at a 6 h discharge rate)
6. Size of each module, m (in.): height, 0.58 (23); width, 0.50 (19.5); length, 0.96 (37.75)
7. Weight, kg (lbm): 1043 (2300)
8. History (age, number of cycles, etc.): Not available

Auxiliary battery

1. Type and manufacturer: Titan Series 6000 Group 27; General Battery Corp.
2. Number of cells: 6
3. Operating voltage, V: 12
4. Capacity, Ah: 36
5. Size, m (in.): height, 0.20 (8); width, 0.17 (6.5); length, 0.30 (12)

Controller

1. Type and manufacturer: 510 R; SCR; General Electric
2. Voltage rating, V: 112
3. Current rating, A: 500
4. Size, m (in.): components on a mounting plate: width, 0.47 (18.5); length, 1.07 (42

Propulsion motor

1. Type and manufacturer: dc traction series; General Electric, 5 BT 2376C6
2. Insulation class: F (115°C)
3. Voltage rating, V: 94

4. Horsepower (rated), kW (hp): 31.5 (42) (0.4-h duty)
5. Size, m (in.): diameter, 0.33 (13); length, 0.61 (24)
6. Speed (rated), rpm: 2300

Battery charger

1. Type and manufacturer: EV 112 A/C 30; C&D Batteries, Division of Eltra Corp.
2. On- or off-board type: on-board
3. Input voltage required, V: 120/208/240
4. Peak current demand, A: 30/15
5. Recharge time, h: variable
6. Size, m (in.): height, 0.55 (21.5); width, 0.25 (10); length, 0.56 (22)
7. Automatic turnoff feature: yes

Body

1. Manufacturer and type: Battronic van
2. Materials: steel
3. Number of doors and type: 3; left and right sliding; rear, hinged
4. Number of windows and type: 2 pane windshield; 1 pane each front quarter; 2 pane sliding each side door; 1 pane each rear quarter; 1 pane rear door
5. Number of seat and type: 1 bucket, front; 5 fiberglass bucket, in cargo area
6. Cargo space volume, m^3 (ft^3): 4.76 (168)
7. Cargo space dimensions, m (ft): height, 1.63 (64); width, 1.83 (72); length, 1.83 (72), minus wheel well

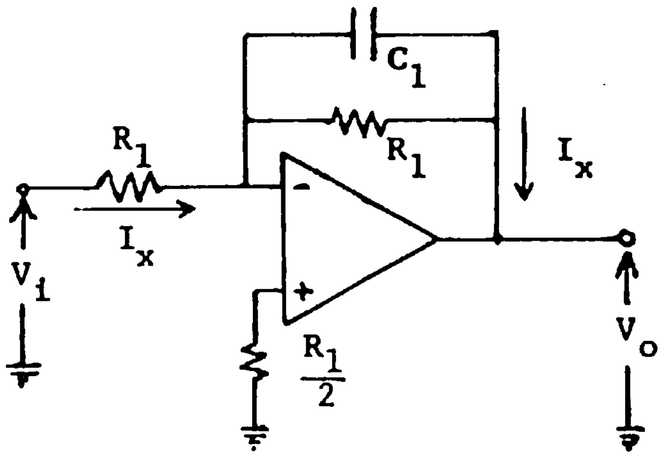
Chassis

1. Frame
   A. Type and manufacturer: Battronic Truck Corp.; box
   B. Materials: steel
2. Springs and shocks
   A. Type and manufacturer: springs - 6 leaf laminated; shocks - direct-acting hydraulic cylinders
   B. Modifications: none

3. Axles
   - A. Manufacturer: Spicer (Dana)
   - B. Front: Clark
   - C. Rear: Semi-floating, hypoid gears, flanged axle shafts
4. Transmission
   - A. Gear ratios: rear axle, 3.07; transfer box, 1:1 and 1:1.96
   - B. Driveline ratio: 6.02:1 and 3.07:1
5. Steering
   - A. Type and manufacturer: worm and nut (recirculating ball); Saginaw
   - B. Turning ratio: 24:1
   - C. Turning diameter, m (ft): 11.3 (37)
6. Brakes
   - A. Front: hydraulic drum
   - B. Rear: hydraulic drum
   - C. Parking: mechanical on rear axle; two-position cable
   - D. Regenerative: no
7. Tires
   - A. Manufacturer and type: Firestone; Transport 110, 6-ply rating, load range C
   - B. Size: 6.70-15
   - C. Pressure, kPa (psi):
     Front: 310 (45)
     Rear: 310 (45)
   - D. Rolling radius, m (in.): 0.33 (12.9)
   - E. Wheel weight, kg (lbm):
     with drum: 23 (50.7)

Appendix C. Signal Conditioning Requirements

Consider a single stage low pass filter:



The transfer function of this circuit, using p-operator notation and

Z_T = parallel combination of R_1 and C_1, is

$$Z_T = \frac{(R_1/pC_1)}{\frac{1}{pC_1} + R_1} = \frac{R_1}{1 + pR_1C_1} .$$

Assuming an ideal operational amplifier,

$$V_O = -I_xZ_T \quad \text{and} \quad I_x = \frac{V_i}{R_1} .$$

Therefore

$$V_O = -\frac{V_i}{R_1}\left(\frac{R_1}{1 + pR_1C_1}\right) = -V_i\left(\frac{1}{1 + pR_1C_1}\right)$$

$$\frac{V_O}{V_i} = -\frac{1}{1 + pR_1C_1} \tag{1}$$

The circuit is a first order system, with time constant $\tau = R_1C_1$, and is required to provide a running average of the input signal, filtering of high frequencies, e.g. signal pulsing generated by the chopper controller, and respond to input signal changes: the output should be at least 99 percent of its final value within one measurement interval (one second). The changing signal constraint requires approximately five time constants, i.e.

$$\tau = R_1C_1 = \frac{1}{5}\ \text{s} = 0.2\ \text{s} \qquad (2)$$

Signal averaging requires time integration, i.e.

$$V_0 = K \int_0^t V_i\, dt$$

or, in p-operator notation,

$$V_0 = \frac{K}{p} V_i$$

letting $K = -\frac{1}{R_1C_1}$, then

$$\frac{V_0}{V_i} = -\frac{1}{pR_1C_1} \quad . \qquad (3)$$

The circuit is a time integrator, cf. (1), (3), when

$$pR_1C_1 \gg 1$$

or, since

$$p \rightarrow j\omega = j2\pi f ,$$

$$|j2\pi fR_1C_1| \gg 1 \tag{4}$$

where f is the base signal frequency. For the chopper controller the minimum observed operation frequency, or fundamental component of the Fourier spectrum, is approximately 65 Hz. Since $R_1C_1 = 0.2$ by (2), the inequality

$$|j2\pi(65)(0.2)| \gg 1$$

or

$$81.7 \gg 1$$

indicates that all chopper induced frequency components will be averaged within a few percent error. Generally this is adequate since the controller seldom operates at such low frequencies (only on vehicle start-up). If further averaging is required, e.g. duty cycle, a two stage filter with overall time constant $\tau = 0.2$ seconds has inequality (4)

$$(2\pi f R_1 C_1)^2 >> 1$$

or

$$(81.7)^2 >> 1$$

therefore

$$6675 >> 1 \quad ,$$

and error due to high frequency components is correspondingly reduced.

APPENDIX D Campus Route Data

TIME (SEC)	DUTY CYCLE	INCLINE (DEG)	SPEED (KM/HR)	ACCEL (G)	DIST (M)	TORQUE (NT-M)	VBATT (V)	IBATT (A)	VA (V)	VF (V)	FN	TEMPERATURES OUT	TEMPERATURES IN
0.0	0.000	.1	0.0	.014	0.0	-4.5	110.9	14.0	.0	.4	OUT	33.6	35.6
1.0	0.000	.1	0.0	.051	0.0	-4.5	110.9	14.0	.0	.4	OUT	33.6	35.6
2.0	0.000	.1	0.0	.044	0.0	-4.5	110.9	14.0	.0	.4	OUT	33.6	35.6
3.0	0.000	.1	0.0	-.031	0.0	-4.5	110.9	14.0	.0	.4	OUT	33.6	35.6
4.0	0.000	.1	0.0	.008	0.0	-4.5	110.9	14.0	.0	.4	OUT	33.6	35.6
5.0	0.000	.1	0.0	.029	0.0	-4.5	119.5	14.0	.0	.4	OUT	33.6	35.6
6.0	0.000	.1	0.0	.051	0.0	-4.5	110.9	14.0	.0	.2	OUT	33.6	35.6
7.0	0.000	.1	0.0	-.001	0.0	-4.5	110.9	14.0	.0	.4	OUT	33.6	35.6
8.0	0.000	.1	0.0	-.024	0.0	-4.5	119.5	14.0	.0	.4	OUT	33.6	35.6
9.0	0.000	.1	0.0	-.001	0.0	-4.5	110.4	14.0	.0	.4	OUT	33.6	35.6
10.0	0.000	.1	0.0	.021	0.0	-4.5	110.9	14.0	.0	.4	OUT	33.6	35.6
11.0	0.000	-.4	0.0	.051	0.0	-4.5	110.9	14.0	.0	.4	OUT	33.6	35.6
12.0	0.000	-.4	0.0	.029	0.0	-4.5	110.9	14.0	.0	.8	OUT	33.6	35.6
13.0	0.000	-.4	0.0	.021	0.0	-4.5	110.9	14.0	.0	.4	OUT	33.6	35.6
14.0	0.000	-.4	0.0	-.016	0.0	-4.5	110.9	14.0	.0	.4	OUT	33.6	35.6
15.0	0.000	-.4	0.0	.008	0.0	-13.4	110.9	14.0	0.0	.4	OUT	33.6	35.6
16.0	0.000	-.4	0.0	.021	0.0	-13.4	110.9	14.0	.0	.4	OUT	33.6	35.6
17.0	0.000	.1	0.0	.029	0.0	-13.4	110.9	14.0	.0	.4	OUT	33.6	35.6
18.0	0.000	.1	0.0	.021	0.0	-13.4	110.9	14.0	.0	.4	OUT	33.6	35.6
19.0	0.000	.1	0.0	.029	.3	-13.4	110.9	14.0	.0	.4	OUT	33.6	35.6
20.0	0.000	.1	0.0	.044	0.0	-13.4	110.9	14.0	.0	.4	OUT	33.6	35.6
21.0	0.000	.1	0.0	.021	0.0	-13.4	110.9	14.0	.0	.4	OUT	33.6	35.6
22.0	.004	.1	0.0	.021	0.0	-13.4	110.9	14.0	.0	.4	OUT	33.6	35.6
23.0	0.000	.5	0.1	-.039	0.0	-13.4	110.9	14.0	0.0	-0.0	OUT	33.6	35.6
24.0	.094	.5	.7	.193	0.0	234.4	116.0	60.0	7.0	2.3	OUT	33.6	35.6
25.0	.266	.5	4.3	.111	.9	491.0	109.0	191.9	10.7	3.9	OUT	33.6	35.6
26.0	.301	.5	7.8	.119	2.7	340.6	109.6	163.0	25.0	3.1	OUT	33.6	35.6
27.0	.313	.5	9.9	.089	5.2	222.1	110.2	145.1	28.9	2.5	OUT	33.6	35.6
28.0	.320	.9	11.4	.044	8.2	199.0	110.7	139.7	32.0	2.1	OUT	33.6	35.6
29.0	.336	.9	14.2	.103	12.2	181.3	110.2	131.1	33.6	2.3	OUT	33.6	35.6
30.0	.340	.9	15.6	.102	16.2	163.6	110.7	128.4	35.2	2.0	OUT	33.6	35.6
31.0	.355	.9	16.3	.029	19.6	137.1	110.7	128.4	37.5	2.0	OUT	33.6	35.6
32.0	.363	.5	17.7	.051	24.7	137.1	110.7	120.4	38.3	1.8	OUT	33.6	35.6
33.0	.375	.9	18.5	.074	29.6	119.4	110.7	121.7	39.1	1.8	OUT	33.6	35.6
34.0	.348	.5	19.9	-.001	34.7	92.4	111.3	103.0	37.5	1.4	OUT	33.6	35.6
35.0	.385	.5	19.9	-.016	41.5	57.4	112.5	84.3	33.6	1.2	OUT	33.6	35.6
36.0	.389	.5	20.6	.014	45.1	57.4	112.5	84.3	34.4	1.2	OUT	33.6	35.6
37.0	.313	.9	21.3	.008	50.6	57.4	112.5	84.3	34.4	1.2	OUT	33.6	35.6
38.0	.311	1.4	20.6	-.024	56.1	57.4	112.5	84.3	34.4	1.2	OUT	33.6	35.6
39.0	.313	.9	21.3	.036	61.6	57.4	113.1	84.3	35.2	1.2	OUT	33.6	35.6
40.0	.313	1.4	22.0	.041	67.4	57.4	113.1	94.3	35.2	1.2	OUT	33.6	35.6
41.0	.320	.9	22.0	-.203	73.2	57.4	112.9	80.9	35.9	1.2	OUT	33.6	35.6
42.0	.324	.9	22.7	-.071	79.2	57.4	112.9	84.3	35.9	1.2	OUT	33.6	35.6
43.0	.347	.9	22.7	-.024	85.0	84.0	111.3	112.3	42.2	1.6	OUT	33.6	35.6
44.0	.395	.9	21.4	-.054	91.1	84.0	110.7	112.3	43.0	1.6	OUT	33.6	35.6
45.0	.402	.9	24.1	.014	97.2	84.0	111.3	112.3	43.0	1.6	OUT	33.6	35.6
46.0	.402	.9	24.8	-.024	103.3	84.0	110.7	112.3	43.0	1.6	OUT	33.6	35.6
47.0	.391	.9	25.5	-.011	110.3	66.3	111.3	103.0	43.0	1.2	OUT	33.6	35.6
48.0	.383	.9	25.5	.016	117.0	66.3	111.3	90.3	42.2	1.2	OUT	33.6	35.6
49.0	.256	.9	25.5	-.009	123.7	22.0	113.7	60.0	30.9	.8	OUT	33.6	35.6
50.0	.230	.9	25.5	.044	129.0	19.2	113.7	60.0	28.1	1.0	OUT	33.6	35.6
51.0	.230	.9	25.5	-.016	136.6	22.0	114.1	60.0	27.3	.8	OUT	33.6	35.6

TIME (SEC)	DUTY CYCLE	INCLINE (DEG)	SPEED (KM/HR)	ACCEL (G)	DIST (M)	TORCUE (NT-M)	VBATT (V)	IBATT (A)	VA (V)	VF (V)	FW	TEMPERATURES OUT	IN
52.0	.230	.5	25.9	.008	143.0	22.0	113.7	60.0	20.1	.0	OUT	33.6	35.6
53.0	.230	.5	25.9	.059	149.4	13.2	113.7	60.0	20.1	.0	OUT	33.6	35.6
54.0	.230	.5	25.5	-.009	156.1	13.2	113.1	60.0	20.1	.0	OUT	33.6	35.6
55.0	.152	.5	25.5	-.031	162.5	-4.5	114.0	37.4	20.3	.4	OUT	33.6	35.6
56.0	.012	.5	25.5	.051	169.2	-13.4	116.0	14.0	3.1	.4	OUT	33.6	35.6
57.0	0.000	.1	24.0	-.121	175.9	-4.5	116.6	14.0	1.6	.4	OUT	33.6	35.6
58.0	0.000	.1	19.9	-.001	181.4	-13.4	116.6	14.0	.0	1.0	OUT	33.6	35.6
59.0	0.000	.1	19.9	.029	186.5	-13.4	116.6	14.0	3.1	.4	OUT	33.6	35.6
60.0	0.000	.1	19.9	-.024	191.1	-13.4	117.2	14.0	.0	.4	OUT	33.6	35.6
61.0	0.000	.9	19.2	-.061	196.6	-13.4	117.2	14.0	.0	.6	OUT	33.6	35.6
62.0	.070	.5	19.2	.014	201.2	-4.5	116.0	32.0	10.2	.6	OUT	33.6	35.6
63.0	.363	.5	19.2	.021	206.7	119.4	110.7	121.7	39.1	1.0	OUT	33.6	35.6
64.0	.395	.1	20.6	.051	211.5	119.4	110.2	126.4	42.2	3.1	OUT	33.6	35.6
65.0	.406	.1	21.3	-.001	217.0	110.5	110.2	121.7	43.0	1.6	OUT	33.6	35.6
66.0	.414	.1	22.7	-.001	222.0	110.5	109.6	126.4	44.5	1.6	OUT	33.6	35.6
67.0	.209	.1	23.4	.006	229.2	39.7	113.7	74.9	32.0	1.0	OUT	33.6	35.6
68.0	.230	.1	23.4	-.024	235.0	13.2	114.3	51.5	27.3	.6	OUT	33.6	35.6
69.0	.027	.5	23.4	.006	241.4	-13.4	115.4	10.7	9.5	-0.0	OUT	33.6	35.6
70.0	0.000	.5	22.7	-.024	247.2	-22.2	117.2	14.0	1.6	.4	OUT	33.6	35.6
71.0	0.000	.1	22.7	.029	253.0	-13.4	116.6	14.0	.0	.4	OUT	33.6	35.6
72.0	0.000	-.4	21.3	-.009	259.1	-13.4	116.6	14.0	.0	.4	OUT	33.6	35.6
73.0	0.000	-.4	19.2	-.076	264.0	-13.4	116.6	14.0	.0	.4	OUT	33.6	35.6
74.0	.004	-.4	15.6	-.113	268.0	-4.5	116.6	14.0	-.0	.4	OUT	33.6	35.6
75.0	0.000	-.0	11.4	-.091	272.2	-4.5	117.2	14.0	.0	.4	OUT	33.6	35.6
76.0	0.000	-.0	8.5	-.151	274.6	-4.5	117.2	10.7	.0	.4	OUT	33.6	35.6
77.0	0.000	-.0	5.0	-.061	276.1	-4.5	116.6	10.7	.0	.4	OUT	33.6	35.6
78.0	0.000	-.0	0.0	.029	276.1	-4.5	117.2	10.7	.0	.4	OUT	33.6	35.6
79.0	0.000	-.0	0.0	.021	276.1	-13.4	116.6	10.7	.0	.4	OUT	33.6	35.6
80.0	.004	-.0	0.0	.029	276.1	-4.5	117.2	14.0	.0	.4	OUT	33.6	35.6
81.0	0.000	-.0	0.0	.014	274.5	-13.4	117.2	10.7	.0	.2	OUT	33.6	35.6
82.0	.054	-.0	2.1	.059	276.5	137.1	115.4	51.5	7.0	1.0	OUT	33.6	35.6
83.0	.070	-1.0	5.0	-.113	278.0	22.0	116.0	32.0	7.0	.0	OUT	33.6	35.6
84.0	.070	-1.7	3.5	-.016	278.9	57.4	115.4	37.4	7.0	1.2	OUT	33.6	35.6
85.0	.094	4.4	4.3	-.009	279.0	57.4	115.4	42.1	0.6	1.4	OUT	33.6	35.6
86.0	.164	6.1	4.3	.020	281.3	314.0	111.3	112.3	13.3	2.7	OUT	33.6	35.6
87.0	.273	6.1	4.3	.065	282.2	491.0	107.2	107.2	19.5	3.9	OUT	33.6	35.6
88.0	.332	4.7	5.7	.102	283.5	544.1	104.3	243.4	23.4	4.3	OUT	33.6	35.6
89.0	.395	4.0	9.5	.051	285.9	517.6	103.1	262.1	20.9	4.3	OUT	33.6	35.6
90.0	.395	4.0	10.6	-.017	288.1	420.2	104.9	234.0	32.0	3.7	OUT	33.6	35.6
91.0	.402	4.4	11.4	-.054	291.1	359.3	104.9	215.3	34.4	3.1	OUT	33.6	35.6
92.0	.449	4.4	12.0	.020	294.4	387.1	103.7	230.7	39.1	3.1	OUT	33.6	35.6
93.0	.469	5.3	13.5	-.024	298.1	349.4	103.7	239.7	41.4	3.1	OUT	33.6	35.6
94.0	.473	5.3	14.9	-.024	302.4	322.9	103.7	234.0	42.2	3.1	OUT	33.6	35.6
95.0	.480	5.7	14.9	-.024	306.0	314.0	97.5	229.3	43.0	3.1	OUT	33.6	35.6
96.0	.484	5.7	15.6	.021	310.3	296.3	104.3	224.7	44.5	2.9	OUT	33.6	35.6
97.0	.486	5.7	16.3	-.047	314.6	296.3	104.3	224.7	44.5	2.9	OUT	33.6	35.6
98.0	.480	5.7	16.3	-.009	318.0	296.3	104.3	224.7	44.5	2.9	OUT	33.6	35.6
99.0	.484	5.3	17.0	-.032	321.4	287.5	104.3	224.7	45.3	2.9	OUT	33.6	35.6
100.0	.497	5.7	17.0	.013	328.0	276.6	104.3	224.7	45.3	2.9	OUT	33.6	35.6
101.0	.489	5.7	16.3	.050	332.2	279.4	104.3	224.7	46.1	2.9	OUT	33.6	35.6
102.0	.492	5.7	17.0	-.035	336.5	276.6	104.3	224.7	46.1	2.9	OUT	33.6	35.6
103.0	.492	5.3	17.0	-.017	340.0	269.4	104.3	219.3	46.1	2.7	OUT	33.6	35.6

TIME (SEC)	DUTY CYCLE	INCLINE (DEG)	SPEED (KM/HR)	ACCEL (G)	DIST (M)	TORQUE (NT-M)	VBATT (V)	IBATT (A)	VA (V)	VF (V)	FW	TEMPERATURES	
												OUT	IN
104.0	.492	5.3	17.7	-.039	345.6	269.0	104.3	215.3	46.1	2.7	OUT	33.6	35.6
105.0	.469	5.3	17.0	.013	349.9	243.2	104.9	196.6	45.3	2.5	OUT	33.6	35.6
106.0	.461	5.7	17.0	.050	354.5	252.1	106.1	196.6	44.5	2.7	OUT	33.6	35.6
107.0	.465	5.3	16.3	.051	359.1	252.1	105.5	196.6	43.5	2.7	OUT	33.6	35.6
108.0	.461	5.7	16.3	.021	363.3	260.9	104.9	201.3	45.3	2.7	OUT	33.6	35.6
109.0	.359	5.7	16.3	-.122	367.8	119.4	109.6	112.3	35.9	1.4	OUT	33.6	35.6
110.0	.002	5.7	14.2	-.039	371.6	4.3	114.3	32.0	10.9	.6	OUT	33.6	35.6
111.0	.043	5.3	11.6	-.039	374.6	-4.5	115.4	23.6	6.3	.4	OUT	33.6	35.6
112.0	0.000	4.8	8.5	-.069	377.0	-13.4	115.4	18.7	3.1	.4	OUT	33.6	35.6
113.0	0.000	4.8	5.7	-.092	378.9	-4.5	116.0	18.7	.0	.4	OUT	33.6	35.6
114.0	0.000	4.4	2.1	-.114	379.5	-4.5	116.0	18.7	.0	.4	OUT	33.6	35.6
115.0	0.000	4.8	0.0	.013	379.5	-4.5	116.0	14.0	0.0	.4	OUT	33.6	35.6
116.0	0.000	4.8	0.0	.021	379.5	-4.5	116.0	14.0	.0	.4	OUT	33.6	35.6
117.0	0.000	4.8	0.0	-.009	379.8	-4.5	116.0	18.7	.0	.4	OUT	33.6	35.6
118.0	.008	4.4	0.0	.042	379.8	22.0	116.0	20.1	.0	1.2	OUT	33.6	35.6
119.0	.164	4.8	.7	.050	380.4	464.5	110.2	131.1	10.2	3.7	OUT	33.6	35.6
120.0	.352	4.8	4.3	.223	380.4	659.1	102.0	205.5	21.1	5.1	OUT	33.6	35.6
121.0	.430	5.7	7.0	.095	382.2	579.5	100.2	313.6	31.3	4.7	OUT	33.6	35.6
122.0	.453	5.7	10.6	.052	385.3	422.2	101.4	285.3	35.2	4.1	OUT	33.6	35.6
123.0	.453	4.8	12.8	.105	388.3	402.5	103.1	257.4	37.5	3.7	OUT	33.6	35.6
124.0	.457	4.4	14.2	.140	392.0	345.4	103.1	238.7	39.8	4.7	OUT	33.6	35.6
125.0	.473	4.8	14.9	.051	395.9	322.9	103.1	229.3	42.2	3.1	OUT	33.6	35.6
126.0	.477	3.5	16.3	.013	400.5	287.5	104.3	224.7	43.0	3.1	OUT	33.6	35.6
127.0	.484	2.7	17.0	.008	405.4	280.9	104.9	210.6	46.1	2.7	OUT	33.6	35.6
128.0	.500	3.1	19.5	-.039	410.3	243.2	37.5	205.9	48.4	2.7	OUT	33.6	35.6
129.0	.535	2.7	19.9	.008	415.1	252.1	103.7	229.3	51.6	2.7	OUT	33.6	35.6
130.0	.563	3.1	21.3	.006	421.2	252.1	103.7	229.3	53.9	2.7	OUT	33.6	35.6
131.0	.566	3.5	22.0	.028	424.0	234.4	104.3	224.7	55.5	2.5	OUT	33.6	35.6
132.0	.574	3.5	22.7	-.017	432.0	225.5	103.7	224.7	57.0	2.5	OUT	33.6	35.6
133.0	.582	3.1	23.4	-.039	439.5	216.7	104.3	224.7	57.8	2.5	OUT	33.6	35.6
134.0	.590	3.5	24.8	.008	446.2	207.8	104.3	215.3	58.6	2.5	OUT	33.6	35.6
135.0	.590	3.5	25.5	-.017	453.9	199.0	103.7	215.3	60.2	2.5	OUT	33.6	35.6
136.0	.602	3.1	25.9	-.039	460.2	199.0	104.3	215.3	60.9	2.5	OUT	33.6	35.6
137.0	.609	3.1	27.0	.013	467.6	190.1	104.9	215.3	62.5	2.3	OUT	33.6	35.6
138.0	.617	3.1	27.0	.001	474.9	181.3	104.9	210.6	63.3	2.3	OUT	33.6	35.6
139.0	.625	3.1	27.7	.008	482.2	181.3	104.9	210.6	63.3	2.1	OUT	33.6	35.6
140.0	.629	3.1	28.4	.021	490.1	181.3	104.9	210.6	64.1	2.3	OUT	33.6	35.6
141.0	.637	2.7	29.1	-.031	498.0	172.4	104.3	210.6	64.8	2.1	OUT	33.6	35.6
142.0	.641	2.7	29.1	-.004	505.7	172.4	104.9	210.6	65.6	2.1	OUT	33.6	35.6
143.0	.648	3.1	29.8	-.047	513.9	172.4	104.9	205.9	66.4	2.1	OUT	33.9	35.6
144.0	.644	3.1	29.8	-.024	522.4	172.4	104.9	205.9	67.2	2.1	OUT	33.6	35.6
145.0	.644	3.5	30.5	-.009	530.7	183.4	105.9	201.3	67.2	2.1	OUT	33.6	35.6
146.0	.461	2.7	29.8	.050	539.2	88.3	110.2	112.3	50.0	1.0	OUT	33.9	35.6
147.0	.320	2.7	29.1	.043	547.4	30.9	111.9	79.6	37.5	1.0	OUT	33.9	35.6
148.0	.254	2.7	27.7	.020	555.0	13.2	113.7	56.2	30.5	.6	OUT	33.9	35.6
149.0	.070	2.2	27.0	-.039	562.4	-13.4	114.0	32.0	12.5	.6	OUT	33.9	35.6
150.0	.070	2.2	25.5	-.001	569.1	-4.5	114.0	20.1	12.5	.6	OUT	33.9	35.6
151.0	.070	1.8	24.0	-.009	575.8	-4.5	114.0	20.1	12.5	.6	OUT	33.9	35.6
152.0	.070	1.4	23.4	-.024	582.2	-4.5	114.0	20.1	5.5	.6	OUT	33.9	35.6
153.0	.070	.9	22.0	-.039	588.3	-4.5	115.4	20.1	10.9	.6	OUT	33.9	35.6
154.0	.086	2.2	21.3	-.054	594.1	-4.5	114.0	37.4	13.3	1.0	OUT	33.9	35.6
155.0	.391	2.7	20.6	.021	599.0	110.9	110.2	121.7	42.2	1.0	OUT	33.9	35.6

TIME (SEC)	DUTY CYCLE	INCLINE (DEG)	SPEED (KM/HR)	ACCEL (G)	DIST (M)	TORQUE (NT-M)	VBATT (V)	IBATT (A)	VA (V)	VF (V)	FM	TEMPERATURES OUT	IN
156.0	.492	5.7	19.2	.051	605.3	207.5	106.6	191.9	49.2	2.5	OUT	33.9	35.6
157.0	.516	7.0	18.5	-.369	610.2	260.9	104.3	224.7	50.0	2.7	OUT	33.9	35.6
158.0	.523	19.1	18.5	-.155	615.4	270.6	103.7	234.0	49.2	2.9	OUT	33.9	35.6
159.0	.523	7.4	17.7	-.024	620.0	290.1	103.1	238.7	48.4	2.9	OUT	33.9	35.6
160.0	.516	7.9	17.0	-.099	625.1	314.0	103.1	243.4	46.9	3.1	OUT	33.9	35.6
161.0	.527	8.3	15.6	-.017	629.7	350.1	100.0	271.5	46.9	3.5	OUT	33.9	35.6
162.0	.535	8.3	15.6	.050	634.3	376.0	100.0	280.0	46.1	3.5	OUT	33.9	35.6
163.0	.531	8.3	14.9	-.039	638.3	384.0	100.0	285.5	46.1	3.5	OUT	33.9	35.6
164.0	.535	7.9	14.9	-.009	642.0	393.7	100.0	285.5	46.1	3.5	OUT	33.9	35.6
165.0	.535	7.9	14.9	-.032	646.0	393.7	100.0	290.2	45.3	3.7	OUT	33.9	35.6
166.0	.531	7.9	14.9	-.032	651.1	402.5	100.2	290.2	45.3	3.7	OUT	33.9	35.6
167.0	.531	7.4	14.9	.008	655.0	402.5	100.2	290.2	44.5	3.7	OUT	33.9	35.6
168.0	.531	7.4	14.9	-.032	659.3	402.5	100.2	290.2	44.5	3.7	OUT	33.9	35.6
169.0	.531	7.4	14.9	.008	663.2	402.5	100.2	290.2	44.5	3.7	OUT	33.9	35.6
170.0	.531	7.4	14.9	.035	667.2	393.7	100.2	290.2	44.5	3.7	OUT	33.9	35.6
171.0	.531	7.4	14.9	-.054	671.2	393.7	100.2	290.2	45.3	3.5	OUT	33.9	35.6
172.0	.531	7.4	14.9	.020	675.4	393.7	100.2	290.2	44.5	3.9	OUT	33.9	35.0
173.0	.531	7.4	14.9	-.009	679.4	402.5	100.2	290.2	44.5	3.9	OUT	33.9	35.6
174.0	.531	7.4	14.9	.335	683.4	393.7	100.0	290.2	45.3	3.7	OUT	33.9	35.6
175.0	.531	7.9	14.9	-.009	687.6	402.5	100.2	290.2	44.5	3.5	OUT	33.9	35.6
176.0	.527	7.4	14.9	.073	691.6	411.4	100.2	290.2	43.0	3.7	OUT	33.9	35.0
177.0	.531	6.6	15.6	-.032	695.9	393.7	100.2	290.2	44.5	3.7	OUT	33.9	35.0
178.0	.535	5.7	16.3	.065	700.4	367.1	100.0	280.0	46.1	3.5	OUT	33.9	35.0
179.0	.543	4.4	17.7	.050	705.3	340.6	100.0	271.5	48.4	3.5	OUT	33.9	35.0
180.0	.563	4.0	19.2	.006	710.5	305.2	102.0	262.1	50.0	3.1	OUT	33.9	35.0
181.0	.332	3.1	19.9	-.009	716.0	66.3	111.3	84.3	34.4	1.0	OUT	33.9	35.0
182.0	.074	3.1	18.5	-.039	720.9	-4.5	113.7	20.1	10.9	.4	OUT	33.9	35.0
183.0	0.000	3.1	17.0	-.054	725.7	-13.4	116.0	14.0	1.6	.4	OUT	33.9	35.0
184.0	.000	3.1	15.6	-.024	729.7	-13.4	116.0	14.0	1.6	.4	OUT	33.9	35.0
185.0	0.000	3.1	14.2	-.084	733.4	-13.4	116.0	14.0	0.0	.4	OUT	33.9	35.0
186.0	0.000	2.7	9.9	-.151	736.7	-4.5	115.4	14.0	3.1	.2	OUT	33.9	35.0
187.0	0.000	2.7	5.7	-.114	738.2	-4.5	117.2	14.0	-.0	.6	OUT	33.9	35.0
188.0	0.000	2.7	1.4	-.084	739.1	-4.5	116.0	14.0	.0	.4	OUT	33.9	35.0
189.0	.004	3.1	0.0	.086	739.1	-4.5	116.8	14.0	.0	.4	OUT	33.9	35.0
190.0	.004	3.1	0.0	-.032	739.1	-13.4	116.0	14.0	.0	.4	OUT	33.9	35.0
191.0	0.000	2.7	0.0	-.017	739.1	-4.5	116.0	14.0	.0	-0.0	OUT	33.9	35.0
192.0	0.000	2.7	0.0	.038	739.1	-4.5	116.6	14.0	.0	.4	OUT	33.9	35.0
193.0	.094	2.7	0.0	.111	739.1	290.3	113.1	84.3	6.3	2.9	OUT	33.9	35.0
194.0	.307	3.1	9.0	.111	740.4	685.7	100.2	323.0	25.0	5.3	OUT	33.9	35.0
195.0	.477	3.9	9.9	.290	742.2	552.9	99.0	327.6	35.2	4.1	OUT	33.9	35.0
196.0	.516	3.5	13.5	.051	745.9	446.0	100.2	304.2	42.2	4.1	OUT	33.9	35.0
197.0	.531	3.9	15.6	.050	749.5	376.0	100.0	280.1	46.1	3.5	OUT	33.9	35.0
198.0	.547	3.5	17.7	.021	754.7	322.9	102.0	266.0	49.2	3.1	OUT	33.9	35.0
199.0	.563	2.7	19.9	.013	760.2	287.5	102.5	252.0	52.3	3.1	OUT	33.9	35.0
200.0	.574	1.0	21.1	.000	765.7	260.9	103.1	243.4	54.7	2.9	OUT	33.9	35.0
201.0	.590	1.4	22.7	.014	771.1	234.6	103.1	234.0	57.0	2.7	OUT	33.9	35.0
202.0	.580	.9	24.9	.059	778.2	137.1	107.2	199.1	52.3	2.0	OUT	33.9	35.0
203.0	.516	1.4	26.1	.051	784.9	120.2	107.0	159.1	53.9	2.0	OUT	33.9	35.0
204.0	.520	1.0	26.1	-.108	791.9	120.2	108.4	154.5	55.5	2.0	OUT	33.9	35.0
205.0	.531	2.2	27.0	-.233	799.2	119.4	107.0	154.5	56.3	2.0	OUT	33.9	35.0
206.0	.539	1.4	27.7	.014	806.5	119.4	107.0	154.9	57.0	2.0	OUT	33.9	35.0
207.0	.531	1.4	29.1	-.001	814.4	101.7	109.0	140.4	58.3	1.0	OUT	33.9	35.0

TIME (SEC)	DUTY CYCLE	INCLINE (DEG)	SPEED (KM/HR)	ACCEL (G)	DIST (M)	TORQUE (NT-M)	VBATT (V)	IBATT (A)	VA (V)	VF (V)	FM	TEMPERATURES OUT	TEMPERATURES IN
208.0	.352	1.4	29.1	-.016	822.0	39.7	111.9	84.3	39.0	1.0	OUT	33.9	35.0
209.0	.344	.9	29.1	-.010	829.7	30.9	112.5	74.9	39.1	1.0	OUT	33.9	41.7
210.0	.098	1.4	29.1	.038	837.3	-13.4	114.0	32.8	14.1	.4	OUT	33.9	35.0
211.0	.055	1.4	28.4	-.054	844.6	-13.4	115.4	23.4	10.2	.4	OUT	33.9	35.0
212.0	0.000	1.4	28.4	-.010	852.2	-13.4	116.0	14.0	1.6	.6	OUT	33.9	35.0
213.0	.004	.9	27.0	-.120	859.2	-13.4	116.0	10.7	1.6	.4	OUT	33.9	35.0
214.0	0.000	.9	22.0	-.211	865.6	-4.5	116.0	14.0	.0	.4	OUT	33.9	35.0
215.0	0.000	1.4	18.5	.098	870.0	-13.4	116.6	14.0	.8	.4	OUT	34.1	35.0
216.0	0.000	1.4	17.8	-.010	875.7	-13.4	116.0	14.0	3.1	.4	OUT	33.9	35.9
217.0	.086	.9	17.0	-.001	880.3	13.2	114.0	37.4	11.7	1.0	OUT	34.1	35.0
218.0	.352	-.8	17.7	.066	884.5	119.4	110.2	121.7	37.5	2.0	OUT	33.9	35.0
219.0	.242	-.8	19.9	.044	889.4	30.9	113.7	68.0	26.6	.4	OUT	33.9	35.0
220.0	.159	-.8	20.0	.029	894.9	-13.4	115.4	28.1	9.4	1.2	OUT	34.1	35.0
221.0	0.000	-.8	21.3	-.001	900.4	-22.2	118.6	14.0	1.6	.4	OUT	33.9	35.0
222.0	0.000	-.8	20.6	-.091	905.8	-13.4	115.4	10.7	3.1	.6	OUT	33.9	35.0
223.0	0.000	-1.2	17.7	-.100	910.4	-4.5	116.6	10.7	1.6	.4	OUT	34.1	35.0
224.0	0.000	-1.7	12.8	-.120	914.7	-4.5	116.6	14.0	.0	.4	OUT	34.1	35.0
225.0	0.000	-2.5	8.5	-.113	916.5	-4.5	116.6	14.0	0.0	.2	OUT	34.1	35.0
226.0	0.000	-3.0	5.0	-.083	918.1	-4.5	116.0	14.0	1.6	.4	OUT	34.1	35.0
227.0	0.000	-3.4	2.1	-.083	919.0	-4.5	116.6	10.7	.0	.4	OUT	34.1	35.0
228.0	0.000	-3.6	0.0	-.018	919.0	-4.5	116.6	10.7	.0	.4	OUT	34.1	35.0
229.0	0.000	-3.6	0.1	.029	919.0	-4.5	117.2	10.7	-.0	.4	OUT	34.1	35.0
230.0	0.000	-3.8	.7	.059	919.3	-13.4	116.0	10.7	.0	.4	OUT	34.1	35.0
231.0	.133	-4.7	5.9	.202	919.6	225.5	113.1	84.3	10.9	2.5	OUT	34.1	35.0
232.0	.215	-6.0	7.0	.172	921.7	163.6	111.9	93.8	20.3	2.0	OUT	34.1	36.1
233.0	.230	-4.3	13.5	.022	924.5	92.8	111.9	84.3	25.0	1.6	OUT	34.1	35.0
234.0	.246	-3.0	16.3	.029	928.7	75.1	112.5	84.3	28.1	1.6	OUT	34.1	36.1
235.0	.277	-4.7	19.2	.067	933.9	97.4	112.5	84.3	30.5	1.4	OUT	34.1	36.1
236.0	.336	-4.7	21.3	.157	939.4	86.3	111.3	98.3	37.5	1.4	OUT	34.1	35.0
237.0	.391	-4.7	24.8	.074	945.5	66.3	111.3	103.0	43.0	1.0	OUT	34.1	36.1
238.0	.209	-4.7	28.4	.079	952.0	13.2	113.7	60.0	33.6	.4	OUT	34.1	35.0
239.0	.012	-4.7	30.5	.052	961.3	-22.2	116.0	10.7	3.9	.4	OUT	34.1	36.1
240.0	0.000	-4.7	33.4	.112	969.3	-22.2	116.6	14.0	.0	.4	OUT	34.1	36.1
241.0	0.000	-4.7	34.1	.059	978.7	-22.2	116.6	14.0	1.6	.4	OUT	34.1	36.1
242.0	0.000	-4.7	34.1	-.030	987.9	-13.4	116.6	14.0	1.6	.4	OUT	34.1	36.1
243.0	0.000	-5.6	31.2	.015	996.4	-13.4	116.0	14.0	3.1	.4	OUT	34.1	36.1
244.0	0.000	-5.6	28.4	-.150	1004.0	-4.5	116.0	14.0	1.6	.4	OUT	34.1	36.1
245.0	0.000	-3.0	25.5	-.030	1011.0	-13.4	116.6	14.0	3.1	.4	OUT	34.1	36.1
246.0	0.000	-3.0	24.6	-.001	1018.0	-22.2	117.2	10.7	1.6	.4	OUT	34.1	36.1
247.0	.457	.5	25.5	.060	1029.0	154.7	107.0	163.0	40.4	2.1	OUT	34.1	36.1
248.0	.590	2.7	25.5	.013	1031.0	211.7	104.9	224.7	59.4	2.7	OUT	34.1	36.1
249.0	.629	3.1	25.5	.133	1040.2	225.5	104.3	234.0	62.5	2.7	OUT	34.1	36.1
250.0	1.000	3.1	26.3	.051	1045.5	243.2	101.4	290.2	64.1	2.5	OUT	34.1	36.1
251.0	1.000	3.5	29.0	.208	1053.1	455.6	90.0	524.2	85.9	3.7	OUT	34.1	36.1
252.0	1.000	3.1	31.9	.073	1061.3	304.0	93.0	460.1	89.0	3.1	OUT	34.1	36.1
253.0	1.000	3.5	34.1	-.054	1070.5	340.6	94.9	425.9	92.2	2.9	OUT	34.1	36.1
254.0	1.000	3.5	36.2	-.002	1079.3	376.0	89.6	530.3	87.5	2.1	IN	34.1	36.1
255.0	1.000	3.5	38.3	.058	1090.0	349.4	90.0	510.2	89.1	2.1	IN	34.1	36.1
256.0	1.000	3.5	39.7	.103	1100.3	322.9	92.0	480.0	89.8	2.0	IN	34.1	36.1
257.0	1.000	3.5	41.9	.021	1111.0	290.1	93.2	463.4	91.4	2.0	IN	34.1	36.1
258.0	1.000	3.1	43.3	.000	1122.3	270.6	94.3	449.3	92.2	2.0	IN	34.1	36.1
259.0	1.000	2.2	44.7	-.089	1134.9	260.9	94.3	425.9	93.0	1.8	IN	34.1	36.1

TIME (SEC)	DUTY CYCLE	INCLINE (DEG)	SPEED (KM/HR)	ACCEL (G)	DIST (M)	TORQUE (NT-M)	VBATT (V)	IBATT (A)	VA (V)	VF (V)	FW	TEMPERATURES	
												OUT	IN
260.0	1.000	2.2	46.1	-.031	1146.7	257.1	95.5	407.2	94.5	1.0	IN	34.1	36.1
261.0	1.000	1.0	48.3	-.016	1159.2	234.6	96.1	393.2	95.3	1.0	IN	34.1	36.1
262.0	1.000	1.4	49.7	.021	1172.0	207.8	97.3	374.6	96.1	1.6	IN	34.1	36.1
263.0	1.000	1.0	51.1	.029	1186.0	199.0	97.9	355.7	96.9	1.0	IN	34.1	36.1
264.0	1.000	1.4	52.5	.029	1199.7	181.3	98.4	346.4	97.7	1.4	IN	34.1	36.1
265.0	1.000	1.4	54.6	-.024	1213.7	172.6	99.0	337.0	98.4	1.4	IN	34.1	36.1
266.0	1.000	1.4	55.4	.014	1228.0	172.6	99.6	323.0	98.4	1.4	IN	34.1	36.1
267.0	.863	.9	56.1	.008	1243.0	39.7	100.4	145.1	67.2	.0	OUT	34.1	36.1
268.0	.709	1.0	56.0	-.046	1258.5	66.3	107.0	149.0	90.6	1.4	OUT	34.1	36.1
269.0	.824	2.2	56.1	-.016	1273.5	66.3	107.0	154.5	93.0	1.4	OUT	34.1	36.1
270.0	.824	1.4	56.1	.126	1288.1	66.3	107.0	154.5	93.0	1.4	OUT	34.4	36.1
271.0	.762	.9	55.1	-.001	1303.6	40.6	109.0	135.7	87.5	1.2	OUT	34.4	36.1
272.0	.301	.5	56.1	.008	1318.6	4.3	113.1	56.2	50.0	.2	OUT	34.4	36.1
273.0	.004	.5	56.1	.133	1333.2	-22.2	115.4	14.0	3.1	.4	OUT	34.1	36.1
274.0	0.000	.9	55.4	.066	1348.4	-13.4	116.0	14.0	.0	.4	OUT	34.4	36.1
275.0	0.000	.5	53.2	-.054	1362.9	-22.2	116.0	14.0	1.6	.4	OUT	34.4	36.1
276.0	0.000	.5	51.1	-.090	1376.2	-13.4	115.4	14.0	1.6	.4	OUT	34.4	36.1
277.0	0.000	.5	49.0	-.048	1389.9	-13.4	116.0	14.0	.0	.4	OUT	34.4	36.1
278.0	0.000	.5	46.0	-.046	1401.8	-13.4	116.0	14.0	1.6	.4	OUT	34.4	36.1
279.0	0.000	.1	44.7	-.090	1414.3	-13.4	116.0	14.0	1.6	.4	OUT	34.4	36.1
280.0	.004	-.4	42.6	-.090	1425.2	-13.4	116.6	14.0	1.6	.4	OUT	34.4	36.1
281.0	0.000	-.4	39.0	-.100	1436.2	-4.5	116.0	10.7	1.6	.4	OUT	34.4	36.1
282.0	0.000	.1	34.1	-.160	1445.4	-4.5	117.2	10.7	-.0	.4	OUT	34.4	36.1
283.0	0.000	-.0	28.4	-.190	1453.6	-4.5	116.6	10.7	.0	.4	OUT	34.4	36.1
284.0	0.000	-.0	23.4	-.121	1460.0	-4.5	116.0	14.0	.0	.4	OUT	34.4	36.1
285.0	0.000	-.4	19.9	-.076	1465.0	-13.4	117.2	14.0	.0	.4	OUT	34.4	36.1
286.0	0.000	-.0	17.7	-.023	1470.1	-13.4	116.6	14.0	.0	.4	OUT	34.4	36.1
287.0	0.000	-2.5	18.5	.044	1475.2	-13.4	116.0	14.0	1.6	.4	OUT	34.4	36.1
288.0	.004	-2.1	20.6	-.000	1480.1	-22.2	116.6	10.7	1.6	.4	OUT	34.4	36.1
289.0	.063	-2.1	21.3	.029	1485.9	-13.4	116.0	20.1	9.4	.4	OUT	34.4	36.1
290.0	.009	-2.1	22.7	.089	1491.7	-22.2	116.6	14.0	2.3	.4	OUT	34.4	36.1
291.0	0.000	-2.1	24.0	-.060	1498.1	-13.4	116.6	14.0	1.6	.4	OUT	34.4	36.1
292.0	0.000	-1.7	22.7	-.016	1504.9	-13.4	117.2	14.0	1.6	.4	OUT	34.4	36.3
293.0	0.000	-1.7	24.1	.066	1510.3	-13.4	117.2	14.0	1.6	.4	OUT	34.4	36.3
294.0	.004	-2.1	24.1	-.023	1517.0	-22.2	117.2	14.0	1.6	.4	OUT	34.4	36.3
295.0	0.000	-1.7	26.3	.096	1523.4	-13.4	116.6	14.0	1.6	.4	OUT	34.4	36.3
296.0	0.000	-2.1	27.0	.014	1530.7	-22.2	117.2	14.0	1.6	.4	OUT	34.4	36.3
297.0	.004	-2.1	28.4	-.120	1538.0	-22.2	116.6	14.0	1.6	.4	OUT	34.4	36.3
298.0	.004	-2.1	28.4	.022	1545.0	-13.4	116.6	14.0	1.6	.4	OUT	34.4	36.3
299.0	0.000	-2.1	28.4	.007	1552.7	-13.4	117.2	14.0	1.6	.4	OUT	34.4	36.3
300.0	0.000	-.0	27.7	-.023	1559.7	-13.4	117.2	14.0	1.6	.4	OUT	34.4	36.3
301.0	0.000	-.0	27.0	-.001	1566.7	-13.4	117.2	14.0	1.6	.4	OUT	34.4	36.3
302.0	0.000	-2.1	27.0	-.076	1573.7	-22.2	117.2	14.0	1.6	.4	OUT	34.4	36.3
303.0	0.000	-1.2	27.0	.044	1580.7	-22.2	117.0	14.0	1.6	.4	OUT	34.4	36.3
304.0	0.000	-.0	27.7	.021	1588.0	-13.4	117.2	14.0	1.6	.4	OUT	34.4	36.3
305.0	0.000	-.0	27.7	-.031	1594.7	-22.2	118.4	14.0	.0	.6	OUT	34.4	36.3
306.0	0.000	-1.7	27.7	-.053	1602.6	-13.4	117.2	10.7	1.6	.4	OUT	34.6	36.3
307.0	0.000	-1.2	25.5	-.121	1609.3	-4.5	117.2	10.7	.9	.4	OUT	34.4	36.3
308.0	0.000	-1.7	21.3	-.138	1614.4	-13.4	117.2	10.7	.0	.4	OUT	34.4	36.3
309.0	0.000	-1.2	19.2	-.078	1620.3	-13.4	117.2	14.0	.9	.4	OUT	34.4	36.3
310.0	0.000	-.0	19.5	-.066	1625.2	-13.4	117.2	14.0	.0	.4	OUT	34.6	36.3
311.0	0.000	-1.2	18.9	-.023	1629.0	-22.2	117.2	14.0	.0	.4	OUT	34.6	36.3

TIME (SEC)	DUTY CYCLE	INCLINE (DEG)	SPEED (KM/HR)	ACCEL (G)	DIST (M)	TORQUE (NT-M)	VBATT (V)	IBATT (A)	VA (V)	VF (V)	FW	TEMPURATURES OUT	IN
312.0	.055	.1	10.5	-.061	1635.0	-4.5	116.0	20.1	5.5	.6	OUT	34.6	36.3
313.0	.387	1.0	18.5	.073	1639.0	163.6	109.6	154.5	40.6	2.3	OUT	34.6	36.3
314.0	.551	2.7	20.6	-.046	1645.0	252.1	104.9	234.0	53.9	2.9	OUT	34.6	36.3
315.0	.570	2.7	22.0	.073	1651.1	243.2	104.9	229.3	56.3	2.7	OUT	34.6	36.3
316.0	.586	2.7	24.1	.036	1657.5	225.5	104.3	224.7	57.9	2.5	OUT	34.6	36.3
317.0	.599	2.7	24.0	.050	1663.6	207.0	104.3	224.7	60.2	2.5	OUT	34.6	36.3
318.0	.609	2.7	26.3	-.009	1670.9	199.0	104.9	224.7	62.5	2.5	OUT	34.6	36.3
319.0	.625	2.7	27.0	.001	1677.6	190.1	104.3	224.7	63.3	2.5	OUT	34.6	36.3
320.0	.633	2.7	28.4	-.048	1685.2	190.1	104.9	215.3	64.0	2.3	OUT	34.6	36.3
321.0	.645	2.2	29.1	.020	1692.9	181.3	104.9	215.3	66.4	2.3	OUT	34.6	36.3
322.0	.660	2.2	30.5	.103	1700.5	172.4	104.9	210.6	68.0	2.1	OUT	34.6	36.3
323.0	.613	1.8	31.2	-.061	1708.7	119.4	107.2	160.5	64.1	1.0	OUT	34.6	36.3
324.0	.527	2.2	31.9	-.024	1716.9	84.0	109.0	131.1	58.3	1.4	OUT	34.6	36.3
325.0	.523	1.8	31.9	-.048	1725.5	75.1	109.6	131.1	57.0	1.4	OUT	34.6	36.3
326.0	.527	2.2	32.6	.036	1734.0	75.1	109.6	131.1	57.0	1.4	OUT	34.6	36.3
327.0	.531	2.2	32.6	-.001	1742.5	75.1	109.6	131.1	57.0	1.4	OUT	34.6	36.3
328.0	.531	2.2	32.6	-.001	1751.1	75.1	109.6	131.1	57.0	1.4	OUT	34.6	36.3
329.0	.531	2.2	33.4	-.016	1759.3	75.1	109.6	131.1	57.0	1.4	OUT	34.6	36.3
330.0	.500	2.2	33.4	-.024	1768.2	66.3	110.2	117.9	54.7	1.2	OUT	34.6	36.3
331.0	.469	2.2	32.6	-.031	1776.4	48.6	109.6	107.7	51.6	1.2	OUT	34.6	36.3
332.0	.289	2.7	32.0	-.054	1784.9	13.2	113.1	74.9	33.6	1.0	OUT	34.6	36.3
333.0	.094	2.2	31.2	-.009	1792.0	-4.5	114.0	32.0	14.1	.4	OUT	34.6	36.3
334.0	.004	2.2	30.5	-.048	1800.0	-13.4	115.4	14.0	6.3	.4	OUT	34.6	36.3
335.0	0.000	2.2	29.1	-.031	1808.4	-13.4	116.0	14.0	1.6	.4	OUT	34.6	36.3
336.0	0.000	2.2	28.4	-.084	1816.0	-13.4	116.0	14.0	.1	-0.0	OUT	34.6	36.3
337.0	0.000	2.2	25.5	-.099	1822.4	-4.5	116.0	14.0	1.6	.4	OUT	34.6	36.3
338.0	0.000	2.2	21.3	-.159	1828.2	-4.5	116.6	14.0	.1	.4	OUT	34.6	36.3
339.0	0.000	1.8	16.3	-.151	1833.1	-4.5	116.6	14.0	1.6	.4	OUT	34.6	36.3
340.0	0.000	2.2	11.4	-.174	1835.0	-4.5	116.6	14.0	0.0	.4	OUT	34.6	36.3
341.0	0.000	1.8	6.4	-.069	1838.0	-4.5	116.6	14.0	.4	.4	OUT	34.6	36.3
342.0	0.000	2.2	3.5	-.144	1839.2	-13.4	116.6	14.0	.0	.4	OUT	34.6	36.3
343.0	.004	2.2	0.0	.038	1839.2	-4.5	116.0	14.0	.0	.4	OUT	34.6	36.3
344.0	0.000	2.2	0.0	-.018	1839.2	-13.4	116.6	14.0	3.1	.4	OUT	34.6	36.3
345.0	0.000	2.2	0.0	.013	1839.5	-13.4	117.2	14.0	.4	1.0	OUT	34.6	36.6
346.0	0.000	2.2	0.0	-.039	1839.5	-4.5	116.6	10.7	.0	.6	OUT	34.6	36.6
347.0	.100	2.7	1.4	.133	1839.5	473.3	109.6	149.0	12.5	3.9	OUT	34.6	36.3
348.0	.359	2.7	5.7	.110	1841.0	570.6	103.1	266.0	25.0	10.9	OUT	34.6	36.3
349.0	.469	2.7	9.9	.133	1843.1	500.7	100.2	304.2	35.2	9.4	OUT	34.6	36.3
350.0	.504	2.7	13.5	.110	1846.5	411.4	100.4	290.2	42.2	3.9	OUT	34.6	36.3
351.0	.527	2.7	16.3	-.002	1850.0	349.4	102.0	271.5	46.1	3.1	OUT	34.6	36.3
352.0	.547	2.7	18.5	.006	1855.3	305.2	102.5	257.4	50.0	3.1	OUT	34.6	36.3
353.0	.563	2.7	20.0	-.046	1860.9	269.0	103.1	243.4	53.0	2.9	OUT	34.6	36.3
354.0	.574	3.1	21.3	.051	1866.0	252.1	103.1	238.7	55.5	2.9	OUT	34.6	36.3
355.0	.586	3.1	22.7	.021	1871.8	243.2	103.1	234.0	57.0	2.7	OUT	34.6	36.3
356.0	.602	3.1	24.1	-.054	1878.2	225.5	103.7	234.0	59.4	2.5	OUT	34.6	36.3
357.0	.609	3.1	24.0	.072	1884.6	216.7	103.7	229.3	60.2	2.5	OUT	34.6	36.6
358.0	.621	3.1	26.3	.043	1891.6	207.9	103.7	229.3	62.5	2.5	OUT	34.6	36.6
359.0	.633	3.1	27.0	.013	1898.3	199.0	103.7	224.7	63.3	2.5	OUT	34.6	36.6
360.0	.500	2.7	27.0	.006	1905.7	101.7	108.4	140.4	53.1	1.6	OUT	34.6	36.6
361.0	.195	2.7	27.0	-.039	1912.3	4.3	113.1	46.0	29.0	.6	OUT	34.6	36.6
362.0	.012	2.7	25.5	.043	1919.3	-13.4	115.4	10.7	3.9	.4	OUT	34.6	36.6
363.0	0.000	2.7	24.0	-.069	1925.7	-13.4	116.0	10.7	3.1	.4	OUT	34.6	36.6

TIME (SEC)	DUTY CYCLE	INCLINE (DEG)	SPEED (KM/HR)	ACCEL (G)	DIST (M)	TORQUE (NT-M)	VBATT (V)	IBATT (A)	VA (V)	VF (V)	FM	TEMPERATURES OUT	TEMPERATURES IN
364.0	0.000	2.2	23.4	-.099	1931.5	-13.4	116.0	14.0	1.6	.4	OUT	34.6	36.6
365.0	0.000	2.2	21.3	-.099	1937.8	-13.4	116.0	14.0	.0	.4	OUT	34.6	36.6
366.0	0.000	1.8	17.0	-.181	1941.6	-4.5	116.0	14.0	.0	.4	OUT	34.6	36.6
367.0	0.000	2.2	11.4	-.211	1945.2	-4.5	116.6	14.0	6.3	.6	OUT	34.6	36.6
368.0	0.000	2.2	6.4	-.174	1947.1	-4.5	114.3	10.7	1.6	.4	OUT	34.6	36.6
369.0	0.000	1.8	2.0	-.004	1948.3	-4.5	116.0	10.7	0.0	1.0	OUT	34.6	36.6
370.0	.004	1.8	1.4	-.031	1948.6	-12.4	116.0	10.7	.0	.4	OUT	34.6	36.6
371.0	.234	1.8	2.1	.102	1948.9	544.1	106.6	196.6	14.0	4.3	OUT	34.6	36.6
372.0	.303	1.8	5.7	.126	1950.4	552.9	102.0	278.2	26.6	4.7	OUT	34.6	36.6
373.0	.457	2.7	9.9	.013	1952.6	473.3	100.4	285.5	35.2	3.9	OUT	34.6	36.6
374.0	.506	2.7	11.4	.020	1955.6	420.2	100.0	294.9	41.4	3.9	OUT	34.6	36.6
375.0	.523	3.5	14.2	-.017	1959.6	376.0	100.0	280.0	44.5	3.5	OUT	34.6	36.6
376.0	.531	4.4	15.6	.102	1963.8	349.4	101.4	271.5	46.9	3.5	OUT	34.6	36.6
377.0	.539	4.8	16.3	-.032	1968.1	331.7	102.0	268.0	48.4	3.5	OUT	34.6	36.6
378.0	.543	5.7	17.0	-.017	1972.7	322.9	102.0	262.1	49.2	3.1	OUT	34.6	36.6
379.0	.551	6.1	17.7	.008	1977.9	322.9	102.0	262.1	50.0	6.3	OUT	34.6	36.6
380.0	.551	5.7	18.5	-.024	1982.4	314.0	102.0	262.1	50.0	3.1	OUT	34.6	36.6
381.0	.551	5.7	19.5	.043	1987.3	314.0	102.0	262.1	50.0	3.1	OUT	34.9	36.6
382.0	.543	5.3	18.9	.000	1992.2	309.2	102.0	257.4	50.0	3.1	OUT	34.9	36.6
383.0	.477	5.3	18.5	.020	1997.1	199.0	106.1	177.9	46.1	2.5	OUT	34.9	36.6
384.0	.344	5.7	17.0	-.054	2001.9	119.4	109.6	112.3	35.2	1.6	OUT	34.9	36.6
385.0	.320	5.7	15.6	-.084	2005.9	120.2	109.6	112.3	33.6	2.0	OUT	34.9	36.6
386.0	.355	5.3	14.2	.008	2009.6	159.0	107.0	145.0	34.4	2.3	OUT	34.9	36.6
387.0	.390	5.3	13.5	-.002	2013.2	207.5	106.6	173.2	37.5	2.7	OUT	34.9	36.6
388.0	.316	4.4	12.0	-.047	2016.6	122.2	110.2	107.7	31.3	1.0	OUT	34.9	36.6
389.0	.199	2.7	11.4	-.046	2019.6	57.4	112.5	60.0	21.1	1.2	OUT	34.9	36.6
390.0	.195	7.0	11.4	-.039	2022.7	66.3	113.1	60.0	21.1	1.2	OUT	34.9	36.6
391.0	.201	3.1	9.9	.008	2025.4	275.9	109.0	140.4	26.6	2.9	OUT	34.9	36.6
392.0	.422	2.2	12.0	.051	2028.0	314.0	104.9	210.6	37.5	3.1	OUT	34.9	36.6
393.0	.441	2.2	14.9	.001	2032.7	269.0	105.5	201.3	40.6	2.9	OUT	34.9	36.6
394.0	.414	2.2	17.0	-.039	2037.0	183.6	108.4	140.4	40.6	2.0	OUT	34.9	36.6
395.0	.059	1.8	17.0	-.061	2041.0	-4.5	115.4	23.4	0.6	.2	OUT	34.9	36.6
396.0	0.000	1.4	16.3	-.039	2046.4	-13.4	116.0	14.0	1.6	.4	OUT	34.9	36.6
397.0	0.000	1.4	14.9	-.114	2050.7	-13.4	116.0	14.0	.4	.6	OUT	34.9	36.6
398.0	0.000	1.4	12.1	-.129	2053.7	-13.4	116.0	14.0	.0	.4	OUT	34.9	36.6
399.0	.000	1.4	8.5	-.129	2056.2	-13.4	116.0	14.0	.0	.4	OUT	34.9	36.6
400.0	0.000	.9	5.7	-.069	2058.3	-13.4	116.0	14.0	.0	.4	OUT	34.9	36.6
401.0	0.000	.9	2.8	-.114	2058.9	-13.4	116.0	14.0	.0	.4	OUT	34.9	36.6
402.0	0.000	.5	.7	-.024	2059.2	-13.4	116.0	14.0	.0	.4	OUT	34.9	36.6
403.0	0.000	.9	0.0	.008	2059.2	-13.4	116.0	14.0	3.1	.4	OUT	34.9	36.6
404.0	0.000	.9	0.0	-.031	2059.5	-12.4	116.6	14.0	.0	.4	OUT	34.9	36.6
405.0	0.000	.9	0.0	.021	2059.2	-13.4	117.2	14.0	.0	.4	OUT	34.9	36.6
406.0	0.000	.9	0.0	-.016	2059.5	-13.4	117.2	14.0	-.0	.4	OUT	34.9	36.6
407.0	0.000	.9	0.0	.014	2059.5	-13.4	116.6	14.0	.0	.4	OUT	34.9	36.6
408.0	.004	.9	0.0	.021	2059.5	-13.4	116.6	14.0	.0	.4	OUT	34.9	36.6
409.0	0.000	.9	0.0	-.031	2059.2	-13.4	116.6	14.0	.0	.4	OUT	34.9	36.6
410.0	.000	.9	0.0	-.001	2059.5	-13.4	117.2	14.0	.0	.4	OUT	34.9	36.6
411.0	.004	.9	0.0	-.001	2059.2	-13.4	116.6	14.0	.0	.4	OUT	34.9	36.6
412.0	0.000	.9	0.0	.038	2059.2	-12.4	116.6	14.0	.4	.4	OUT	34.9	36.6

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