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AMBIENT TEMPERATURE RECORDER*

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ABSTRACT

A temperature data recorder, designated the Ambient Temperature Recorder or ATR-4, has been developed at NASA Ames Research Center to meet particular requirements for space life sciences experiments. The small, self-contained, four-channel, battery-powered device records 32 kilobytes of temperature data over a range of -40 to +60 deg. C at four sampling intervals ranging from 1.875 to 15 min. Data is stored in its internal electronic memory for later readout by a personal computer.

The ATR-4 has been used to record external instrument temperatures on the US-USSR Cosmos Biosatellite, animal enclosures and other space life sciences experiments on several recent Space Shuttle flights. It also has been used to record instrument temperatures on high altitude aircraft flight experiments.

Commercial potentials include the variety of needs for a small, self-contained, unattended temperature recorder for the transportation of perishables or for recording life system or process temperatures over a period of time from minutes to months.

INTRODUCTION

The Ambient Temperature Recorder, ATR-4, measures temperature on one to four channels at pre-selected sampling rates and stores the data for subsequent readout by a personal computer (PC). The ATR-4 was designed to meet the recurring need of NASA Space Life Sciences' experiments for a small, reliable, flight-qualified, and easy-to-use temperature recorder. Operational requirements included a temperature recording range of -40 to +60 deg. C, sampling intervals from 1.875 to 15 min., sufficient memory for typical 10-day missions, and small size (less than 100 x 60 x 25 mm). The unit can be modified to measure temperature from -60 to +155 deg. C, and record data at intervals from 7.0 sec. to 15 min.

The ATR-4 system consists of the ATR-4 recorder, a Computer Interface Unit and operating software. The ATR-4 has been qualified for Space Shuttle use, which includes acceptance testing, verification, and Flight and Ground Phase III Safety Data packages per National Space Transportation System requirements (1).

DESCRIPTION

The ATR-4 measures and records temperatures from -40 to +60 deg. C with an accuracy of +/-1 deg. C. The temperatures are converted to 8-bit digital values, which provides a resolution of 0.4 deg. C over the 100 deg. C temperature range. Up to four external temperature sensor probes may be attached. The recorder's operating range is the same as its measurement range, and the ATR-4 may be used to record its ambient temperature (without probes) by selecting the internal temperature sensor which is thermally bonded to the inside of the front cover of its case.

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The ATR-4 weighs 135 grams and is contained in an anodized aluminum case measuring 23 x 41 x 86 mm which was designed to conform to the size and shape of the small Spacelab Biorack specimen container (Figure 1). Over-center latches secure the o-ring sealed front cover which contains the external probe receptacles. The front cover also supports the entire electronics assembly and batteries on a single circuit board (Figure 2). Two 3.5 volt lithium batteries supply power for the circuit and RAM memory. The battery life is conservatively rated for one year, but its actual shelf or operating life is approximately two years.

A crystal controlled oscillator establishes timing for the circuitry and the time interval between measurements. Four time intervals (1.875, 3.75, 7.5 and 15 min.) may be selected by the Rate switch inside the ATR-4 case. A Probe switch selects the number of probes used, and the Internal/External switch selects between the internal sensor or an external probe for channel 1. There are two other switches - the Reset and the Stop/Operate Jumper switch - described below. All switches are manually set. Figure 3. illustrates the ATR-4 layout.

Digital temperature data is stored sequentially in a 32K byte RAM, and is transferred serially to a PC for readout via a Computer Interface Unit built for the purpose. Connection to the ATR-4 is made with a miniature 20-pin rectangular connector and ribbon cable from the Computer Interface. The Computer Interface Unit is connected by standard RS-232 serial connection to an IBM-compatible computer using the MS-DOS operating system. Figure 4. shows the ATR-4 connected to the Computer Interface Unit and a readout computer.

The ATR-4 has two setup methods. Normal operation of the ATR-4 uses a computer to assist setup and provide storage of setup parameters and experiment information in a Header at the beginning of the ATR-4 memory. With the ATR-4 connected to a computer through the Computer Interface Unit, the ATR Operating Program, guides the user through setting of the ATR-4 probe and sampling interval switches and monitors the switch positions to confirm the desired settings. Either an "immediate start" or "delayed start" of the ATR-4 may be chosen by setting the Stop/Operate Jumper switch to the proper position. In the stop position the timing oscillator is shut down, and no data is taken. In the operate position, timing starts and temperature sampling begins.

The second method is manual setup of the ATR-4 without a computer. It consists of setting the switches and pressing the Reset button, which resets the RAM address to zero and causes data to be recorded, starting at the beginning of memory. Manual setup does not allow a Header to be stored at the beginning of memory.

Temperature data is stored sequentially in memory. There is no off-on power switch, and the memory is never erased except by command as an option. Normally, each time the recorder is set up, the memory is reset and previous data is overwritten. When the memory is filled with data, the ATR-4 stops recording and enters a standby state. ATR-4 recording duration ranges from a minimum of 10 days for 4 probes at the 1.875 min. sampling interval to a maximum of 342 days for 1 channel at the 15 min. interval.

Data readout is accomplished by connecting the ATR-4 to the Computer Interface Unit and following the on-screen directions of the Readout section of the ATR Operating Program. At the beginning of readout, the computer stores an end-of-data (EOD) mark in memory immediately following the last recorded data. It then resets the ATR-4 and reads out the Header and data up to the EOD mark. The transferred data is stored in a file in the computer for subsequent tabular and graphic presentation.

ATR-4 CIRCUIT AND COMPONENTS

Referring to the simplified circuit schematic, Figure 5., the ATR-4 consists of an oscillator-counter timing section, a signal input analog section with operational amplifiers and an analog-to-digital converter (ADC), and a RAM memory section.

The integrated circuits (IC) are low power 4000 series CMOS. To conserve battery energy, the analog input and ADC circuitry, which draw 9 ma, are normally unpowered and only switched on at each sampling interval with a low forward-drop P-MOSFET transistor switch. The remaining digital IC's and RAM draw approximately 30 microamps when in standby mode between sampling intervals.

Temperature is measured with an Analog Devices AD590 integrated circuit temperature sensor that provides a current output linearly proportional to the absolute temperature. A negative 5 volts is applied to the AD590 by a 7660 inverter which produces a negative temperature current that is summed with a positive offset current from a

REF43 precision 2.5 volt reference, which sets the low temperature measurement point. A quad TLC27L9 operational amplifier with feedback resistor-controlled gain inverts the negative input, and produces a 0-2.5v signal output. Precision (0.05%), low temperature coefficient (5 ppm/deg. C) resistors are used to set the offset current, which establishes the -40 deg. C low point, and the gain, which establishes the 100 deg. C measurement range. With the precision resistors, calibration is not required for the specified +/-1 deg. C accuracy. The 0-2.5v analog temperature signals are then converted to 8-bit bytes by a MAX154 four channel ADC.

By selecting different offset and feedback resistor values the low temperature point may be set as low as -60 deg. C, and the range can be adjusted for a high temp point up to 150 deg. C. The narrower the range the higher the resolution. A 100 deg. C range results in a 0.4 deg. C resolution. The operating temperature range of the ATR-4 circuit is limited to -60 to +85 deg. C.

Circuit timing is based on a crystal controlled 4536 programmable timer that provides a periodic sampling pulse at 1.875, 3.75, 7.5 and 15 min. intervals, depending on the Rate switch selection. There are four additional intervals of 7, 14, 28 and 56 seconds which are excluded from ATR-4 use by a mechanical stop on the switch. The sampling pulse sets a NOR gate latch which powers the analog and ADC circuits through the P-MOSFET transistor switch and starts a 4040 circuit timing counter which sequences the ADC read and write and the RAM storage operations through various combinatorial logic gates. Other 4040 output stages are combined through the Probe switch to send a reset pulse to the sampling latch which determines how many channels will be converted. Conversion requires about 3 microseconds, and the time between channel conversions is 6.9 milliseconds.

Data bytes are stored in a 32Kx8 static RAM which is sequentially addressed by another 4040 counter with spill-over into one half of a 4520 counter. The other half of the 4520 provides channel sequencing for the ADC. When the RAM is filled, the next counter stage disables the 4536 oscillator and the ATR-4 reverts to the 30 microamp low power standby state. The oscillator may also be disabled by setting the Stop/Operate Jumper switch to the Stop position.

The ATR-4 switch monitoring feature is implemented by connecting the logic level of each switch position in an 8-bit status byte that is stored in a HC244 register and monitored by the setup- readout computer. The ATR-4's serial number also is read by the computer to identify the unit. A serial number from 0 to 255 is assigned to each ATR-4 by connecting each of its eight data lines to either Vc or ground with 1M resistors. This binary coded data bus resistance pattern is interpreted by the computer as the serial number.

Power for the circuit is provided by two series-connected, hermetically-sealed lithium thionyl chloride 3.5v batteries through a 2936 low forward-drop 5v regulator. Dual redundant reverse-charge blocking diodes and individual battery fuses are provided to meet Space Shuttle battery safety requirements (2). There is no off/on power switch. The low power static RAM and CMOS digital IC's are always on at a low 30 microamp level to insure memory retention.

Besides the eight data lines plus ground, there are six control lines and four analog signal lines connected from the circuit to the 20-pin connector. The control lines are: oscillator disable, analog on, clock, read/write, switch enable and reset. They are used by the Computer Interface Unit for setup and readout functions. The four 0-2.5v analog temperature signals are available at the connector for testing purposes, and can be read by an ancillary hand-held Field Tester which was built for optional use at remote sites where no computer was available. The Field Tester also indicates the state of the stop/operate and manual reset switches. Control line inputs and data lines are protected by 10K current-limiting resistors, and signal inputs are protected by 1K resistors along with rail-to-rail shunting diodes.

ATR-4 ASSEMBLY AND PRODUCTION

To meet small package constraints, the ATR-4 was assembled using surface mount components. Military standard (MS) grade components were used wherever possible for reliability. Surface mount ICs, however, were not available in MS grade in the preferred small outline (SOIC) package with its gull-wing shaped leads. The common MS package was either a leadless chip carrier, which did not allow for stress relieving compliance when soldered to a circuit board, or a J-leaded package with leads bent beneath the chip which prevents adequate inspection. Industrial rated, plastic encapsulated gull-wing SOIC's with typical operating range of -40 to +85 deg.

C were used. For the -40 to +60 deg. C thermal cycle operating condition of the ATR-4, deterioration of the plastic encapsulated SOIC's will be a factor limiting its lifetime to an anticipated 15 years with occasional usage.

A single multilayer printed circuit (PCB) board having six circuit layers was required. Polyimide PCB material was used for its low thermal expansion. The small resistor, capacitor and diode chip components were mounted on the bottom of the board, and the IC's and through-hole switch and connector components were mounted on top.

The initial ATR-4's were assembled using manual placement and a surface mount hot air rework station to solder the components. A small production run was done with a simple table top vapor phase soldering unit (Vaporette) which allowed all of the surface mount components to be soldered in two passes, and subsequent production has been done with a larger vapor phase soldering machine. The small chip components were positioned and soldered on the bottom of the board first (bottom side up), and then the IC's were placed and soldered on the top side. Solder paste was dispensed using a squeegee and a stainless steel solder mask. Component adhesive was not required. The boards were cooled promptly after solder reflow to enhance small grain structure and stronger joints in the solder alloy (3). Final assembly of the units included applying silicone conformal coating for protection from contamination.

COMPUTER INTERFACE UNIT

The ATR-4 is set up and read out by an IBM XT/AT-compatible computer through an AC line-powered Computer Interface Unit. The Computer Interface Unit translates the 8-bit parallel data and decodes the control lines into serial data for downloading via the computer's RS-232 serial port. Data transfer is at 9600 baud.

The Computer Interface Unit is based on the Cybernetics CY233 network controller chip which provides parallel-serial data conversion and also decodes the ATR-4 control lines. A single circuit board contains the controller chip, associated logic chips and power supply.

SOFTWARE

The ATR-4 software is written in PASCAL and provided on a diskette as a single operating program labeled ATR. The program is entirely menu driven and consists of the following functions: Setup, Readout, Data Display, and Utilities.

SETUP is used to prepare the recorder for recording data. It guides the user in setting the Rate and Probe switches and entering Header information. The Header information includes the ATR-4 serial no. (read automatically), setup and battery dates, probe numbers, and a comment field. The ATR-4 switch settings are monitored by the program to minimize setup error and are automatically recorded in the Header.

READOUT enables temperature data stored in the ATR's memory to be transferred to a PC. The end of current data is identified by an end of data (EOD) marker written by the computer immediately after the last current data byte in the ATR-4 memory. The ATR-4 is then reset by the computer and the memory is read out sequentially up to the EOD marker. The temperature data is not affected by readout and may be re-read out indefinitely. Old data is not erased. It is retained in memory until subsequent reset and recording writes over the previous data.

DATA DISPLAY includes tabular and graphic presentations. Tabular data is listed, along with the elapsed time, for the number of probes used. A printed copy of the tabular data, including header information, may be selected.

The graphic display plots temperature versus elapsed time from the start of recording. The program allows the user to select a particular time segment of data, temperature range for plotting, and the number of probes to be displayed. The elapsed time may be correlated to another time, such as mission or actual time, by specifying the start time. Graphic data can be printed with an Epson compatible dot matrix printer.

UTILITIES include selection of the computer serial port (COM1 or COM2), the disk drive to be used for data, an optional ASCII text data file for use with other data reduction programs, and an ATR-4 memory test. The Memory Test writes and reads a test byte to all locations of memory. Its use, of course, writes over all data existing in the ATR-4. Data may be erased with a Memory Erase selection which writes a zero value to all memory locations.

RQA AND ACCEPTANCE TESTING

Reliability and quality assurance (RQA) procedures included failure modes analysis, parts screening, assembly certification and acceptance testing. Failure modes analysis resulted in elimination of an off-on switch. Assembly certification included a 55 cycle temperature test from -50C to +70C (10 degrees beyond each end of the ATR-4's operating range) of the Vaporette-formed surface mount solder joints.

To meet Space Shuttle flight requirements (4,5), the ATR-4 was subjected to offgas and electromagnetic emission testing, and all units were subjected to acceptance testing. The acceptance tests included a 100 hour burnin at +62C, pressure differential test (less than 200 Torr vacuum environment), fluid resistance test (water submersion), random vibration tests, and thermal cycling. The thermal cycle tests included five cycles with the ATR-4 operating over a -38 to +58 deg. C range. The random vibration test applied a sweep and composite of sinusoidal vibrations to each axis of the ATR-4. After each segment of the acceptance testing, limited or full functional operation tests were performed. The full functional test included a full range accuracy test to confirm the +/-1C specified accuracy.

APPLICATIONS

An early version of the ATR-4 was flown on the Russian Cosmos 2044 Biosatellite in 1989 to record external surface radiation dosimeter temperatures as part of a joint US-USSR program. The ATR-4 has flown on several recent Shuttle flights for recording temperatures in various experiments: a Growth Hormone Concentration and Distribution in Plants experiment on STS-34, a Circadian Rhythm of Neuraspora experiment on STS-32, and a Physiological Systems Experiment with Animal Enclosure Modules on STS-41.

A derivative of the ATR-4, called the Flight Temperature Recorder (FTR), is currently used on NASA ER2 high altitude earth resources research aircraft to record instrument temperatures, including values below -60 deg. C on ozone detection instrumentation.

SUMMARY

A small four-channel, battery powered ambient temperature recorder (ATR-4), has been developed to meet NASA Life Science Shuttle payload requirements. It measures temperatures from -40C to +60C at selected intervals, and stores up to 32K bytes of data for subsequent readout by a personal computer.

ACKNOWLEDGEMENTS

Many individuals have contributed to the development of the ATR-4 recorder. In particular, program leadership was provided by J. P. Connolly, design contributions were made by W. F. Barrows, software by G. S. Buhtz and D. J. Ungar, and RQA by S. Askarinam. ATR-4 assembly was performed by the Ames Electronic Instrument Services Branch.

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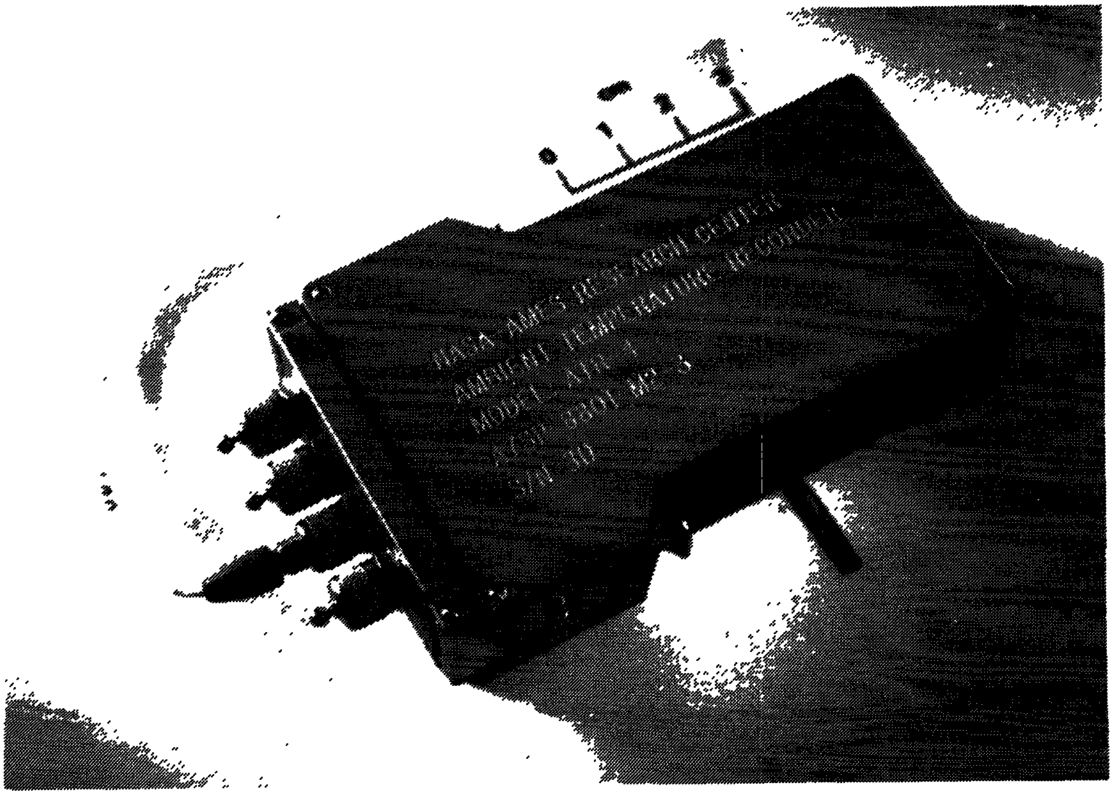

Figure 1. Ambient Temperature Recorder ATR-4

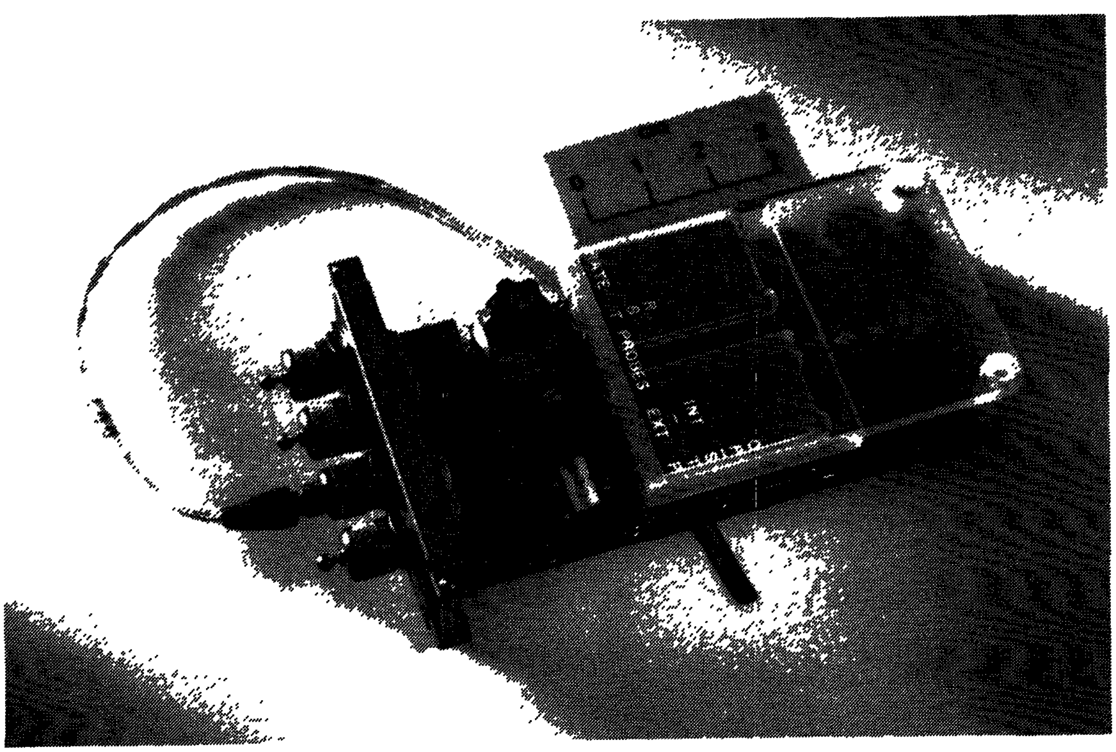

Figure 2. ATR-4 Circuit Board

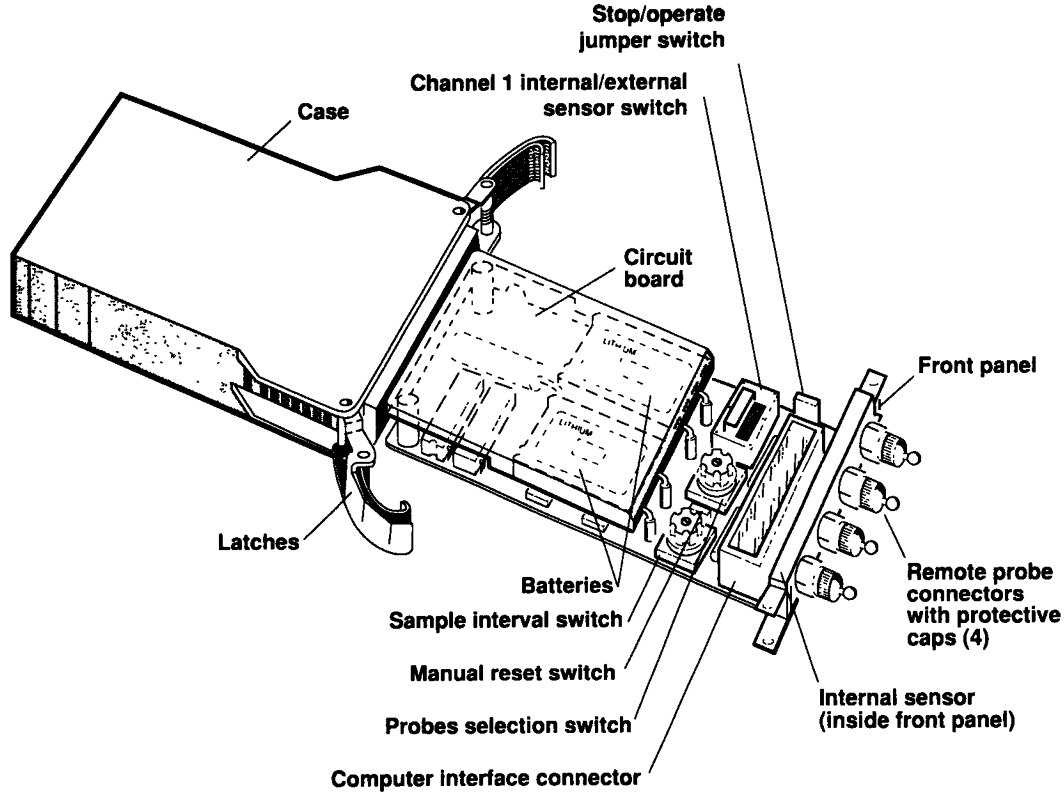

Figure 3. ATR-4 Layout

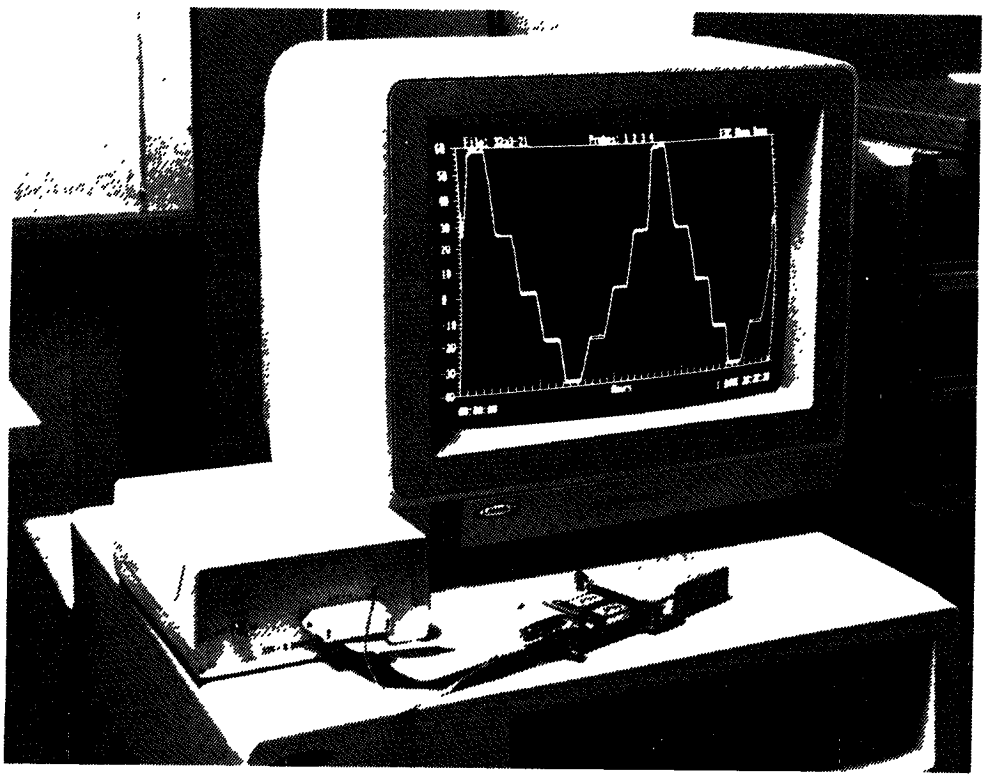

Figure 4. ATR-4 Connected to Computer Interface Unit

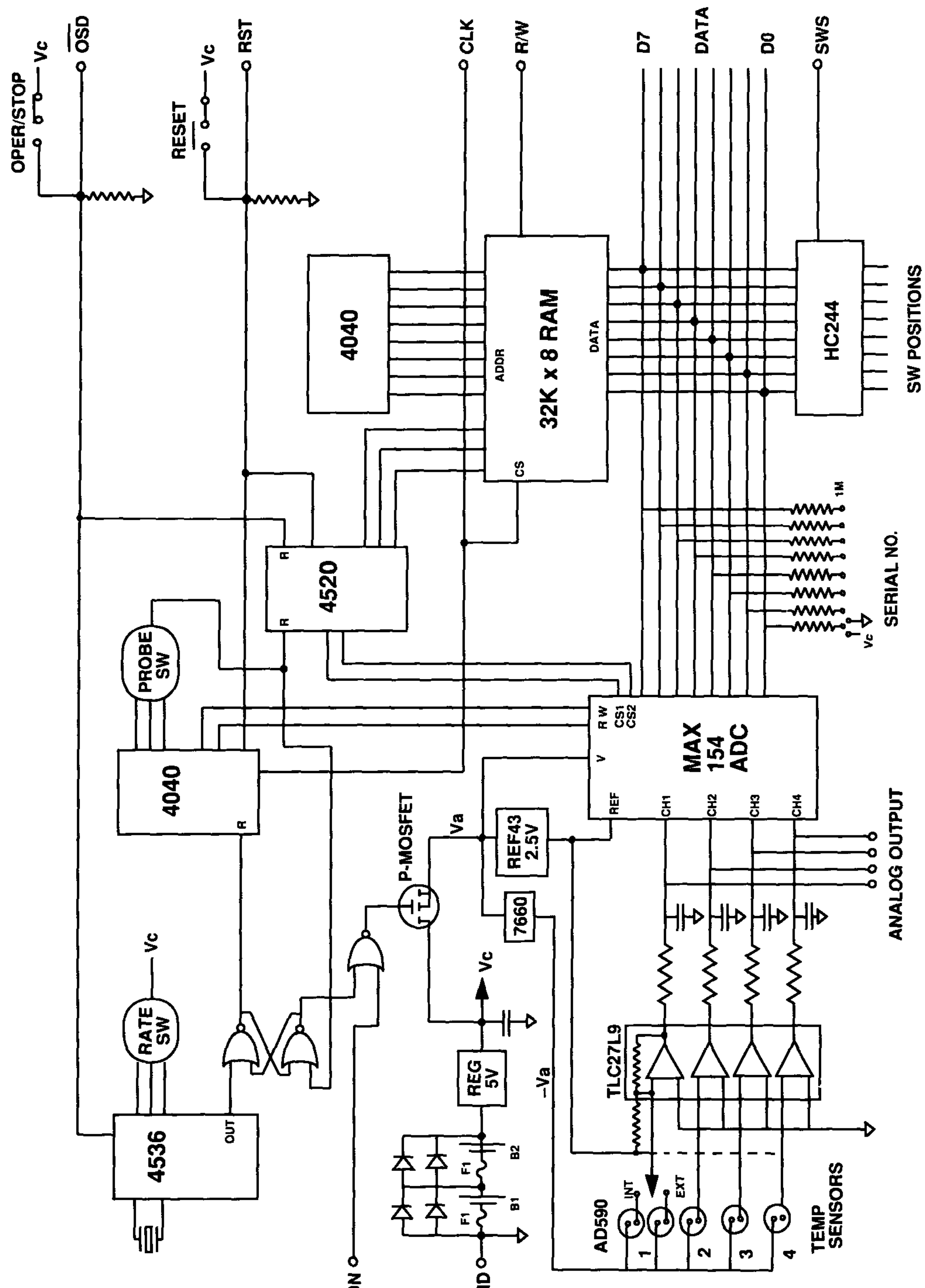

Figure 5. ATR-4 Circuit Schematic