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RESEARCH TRIANGLE INSTITUTE

NASA CR-112105

PRELIMINARY DESIGN STUDY OF A REGENERATIVE LIFE SUPPORT SYSTEM INFORMATION MANAGEMENT AND DISPLAY SYSTEM

Final Report

By

C. D. Parker
J. B. Tommerdahl

April 1972

Prepared under Contract No. NAS1-11077 by
RESEARCH TRIANGLE INSTITUTE
Research Triangle Park, N.C.

for Langley Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

RESEARCH TRIANGLE PARK, NORTH CAROLINA 27709

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

PRELIMINARY DESIGN STUDY OF A REGENERATIVE LIFE SUPPORT SYSTEM INFORMATION MANAGEMENT AND DISPLAY SYSTEM

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SECTION I

INTRODUCTION

The development of regenerative life support systems requires extensive testing of the interacting subsystems and ultimate testing of the system under isolated and manned conditions. Instrumentation requirements for a regenerative life support system are such that numerous parameters must be monitored, and the problems of data acquisition and analysis require careful study. Since human life may be dependent upon the system, it is imperative that instrumentation provide an accurate and continuous measure of the quality of the environment and provide the earliest possible indication of a malfunction or condition that will permit the eventual degradation of the environment. Further, the instrumentation must provide a good record of the operational characteristics of the numerous interacting subsystems so as to enhance their further development.

The parameters to be measured have various levels of importance. The space station or cabin environmental parameters are critically important in that they immediately and directly influence crew health and safety. Parameters indicative of subsystem/cabin interfaces that maintain the cabin environment are less critical than cabin environmental parameters but are critical for extended operation of the system and require instrumentation. Other parameters, e.g., status of stores, backup or emergency subsystem operational status and parameters dedicated to diagnostic purposes, can be critical in a committed life support system and must be instrumented to enhance further development.

To enhance progress with this study, parameters are categorized according to their relative importance and instrumentation procedures. Displays and alarms are assumed for each group. These are largely judgment decisions made to facilitate design and discussion. Data management and display concepts are illustrated by examples utilizing critical subsystems which are reasonably described in the literature. A complete, specific design will require collaboration with subsystems specialists or access to an improved technical description of the subsystems.

The parameters to be measured are temperature, events, flows, pressures, weights, electrical power and atmospheric partial pressures. The number of monitors will be in the 200-300 range, and the majority of these will be temperatures. It is anticipated that most of the parameter measurements will be available as linear, buffered analog voltages from 0-5 V.

SECTION II

LIFE SUPPORT SUBSYSTEMS

Parameter Categories

For the purposes of this study, the life support system (LSS) parameters have been assigned to four categories according to their relative criticality. The first category, Level 1, includes the cabin environmental parameters that directly and immediately influence the health and safety of the cabin crew. These include the cabin temperature, pressure, and the partial pressures that are known to make up the environment, i.e., the partial pressures of oxygen, nitrogen, water vapor and carbon dioxide. It is anticipated that other parameters not descriptive of the environment may fall in this category. It is likely, for example, that certain subsystem temperatures can reach catastrophic values that result in fire or explosion with consequences that reach far beyond the particular subsystem involved. Parameters such as these are not identified herein but are included conceptually in these discussions.

The second category of parameters, Level 2, contains the subsystem interfaces with the cabin environment, i.e., the subsystems' inputs to the cabin that directly maintain the cabin environmental parameters. These include oxygen accumulator pressures from the several electrolysis units, cabin heat exchanger temperature and flow, water storage or flow from the water recovery subsystem and oxygen and nitrogen flow from the two-gas controller. A failure at any of these locations will ultimately result in a Level 1 parameter reaching an unsatisfactory level, excessive use of critical stores or reliance upon a redundant system with the attendant loss of reliability.

The Level 3 category of parameters is of lesser importance to the immediate and short-term operation of the LSS. Unsatisfactory values at this level pose no immediate problem to the life support system environment but indicate maintenance, repair or procedural changes necessary for the continued, long-term operation of the system. Rates-of-change of the Level 1 parameters are also included in the third category in order that an excessive rate-of-change can provide a warning of a malfunction that degrades a Level 1 parameter before the parameter itself reaches a warning level. Level 3 parameters include various subsystem flows and temperatures; stores of oxygen, nitrogen and water; and Level 1 rates-of-change.

The Level 4 parameters are parameters useful as diagnostic indicators and are principally useful at the subsystem level.

The four categories or levels of parameters discussed above are summarized in Table I.

Alarms

The instrumented LSS must provide a suitable warning when any monitored parameter exceeds a satisfactory value. An alarm system is included to provide various alarms at preselected parameter levels to enhance the maintenance and continued operation of the subsystem or, alternatively, to provide maximum warning of an impending failure of the system. The alarm system would function as follows:

(1) A priority alarm is reserved for Level 1 parameters at hazardous values or at values indicative of a loss of control over the parameter. Any priority alarm would have been preceded by two alarms, i.e., a warning and an emergency alarm, and would require prompt, decisive action to restore control and to correct the discrepancy. A priority alarm could be caused to initiate procedures to terminate the operation of an LSS and especially of a manned test. The priority alarm, irrespective of its source, would consist of a central visual indication and a continuing audible indication that would be perceptible over the entire area.

(2) An emergency alarm could be triggered by Level 1 or Level 2 parameters that reach values that are significantly outside design tolerances. An emergency alarm would indicate a need for prompt

TABLE I

PARAMETER CATEGORIES

LEVEL NO. 1:

Parameters that Directly and Immediately Influence Cabin Environment or Crew Health and Safety.

Includes:

Cabin Pressure
Cabin Partial Pressures (O_2, N_2, H_2O, CO_2)
Cabin Temperature Maintenance

LEVEL NO. 2:

Sub-System Inputs to the Cabin that Directly Maintain Level No. 1 Parameters.

Includes:

O_2 Accumulator Pressures
Cabin Heat Exchanger Flow and Temperature
H_2O Storage/Flow from Recovery System
Two-Gas Controller Flows

LEVEL NO. 3:

Parameters Indicative of Subsystems Status/Operation, Critical Parameter Stores, Level No. 1 Parameter Rates-of-Change

Includes:

Stored O_2, N_2, H_2O
Various Pressures, Flows, and Temperatures

LEVEL NO. 4:

Parameters Principally Useful as Diagnostic Indicators action to alleviate the source of the discrepancy. It would be preceded by a warning alarm. Level 1 and Level 2 parameters will have individual status displays, making it reasonable to provide for individual visual indications for each of these parameters. A continuing audible alarm will also sound that can be silenced for a preset period of time by acknowledgment.

(3) A warning alarm can be triggered by a Level 1, 2, or 3 parameter that exceeds design tolerances. It may call for nothing more than increased or more frequent monitoring, but it does alert monitoring personnel of out-of-tolerance conditions. Warning alarms for Level 1 and Level 2 parameters will be inherently a part of the parameter display. A separate visual alarm is proposed, e.g., an amber light, and a single, audible sound. For the Level 3 parameters, a central visual/audible alarm is proposed with a separate, individual alarm at the subsystem console.

(4) An instrumentation alert is actuated by comparable or redundant measurements which are not in reasonable accord. Such comparisons are made at every opportunity and wherever redundant measurements exist. In the case of Level 1 and Level 2 parameters, the instrumentation alert is included in the parameter display, e.g., a green light.

Table II summarizes these proposed alarms.

Preset alarm levels for some of the Level 1 parameters are tabulated in Table III. The design values tabulated were deduced from literature descriptive of earlier tests of life support systems. Generally, warning alarms are indicated for parameters that exceed design values, emergency alarms for parameters that exceed the nominal design value by twice the design tolerance and a priority alarm for parameters that triple the design tolerance. These criteria provide a warning whenever design tolerances are exceeded and higher alarms as deviations increase. In the examples tabulated, the priority alarm is more indicative of a loss of control over a parameter than of an imminent hazard.

Display

Parameter displays provide an assessment of the operational status of the life support system at a glance, and different types of displays

TABLE II

ALARM CATEGORIES

I. PRIORITY ALARM

Level 1 Parameters at Hazardous Levels or Levels Indicative of Loss of Control

Central Visual/Audible Alarm

II. EMERGENCY ALARMS

Levels 1 and 2 Parameters Significantly Outside Design Tolerances

Individual Visual/Audible Alarms

III. WARNING ALARMS

Levels 1, 2 and 3 Parameters Outside Design Tolerances.

Levels 1 and 2, Individual Visual/Audible Alarms

Level 3, Central Visual/Audible Alarm
(Not to preclude individual subsystem alarms)

IV. INSTRUMENTATION ALERT

Comparable Measurements Not in Reasonable Accord

Individual Visual Alerts for Level 1 and Level 2 Parameters

TABLE III

LEVEL I PARAMETER ALARM VALUES

Parameter	Design Value	Warning	Emergency	Priority
Total Pressure	517 ± 15 mmHg	502/532 mmHg	487/547 mmHg	472/562 mmHg
Partial Pressures:				
O_2	155 ± 5 mmHg	150/160 mmHg	145/165 mmHg	140/170 mmHg
N_2	330 ± 8 mmHg	322/338 mmHg	314/346 mmHg	306/354 mmHg
CO_2	4 mmHg	> 8 mmHg	> 12 mmHg	> 16 mmHg
H_2O	7.2 - 12.5 mmHg	6/14 mmHg	4/16 mmHg	2/17 mmHg
Temperature:				
Living Area	70 ± 5°F	65/75°F	60/80°F	55/85°F
Equipment Area	70 ± 5°F	60/80°F	55/85°F	50/90°F

are suggested for the several parameter levels. The Level 1 parameters are critically important, and an extensive display system is suggested for these parameters. For each parameter, a clearly labeled grouping such as illustrated in Figure 1 is suggested. The analog indicators, similarly scaled with respect to nominal and alarm level positions, provide for a quick assessment of the status of the Level 1 parameters by monitoring personnel. A principal criterion for selecting the analog indicators is readability. A ribbon indicator is particularly advantageous for readability, but tends to be larger, more expensive and requires more power and maintenance than other analog indicators. These disadvantages are primarily due to the necessity of providing for a

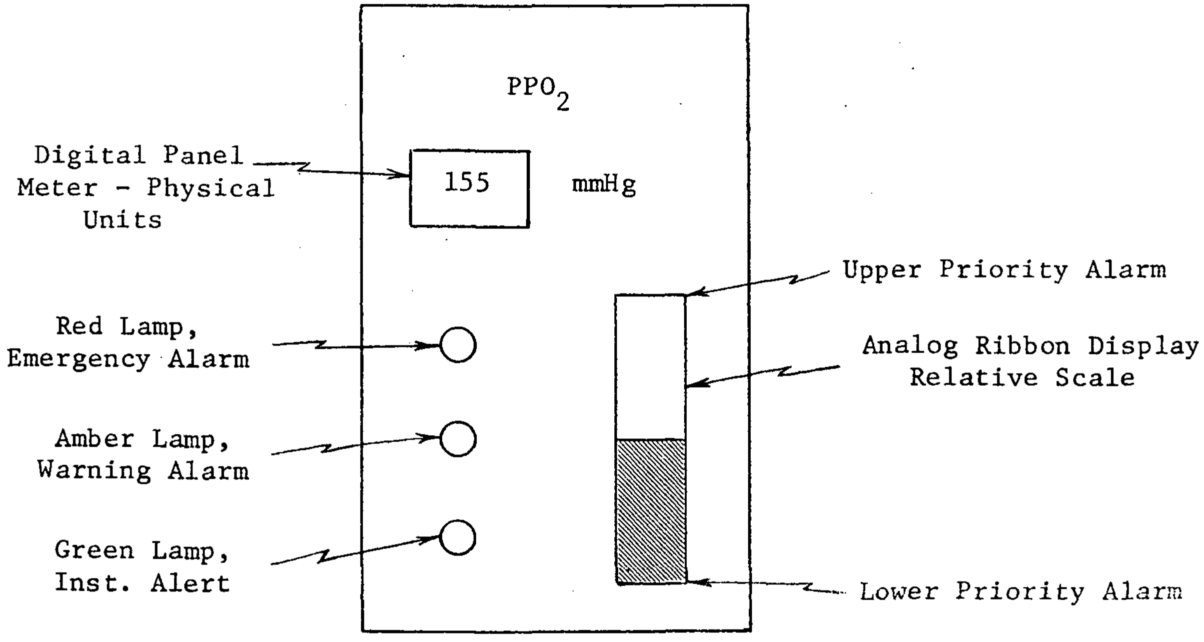

Figure 1. Illustration of a Level 1 Parameter Monitor

separate optical system. Good quality, ribbon indicators suitable for this application cost approximately $100. Other options include conventional analog panel meters available in numerous configurations. A suitable conventional meter costs approximately $60.

A digital panel meter is included in each Level 1 parameter monitor which is labeled and scaled to read-out the parameter value in physical units. Small panel meters that provide a digital read-out as well as an electrical binary output range from $150 to $400, depending upon the number of digits and the form of the electrical output. An electrical output in BIN or BCD format, for example, is useful in reducing the size and complexity of the monitoring circuitry by eliminating other A/D conversions. With some additional logic circuitry the electrical output can interface with a vertical or horizontal series of lights as a substitute for the analog display, but an independent analog display is recommended.

The three lamps on the parameter monitor are utilized as alarm displays. The lamps are not normally illuminated. The green lamp will constitute an instrumentation alert, the amber lamp a warning alarm and the red lamp an emergency alarm. The red lamp is a push-button type to provide for silencing the attendant audible alarm for a preset period of time.

Level 2 parameter displays include labeled annunciators that are illuminated by any alarm mode. Each annunciator has an associated green, amber and red lamp to signal the various alarm conditions. Additionally, selected parameters may have associated panel meters reading in physical units.

Level 3 parameters that are not adequately instrumented at subsystem consoles may have individual digital indicators or individual warning alarm lights displayed. Others will be OR-gated to a central warning alarm indicator. A summary of these parameter displays is tabulated in Table IV.

TABLE IV

PARAMETER DISPLAYS

LEVEL NO. 1

A. Analog Indicator - Relative Scale
B. Digital Indicator - Physical Units
C. Lamps for Instrumentation, Warning, Emergency Alarms

LEVEL NO. 2

A. Labeled, Illuminated Annunciators with Lamps for Instrumentation, Warning, Emergency Alarms
B. Some Digital Indicators - Physical Units

LEVEL NO. 3

A. Some Individual Digital Indicators with Lamps for Warning Alarm
B. Central Panel Warning Lamp from Subsystem Instrumentation

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SECTION III

INSTRUMENTATION

Analog

Parameter Displays. - An instrumentation scheme for a Level 1 parameter, e.g., the partial pressure of oxygen, is described herein for illustrative purposes. A four-gas mass spectrometer has been described which provided a linear, buffered 0-5 V output proportional to the partial pressure of oxygen (PPO_2) and scaled to 0.025 V/torr [ref. 1]. This input is assumed for the instrumentation illustrated in the block diagram of Figure 2. Additionally, a calibration input is available as an input to amplifier 1. The calibration input provides a means of checking the operation of the entire instrumentation illustrated in Figure 2. Gain and offset adjustments are also indicated for amplifier 1 to provide a convenient means of compensating for any changes or errors that occur in the mass spectrometer output. The output of amplifier 1 remains a linear, buffered output at 0.025 V/torr. This output is supplied to transfer function 1 (TF1) and subsequently to a digital panel meter that reads PPO_2 in physical units. In this example, the signal is linear and TF1 is simply an amplifier with gain and offset controls. For nonlinear inputs, TF1 will be significantly more complicated. In the worst case, it may be an analog function generator with a piecewise linear approximation of the transfer function. Since the output is scaled at this point to read in physical units, it is also a convenient point to supply an output to a data acquisition system (DAS). It may be more reasonable to acquire PPO_2 data prior to this transfer function block, but it is somewhat dependent upon the digital equipment that can be committed to the life support system. If a dedicated computer is committed to the system, for example, it will probably be unnecessary to further scale the input.

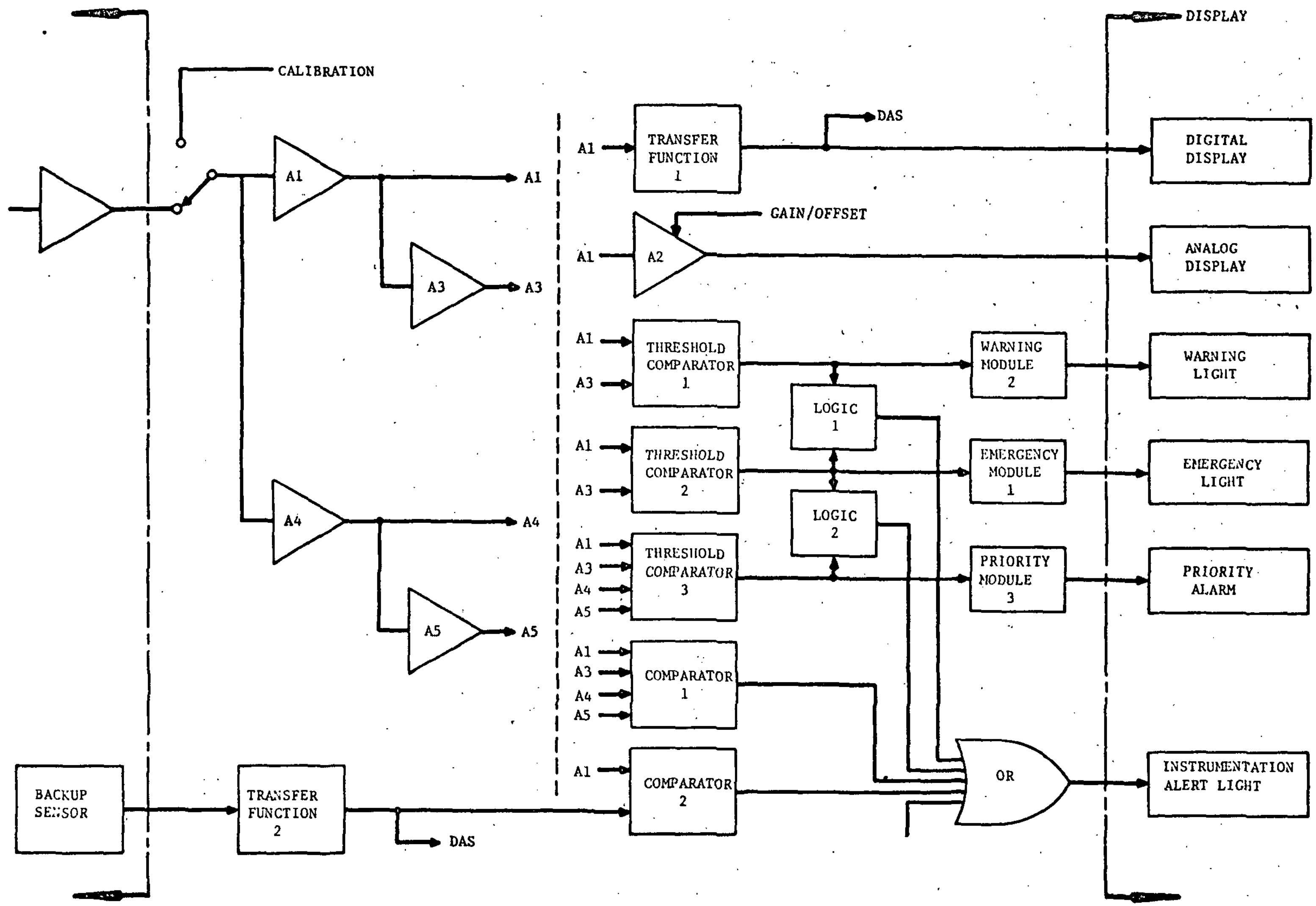

Figure 2. Block Diagram of an Analog Level 1 Parameter Monitor (PPO_2)

The amplifier 1 output is also supplied to amplifier 2 which provides a gain and offset adjustment such that an analog indicator can conveniently display the PPO_2 on a relative scale.

Amplifier 3 further buffers the 0.025 V/torr signal and isolates it from the comparators it subsequently supplies. Each of the three threshold comparators supplied from amplifier 3 has a second, preset input which is omitted from Figure 2 to avoid unnecessary clutter. Threshold comparators 1 and 2 provide an output whenever warning and emergency alarm limits are exceeded to initiate the appropriate alarm. Alarm modules 1 and 2 control the display lights and audible signals. Logic block 1 provides for an instrumentation alert if an emergency alarm occurs without a previous warning alarm.

Amplifiers 4 and 5 parallel amplifiers 1 and 3 to provide inputs to threshold comparator 3 and comparator 1. These amplifiers provide a redundant path to trigger a priority alarm. Threshold comparator 3 provides an output to the priority module if either of its inputs reaches the appropriate level. As before, a logic block functions to provide an instrumentation alert if a priority alarm occurs without a preceding emergency alarm. In comparator 1, the outputs of amplifiers 3 and 4 are compared and an instrumentation alert triggered if they are not in reasonable accord.

If a redundant or backup sensor is used, as in the case of the PPO_2, transfer function 2 converts the backup signal to a form compatible with the output of amplifier 1, and the two outputs are compared in comparator 2. If they are not in reasonable accord, an instrumentation alert occurs.

In the case of the PPO_2, one additional input is provided to the OR-gate that controls the instrumentation alert. The total cabin pressure is compared with the sum of the partial pressures of the constituent gases. If these are not in reasonable accord, an instrumentation alert occurs. The backup sensor is also monitored by the data acquisition system.

Detailed designs for the block diagram of Figure 2 are shown in Figures 3 through 8. In Figure 3 amplifier 1 (A1) is shown with either a calibration input or the 0.025 V/torr input from the mass spectrometer. A gain adjustment is provided by a potentiometer which, in turn, feeds a gain-of-2 input to A1. Nominally, the potentiometer will be set at 0.5 with the 50 kΩ loading compensated. The offset adjustment input is supplied to a gain of 1/10 which provides for an offset of $\pm$ 1.5 volts. The output of A1 is -0.025 V/torr and can be readily scaled or offset to maintain that value if the mass spectrometer scaling drifts.

Since the output of the mass spectrometer and, consequently, the output of A1 are linear, transfer function 1 (TF1) is simply a scaling amplifier. Its gain of 1/2.5 scales the PPO_2 to 0.01 V/torr. Consequently, a three digit panel meter rated for an input of 2 V (or 9.99 V) with the decimal blanked will read the PPO_2 in physical units. To cite a specific example, assume a three data digit panel meter with a full scale range of $\pm$ 199.9 mV. If the gain of TF1 is reduced to 1/25, the digital meter will read the PPO_2 directly in physical units to an accuracy of 1 torr. This scaling is illustrated by the numbers in parentheses in Figure 3.

The output of A1, -0.025 V/torr, is also supplied to amplifier 2 (A2) where it is scaled and offset to interface with an analog panel meter. The input to A2 is gained by a factor of -2 and an offset voltage of + 7.25 V, gained by a factor of -1, is summed with the signal input. Consequently, the output of A2 is (0.05 V/torr -7.25 V). If this is supplied as an input to a 1 V.F.S. analog meter, the meter's midpoint will correspond to 155 torr, its upper limit will correspond to the upper emergency alarm level of 165 torr and its lower limit will correspond to the lower emergency alarm level of 145 torr.

Figure 3 also shows the output of A1 and the inverted, buffered output of amplifier 3 (A3) feeding threshold comparators 1, 2 and 3, and comparator 1.

The various amplifiers shown in Figure 3 are all used in an inverting mode. This is in anticipation of using chopper stabilized amplifiers for their excellent, long-term drift characteristics.

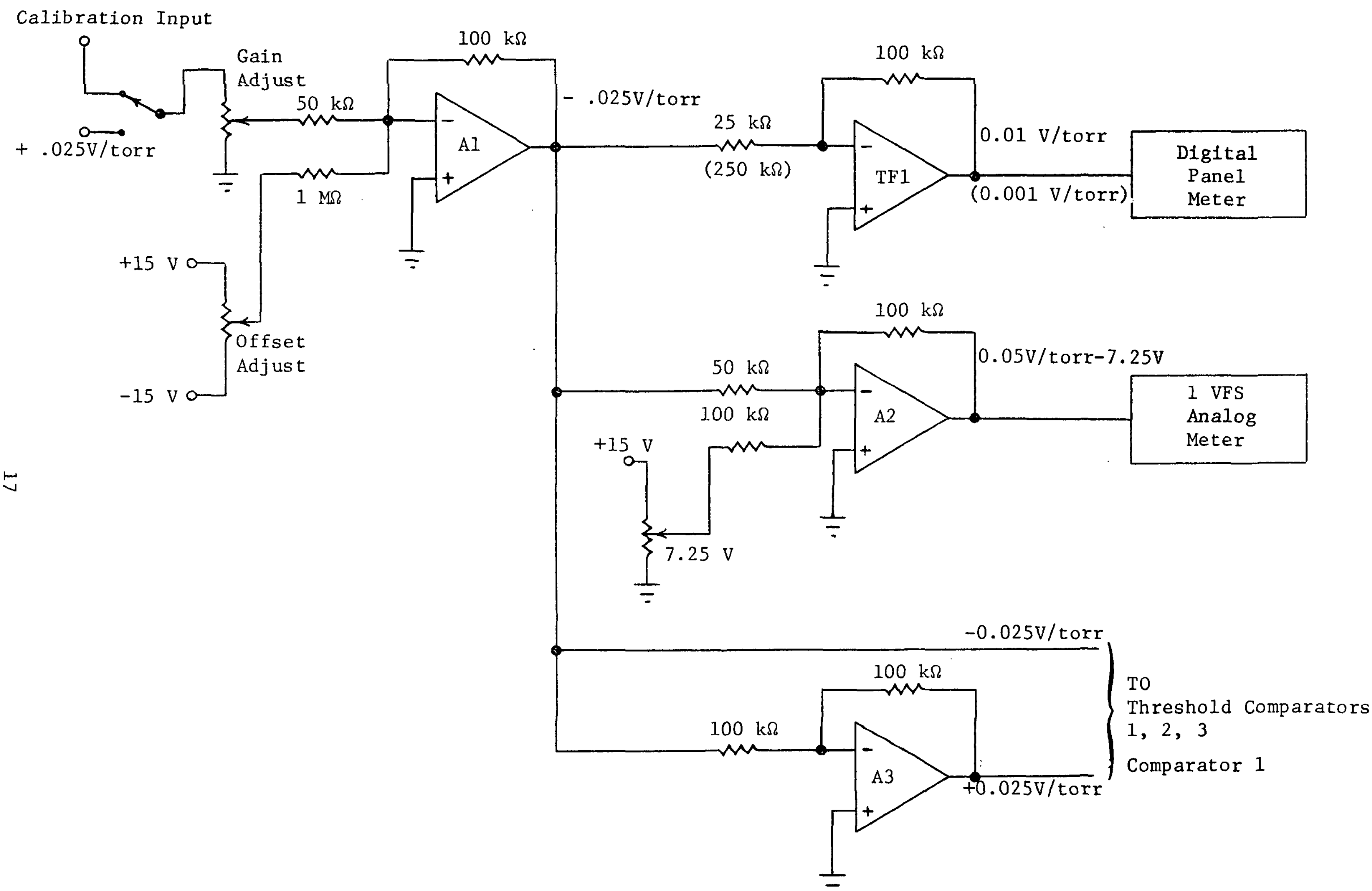

Figure 3. Circuitry for Interfacing Mass Spectrometer Output with Parameter Displays

Threshold Comparators. - Figure 4 illustrates the details of the threshold comparators of Fig. 2. In this example, the values shown correspond to the PPO_2 warning alarm comparator. The threshold comparator 1 amplifier A (TC1-A) functions as an upper warning alarm level detector. As long as the $PPO_2 \leq 160$ torr, i.e., $+ 0.025$ V/torr $\times PPO_2 \leq 4$V, the output of amplifier TC1-A is zero. If the PPO_2 exceeds 160 torr, the output of TC1-A is limited to the zener voltage of the feedback diode, i.e., the output is $-V_z$. Similarly, if the PPO_2 is greater than 150 torr, i.e., if $|- 0.025 \text{ V/torr} \times PPO_2| > 3.75$ V, the output of amplifier TC1-B is zero. Otherwise, it is limited by the zener diode feedback to $-V_z$. The outputs of both TC1-A and TC1-B are summed in amplifier TC1-C along with an incremental positive input. Consequently, the output of TC1-C remains at zero as long as the PPO_2 is within design tolerances, and is $+V_z$ whenever an emergency alarm level is reached.

Threshold comparator 2 (TC-2) is similar to threshold comparator 1. The potentiometer settings on the input amplifiers differ to reflect the emergency alarm levels, i.e., the potentiometers are set for 4.125 V and 3.625 V. This design requires three amplifiers for each threshold comparator. It has the advantages, however, of using inverting mode, chopper stabilized amplifiers, and all non-linear elements are in the amplifiers' feedback paths.

Referring again to Figure 2, amplifiers 4 and 5 provide a redundant path from the mass spectrometer PPO_2 output to threshold comparator 3 and comparator 1 (C1). Amplifier 4 is identical to A1, and A5 is identical to A3. Threshold comparator 3 (TC3) compares inputs from the A1, A3 paths and the A4, A5 paths with the preset priority alarm levels. If either of the two signals reaches a priority alarm level, TC3 will function to initiate the alarm. Threshold comparator 3 differs from TC1 and TC2 in two respects. First, the alarm level potentiometers are set to the priority alarm voltages, i.e., 3.5 V and 4.25 V. Secondly, the redundant or parallel inputs are diode OR-gated to the summing amplifier such that the maximum voltage is compared with the preset input in one amplifier, and the minimum input is compared with the preset input in the other. This configuration is illustrated in Figure 5.

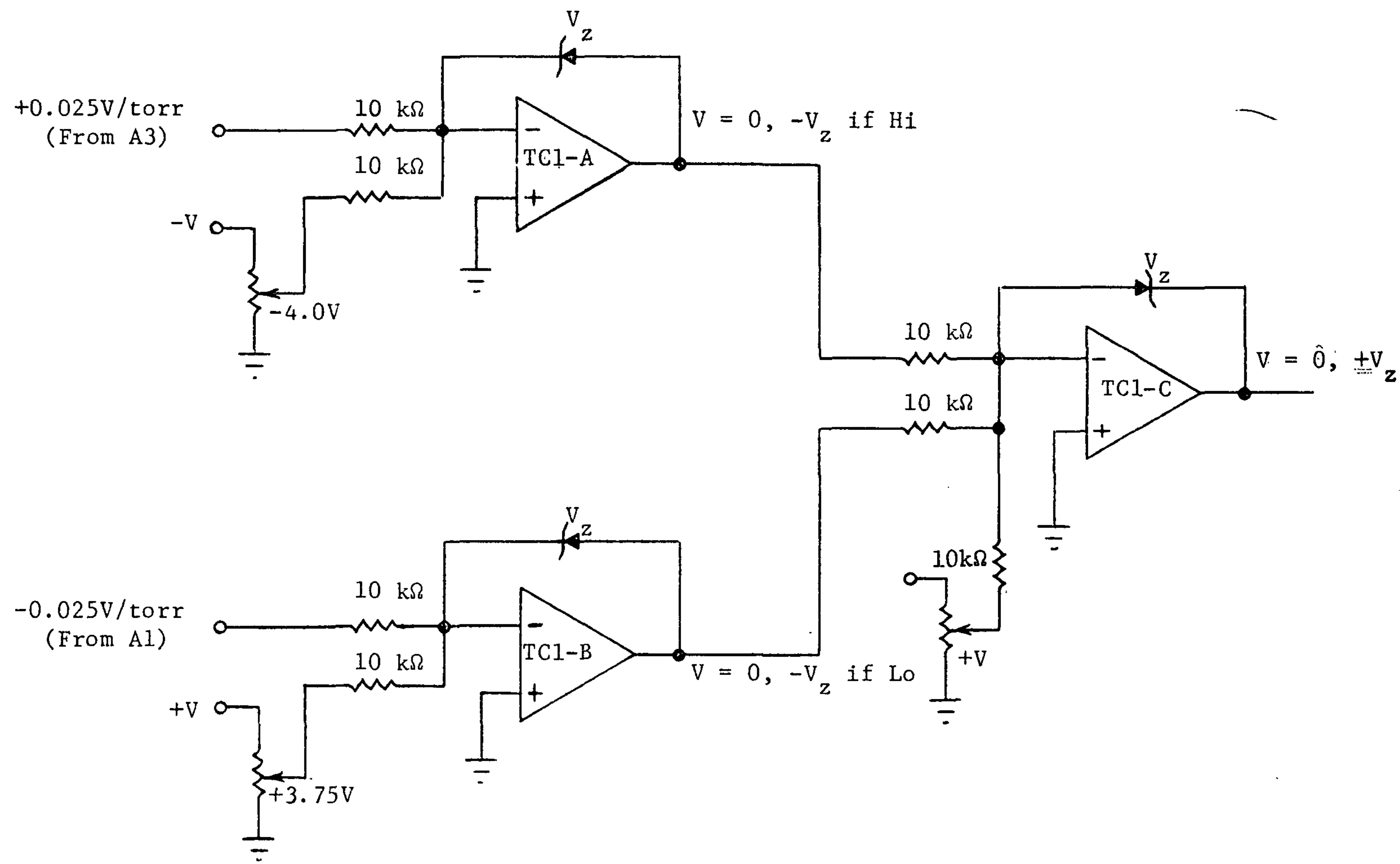

Figure 4. The PPO_2 Warning Alarm Comparator Circuit

The requirements for accuracy and repeatibility in TC3 are stringent. Since the upper priority and emergency alarm levels differ only by 125 mV, a 10 mV variation in the priority alarm detection is very large. It will be important to select reasonably matched diodes for the OR-gates, and it will be necessary to experimentally adjust the preset alarm voltages to compensate for the diode voltage drops. These inaccuracies are disadvantages of the diode OR-gating illustrated in Figure 5, but this arrangement should be satisfactory. There are alternatives that overcome these disadvantages, but they are significantly more complex.

Comparators. - Comparator 1 (C1) in Figure 2 provides for an instrumentation alert if the PPO_2 inputs via A1 and A3 differ significantly from the inputs via A4 and A5. The comparison circuitry suggested here is illustrated in Figure 6 along with the transfer characteristics. A positive input from A3 and a negative input from A4 are summed in amplifier C1-A. Amplifier C1-B provides an active, negative feedback path around C1-A which will maintain the output of C1-A at zero until the output of C1-B saturates or is otherwise limited. When the input voltage difference, $\pm \Delta V_{in}$, reaches a corner value, $\pm V_c$, such that further increases will cause the output, V_o, to increase or decrease from 0, one can write

$$\pm V_c \frac{R_f}{R_i + R_f} = \mp V_{sat} \frac{R_2}{R_2 + R_3}, \text{ or}$$

$$\pm V_c = \mp V_{sat} \frac{R_2}{R_2 + R_3} \left(1 + \frac{R_i}{R_f}\right),$$

where V_{sat} is the saturation voltage of C1-B and the other equation terms are defined in Figure 6. It is probable that the $\pm V_c$ corners can be more closely defined if zener diodes are used to firm the saturation voltage of C1-B. As the value of the differential input voltage increases (or decreases) beyond the $\pm V_c$ limit, C1-A functions as an inverting

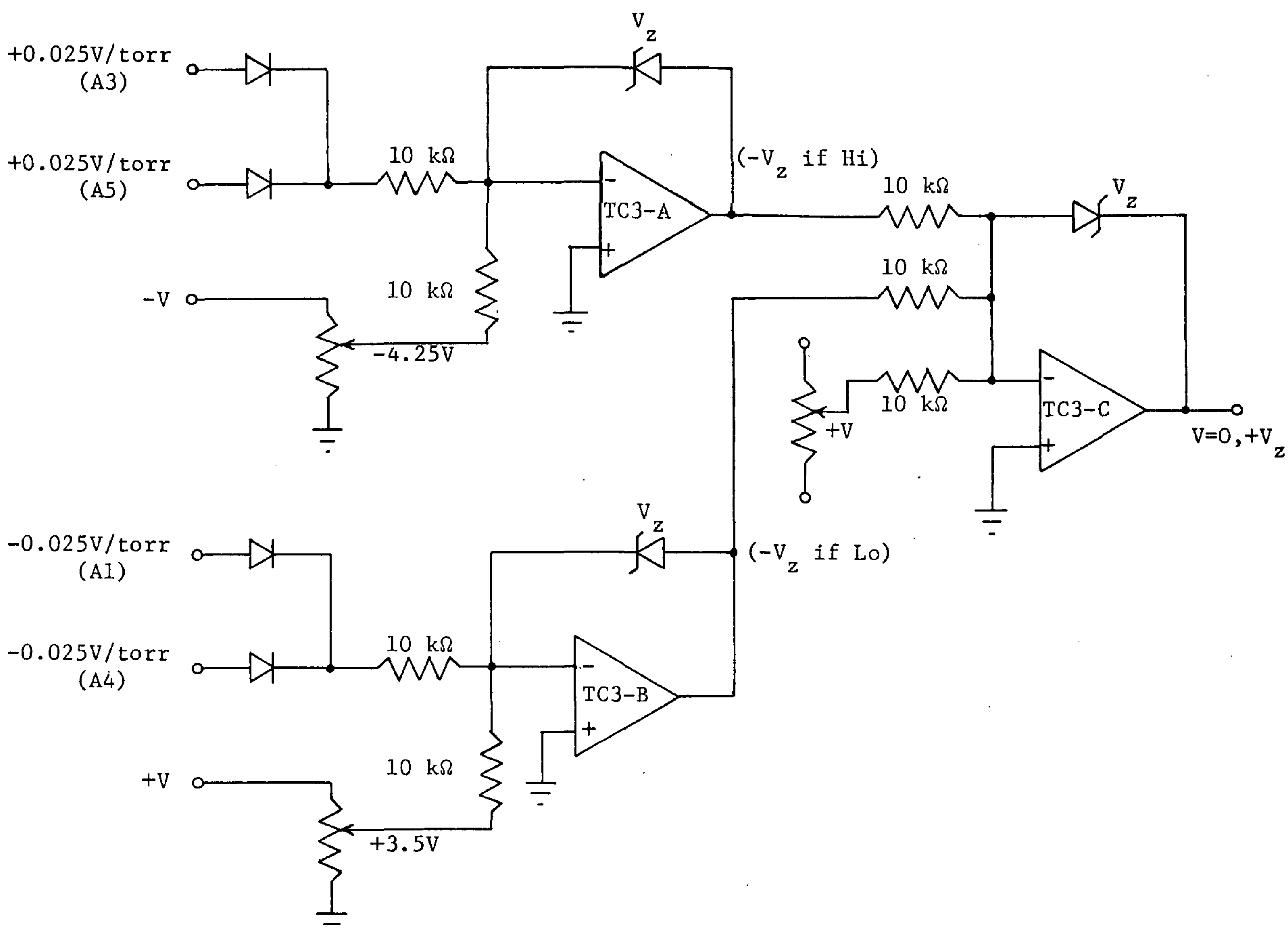

Figure 5. The PPO_2 Priority Alarm Comparator with Redundant Inputs

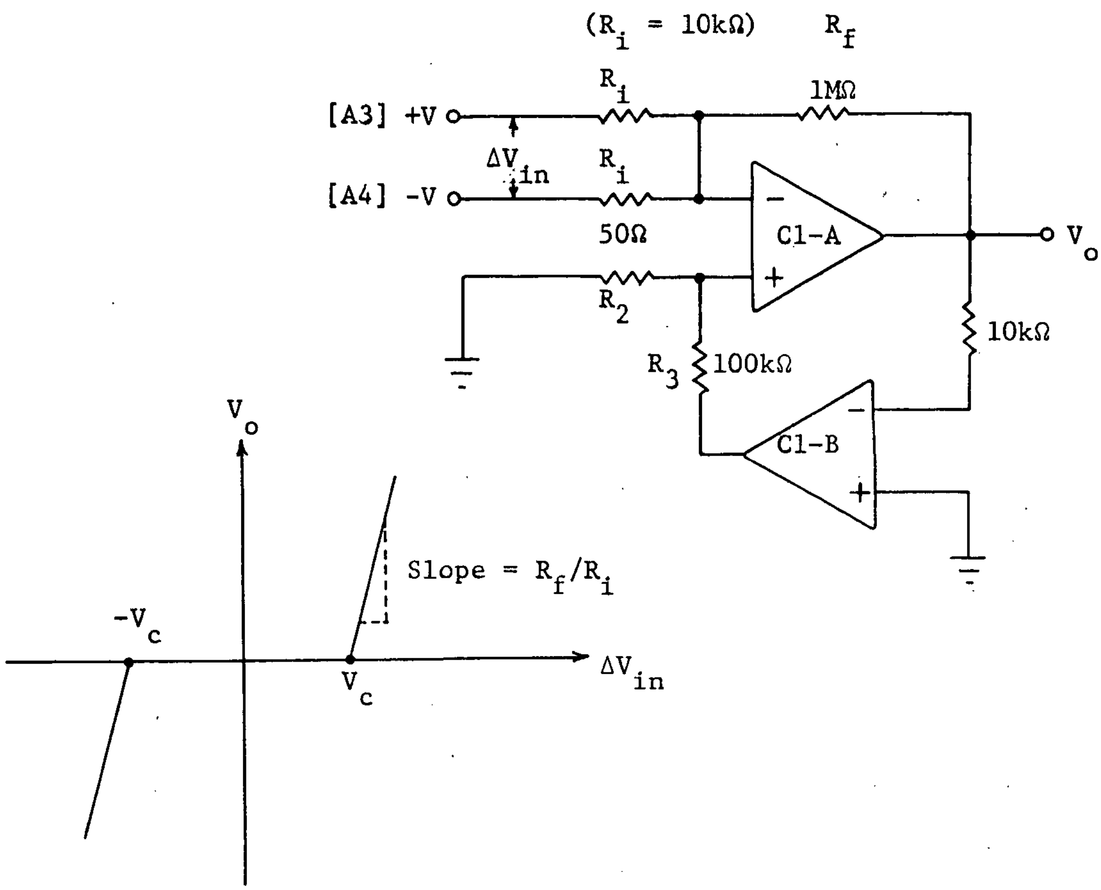

Figure 6. Comparator Circuit with Null Zone

amplifier with a gain fixed by the R_f/R_i ratio. It is desirable that this gain be high, e.g., 100 or greater. The configuration of C1-A requires a bipolar amplifier. Amplifier C1-B is single ended and can be chopper stabilized.

Assume, for example, that a 5 mV error is to be tolerated by C1, V_{sat} is $\pm$ 10 V and the R_f/R_i ratio is 100, i.e., R_f = 1 MΩ and R_i = 10 kΩ. From the preceding equation,

$$\frac{R_2}{R_2 + R_3} = \frac{5 \times 10^{-3}}{10 \times 1.01} \approx 4.95 \times 10^{-4}.$$

For example, let $R_2 = 49.5\ \Omega$, and $R_3 = 100\ k\Omega$. These are realistic values, but they can be altered by reducing the value of V_{sat} with zener diodes. This circuit has not been fabricated or observed in operation, but it is anticipated that it will function satisfactorily. Comparator 2 will function in a similar way to compare the PPO_2 output of the mass spectrometer with that of a backup PPO_2 sensor. It is probable that a significantly larger difference would be acceptable than in the case of comparable inputs to Comparator 1.

Logic For Instrumentation Alert. - A design for the logic elements shown in Figure 2 is illustrated in Figure 7. The configuration is simply a summing amplifier with a zener diode feedback which limits the amplifier output to zero if the summed inputs would yield a positive output and to $-V_z$ if the summed inputs would yield a negative output. Under normal conditions, the negative high warning and low warning inputs from TC1-A and TC1-B are zero, the positive emergency alarm input from TC2 is zero, and the incremental, negative input from the potentiometer assures that the summed inputs are negative. Consequently, the amplifier output is zero. If a warning alarm occurs, the added input is also negative and gained sufficiently to override the subsequent positive input if an emergency alarm should occur. However, if an emergency alarm should occur without a warning alarm, the net positive input would cause the amplifier to be $-V_z$.

The second logic element is identical to the first, but it has different inputs. Negative V_z inputs would be utilized from the high and low emergency alarm amplifiers in TC2, and a positive priority alarm input from TC3. Similarily, its output would remain zero unless a priority alarm occurred without an emergency alarm having previously occurred.

The OR-gate illustrated in Figure 2 can be implemented with an operational amplifier arranged to sum the many binary inputs. As in the case of the various comparators, the preferred method is to sum the inputs, each with the same polarity, in a single amplifier that has a biasing input and a zener diode negative feedback. However, some of

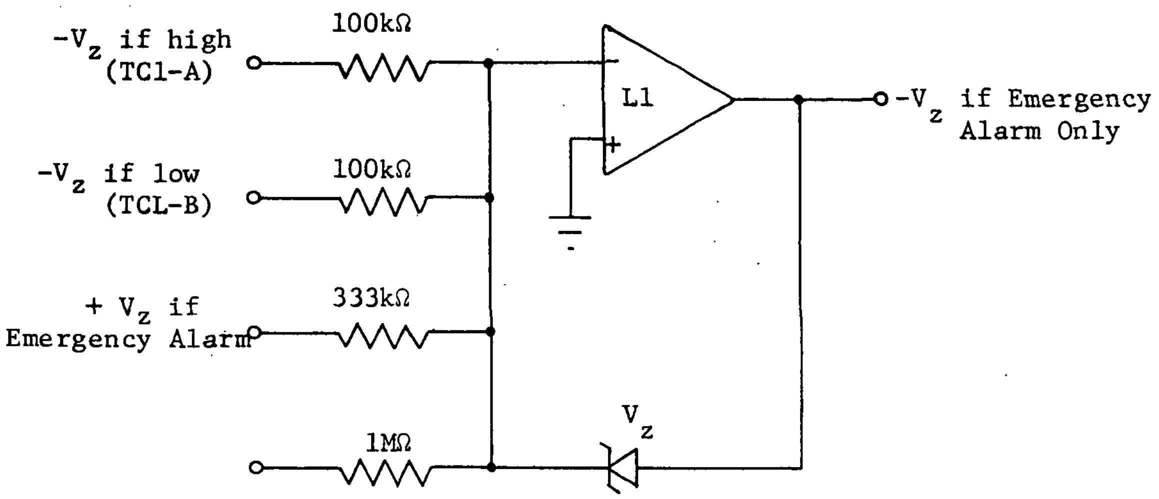

Figure 7. Logic Circuitry for Instrumentation Alert

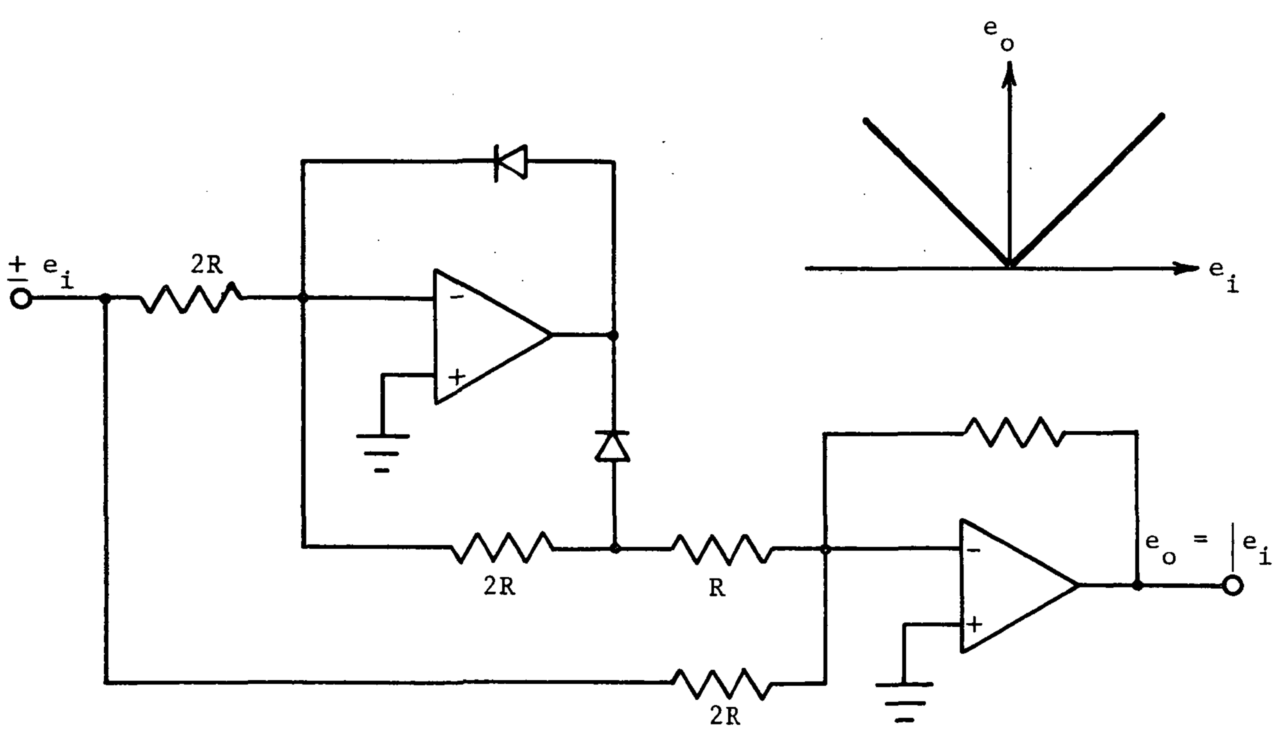

Figure 8. An Absolute Value Circuit

the inputs to the OR-gate are bipolar and an absolute value circuit is required to convert each of these to a single polarity. A frequently used absolute value circuit is illustrated in Figure 8. It requires two inverting amplifiers, and the diodes are located in the feedback loop.

Modular operational amplifiers or boosters are capable of driving low-wattage incandescent lamps or relays directly. Consequently, the OR-gate output can interface with the instrumentation alert directly. It is more likely that a current amplifying stage will be desirable at the interface. This is especially true of the warning, emergency and priority alarms since an audible alarm is included with the visual alarm. The interface modules included in Figure 2 serve that purpose.

Cost Considerations. - The complete analog instrumentation illustrated in Figure 2, and shown in more detail in Figures 3-8, requires 28 amplifiers. This figure includes a small complement of inverting amplifiers not shown in the schematics of Figures 3-8. If these are modular, chopper stabilized amplifiers, the cost would be approximately $1700 for a single Level 1 parameter monitor. This figure can be significantly reduced by using inexpensive, integrated operational amplifiers, e.g., a cost of $800 per parameter monitor is probable. However, some of the amplifiers in Figure 2, e.g., A1, A2, A3, A4, A5 and TF1, should be quality low-drift units. If cost reduction is critical, a reasonable approach is to sacrifice some of the redundancy in instrumentation alert features of the monitor and to use less expensive amplifiers in all but the most critical applications. Most of the features of the example Level 1 parameter monitor discussed herein can be achieved for approximately $1000. These figures include approximately $200 for a power supply for the operational amplifiers.

Digital

Much of the analog instrumentation illustrated in Figure 2 can be done digitally, as illustrated in Figure 9. The desirability of an

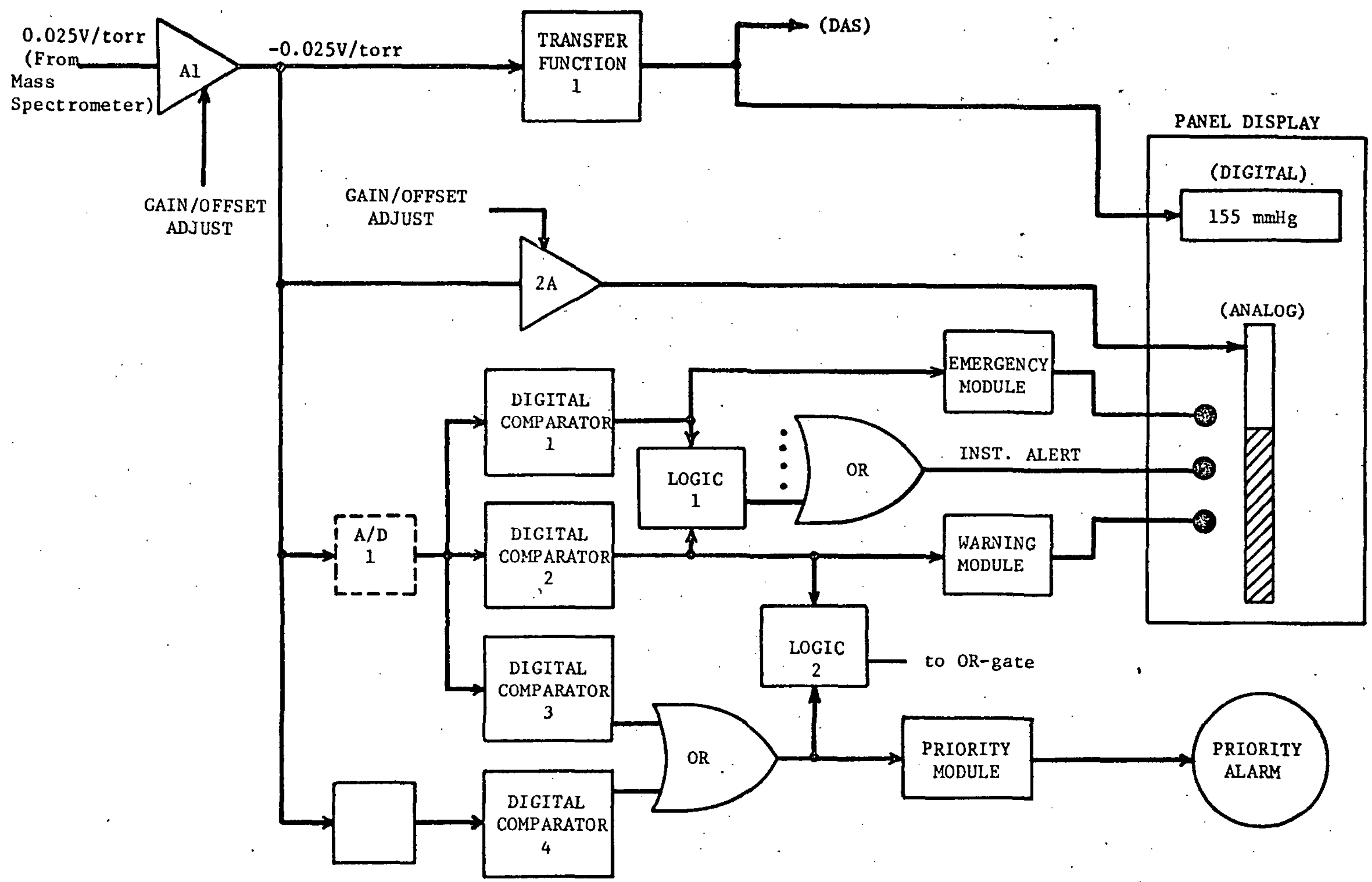

Figure 9. Block Diagram of a Digital Level 1 Parameter Monitor

analog display of Level 1 parameters would call for a duplication of much of the circuitry in Figure 2, i.e., amplifiers 1 and 2, transfer functions 1 and 2 and the parameter display panel are unchanged. Amplifiers 3 and 4 are replaced by analog to digital (A/D) converters, however, and the numerous comparisons done digitally. The logic blocks and priority, emergency and warning modules will perform the same function as before but will differ in design details due to differences in the input signals. The preferred method largely depends upon the availability of commercial components and the amount of digital equipment committed to the LSS. However, digital instrumentation is inherently superior to analog in some cases to be considered, e.g., rate-of-change circuitry and where small differences are significantly important.

To complete the similarity between the analog and digital monitors, Figure 9 requires the addition of an A/D converter (A/D-3) and two additional comparators. The A/D converter changes the output of a backup PPO_2 sensor and transfer function (TF-2 in Figure 2) to a digital form, and the comparators compare the outputs of A/D-1 with A/D-2 and A/D-3. Any significant discrepancies are noted by the comparators and are OR-gated to the instrumentation alert. These components are not included in Figure 9 to avoid unnecessary clutter.

There are several approaches to accomplishing the digital instrumentation indicated in Figure 9. The approach discussed herein is the utilization of a family of compatible digital components, one of several commercially available. It has the advantages of modularity, flexibility, and ease of design.

The digital portion of the Level 1 parameter model is readily evident in Figure 9. This block diagram was carefully arranged to parallel the analog monitor circuitry of Figure 2 and is suitable for comparing the analog and digital systems; however, a block diagram of a specific digital design may be somewhat different.

Comparators. - One of the A/D converters in Figure 9, A/D-1, is inherently a part of the digital panel meter used in the parameter display. The panel meter accepts an analog input scaled to physical units and provides a digital readout and a BCD electrical output that is compatible with the digital comparators. The comparators have high and low limit settings that are dialed on thumb-wheel switches. When either a high or low limit is exceeded, the comparator display changes from an "In-Limit" readout to a "High" or "Low" readout, a relay operates to open and/or close a circuit, and a TTL logic output changes state. Comparators 1, 2, and 3 provide warning, emergency, and priority alarm outputs. Warning, emergency and priority alarm modules are included in Figure 9 to provide for additional signal conditioning, but the comparator relay outputs are adequate to handle the necessary power.

The logic circuitry in Figure 9 consists of an AND-gate and an exclusive OR-gate. The warning and emergency alarm logic outputs are supplied to the AND-gate and the AND output and the emergency alarm logic output are supplied to the exclusive OR-gate. Consequently, the exclusive OR has a single input and an output only when an emergency alarm occurs without a prior warning alarm. A similar arrangement provides for an instrumentation alert if a priority alarm precedes an emergency alarm.

A redundant A/D converter, A/D-2, converts the output of A1 to a BCD output compatible with the digital comparators. The limits on Comparator 4 are set to provide a redundant priority alarm output which is OR-gated with the output of Comparator 3 to the priority module.

Logic. - OR-gating Comparators 3 and 4, as illustrated in Figure 9, to provide for an instrumentation alert if the A/D converter outputs are not in reasonable accord is a desirable feature, but the implementation illustrated is not realistic. It is unlikely that the A/D converter outputs will compare bit for bit, and an instrumentation alert may occur when in fact the two outputs are approximately the same. One method of implementing this logic is illustrated in Figure 10. Assume, for example,

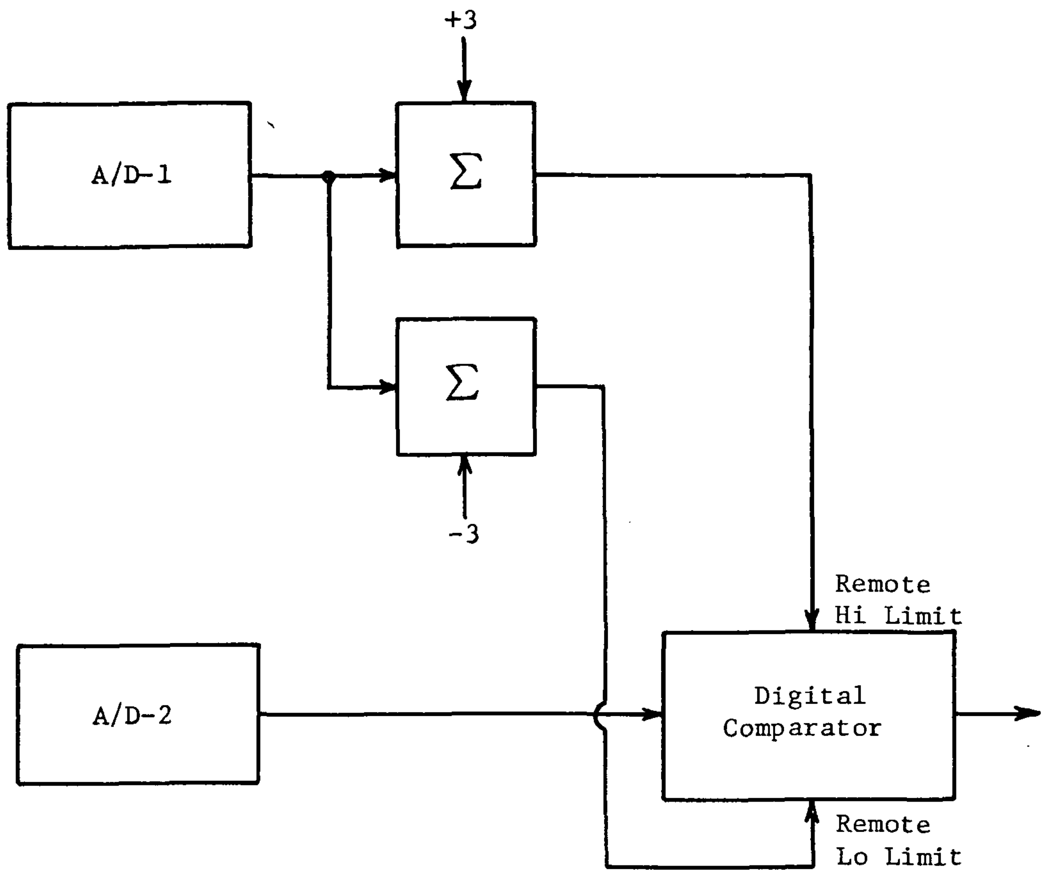

Figure 10. Digital Logic for Detecting Significant Differences in Two Digital Words

that a difference of ± 2 torr is acceptable whereas ± 3 torr is considered excessive. If +3 and -3 are summed with the output of A/D-1 and these summed outputs are used as remote limit inputs to a digital comparator, the comparator output will indicate if the A/D outputs differ by ± 3 torr or more. Digital comparators such as 1, 2, 3, or 4 are readily available with remote limit input options at a modest cost increase.

Another method of implementing the logic circuitry in Figure 9 is illustrated in Figure 11. The output of the A/D converter is increased by 3 and subsequently decreased by the output of a second A/D converter. The resultant outputs are OR-gated to ascertain that all bits more

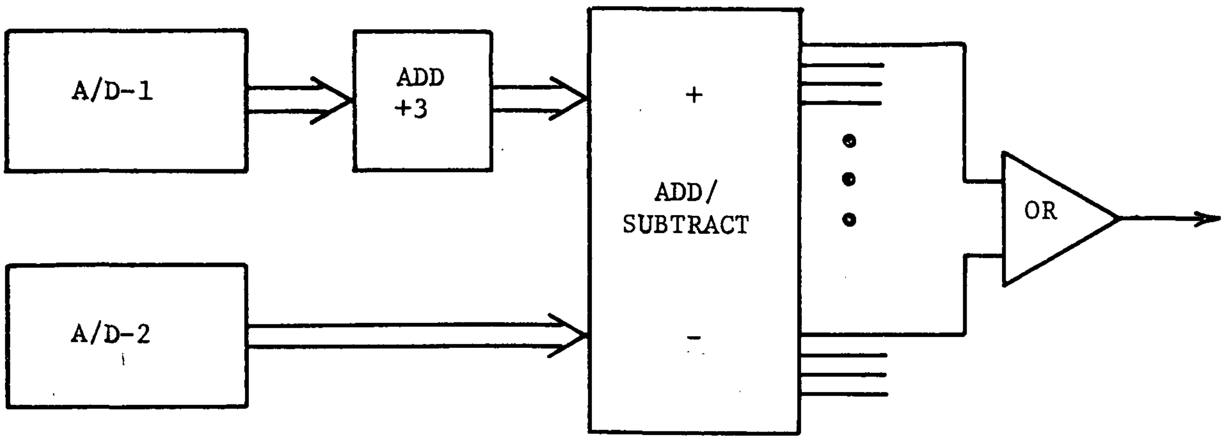

Figure 11. Digital Logic for Detecting Small Differences

significant than the 2^2 bit, for example, are zero. Otherwise, the A/D converter outputs differ by more than $\pm$ 3 and an instrumentation alert occurs.

Cost Considerations. - The monitor circuitry illustrated in Figure 9 can be implemented with discretely packaged digital and analog components for approximately $2,300. This figure can be significantly reduced with less expensive hardware, i.e., compatible families of logic cards and/or individual designs, but the design effort would be significantly increased. Cost reduction can also be achieved by reducing the complexity of the monitoring circuitry indicated in Figure 9, e.g., sacrificing some of the redundancy. It is doubtful that the cost of the instrumentation indicated in Figure 9 can be reduced below $1,500.

Although the digital instrumentation is more expensive, it is more accurate and better suited for detecting small differences in comparable signals and for long periods of operation than the comparable analog circuits.

Parameter Rates-of-Change

Monitoring the rates-of-change of the Level 1 parameters is an essential feature of the data management and display system. The rate-of-change of the PPO_2, for example, can give the earliest indication of an impending problem. The LSS environmental parameters characteristically change very slowly, however, and monitoring their rates-of-change poses some difficulties. It has been estimated that a crew of four in a 116 m^3 cabin would require 14 hours to reduce the PPO_2 from 155 to 145 torr, or the use rate corresponds to 0.715 torr/hr. If the O_2 use rate is nominal and no additional oxygen was added to the system, a rate-of-change of 0.715 torr/hr or 1.99×10^{-4} torr/sec would have to be detected by the instrumentation. It would be desirable to detect slower rates-of-change if the rate-of-change is to be useful as a fault indicator.

Analog. - Various rate-of-change circuits have been described and used. A practical analog rate-of-change circuit, i.e., a differentiator, is illustrated in Figure 12. This rate-of-change circuit functions as well as any that could be used. The transfer function of this circuit can be written as

$$\frac{e_o}{\frac{de_i}{dt}} = \frac{R_f C_i}{(jR_f C_f\ \omega + 1)\ (jR_i C_i\ \omega + 1)} \cdot \qquad (1)$$

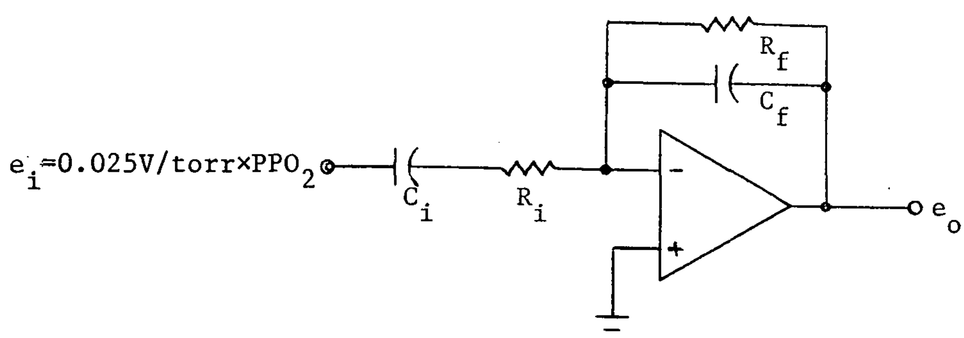

Figure 12. An Analog Rate-of-Change Circuit

Consequently, at frequencies below $\omega = R_f C_f$ and $\omega = R_i C_i$, the circuit output is simply the rate-of-change of the input multiplied by a gain term. In the case of the PPO_2, a signal level of 0.025 V/torr is available from the instrumentation. Consequently, the output would be

$$e_o = \text{Gain} \times \frac{d}{dt} [e_i], \text{ or}$$

$$e_o = \text{Gain} \times (1.99 \times 10^{-4}) (.025)$$

$$\approx \text{Gain} \quad 5 \times 10^{-6} \text{ Volts}$$

for large rates-of-change. Consequently, an extremely high gain would be required to get a detectable signal level out of the circuit. For a practical gain, the expected output is well below the drift expected from a good quality amplifier. It is concluded, therefore, that the analog approach to the PPO_2 rate-of-change is not practical. It is equally impractical for the other gases that comprise the LSS atmosphere.

Digital. - The average rate-of-change of the PPO_2 can be determined digitally by taking the difference between any two samples and dividing by the time elapsed between the samples. This procedure could be repeated at each sample period to continually provide a more recent measure of the rate-of-change. An improved procedure is suggested herein that provides several advantages. If a moving average of the monitored parameter is computed and updated at each sample period, it would provide a smoothed output that was more representative of the parameter and its trend. Furthermore, a rate-of-change computation based upon a comparison of a given sample with the moving average would more accurately represent the parameter rate-of-change and be less susceptible to errors due to spurious errors in the instrumentation output. A moving average readout is particularly useful when the measured parameter changes very slowly as is the case with most of the Level 1 parameters.

Digital Data Averager. - The moving average computation can readily average over any period of time or any number of samples. An hourly moving average may be computed, for example, that is updated at each sample period, and the output of the hourly moving average may be gated to a subsequent averager to compute a moving average over a longer period of time. The circuitry requirements for these computations are minimal, especially if the number of samples considered is an integral power of two.

The block diagram of Figure 13 illustrates the use of a moving average in a rate-of-change computation. At each sample period, an hourly moving average circuit, for example, is updated and its output compared with the current sample to determine a rate-of-change. If desired, the data averaging and comparison can be extended over a greater period of time with only modest increases in circuitry by gating the hourly moving averager and averaging these hourly inputs. The digital computations block subtracts the digital inputs and divides by the elapsed time to determine the rate-of-change. The moving average is also a useful parameter for determining the characteristics of the system and will be monitored by the data acquisition system.

A block diagram of the moving average calculator is shown in Figure 14. The analog input is scaled and impedance matched to interface with the A/D converter. At each sample period, the A/D converter reads and digitizes the analog input, and the sample is moved into storage. At the completion of each A/D conversion, the updated storage registers are multiplexed to a serial adder and the summed data is divided by the number of samples to yield the moving average. Additional detail is illustrated in Figure 15. As shown in this illustration, the A/D converter samples the analog input as commanded by the clock input. A status signal available from the A/D converter indicates that a conversion is in process and returns to its normal state when the conversion is completed. This status signal controls

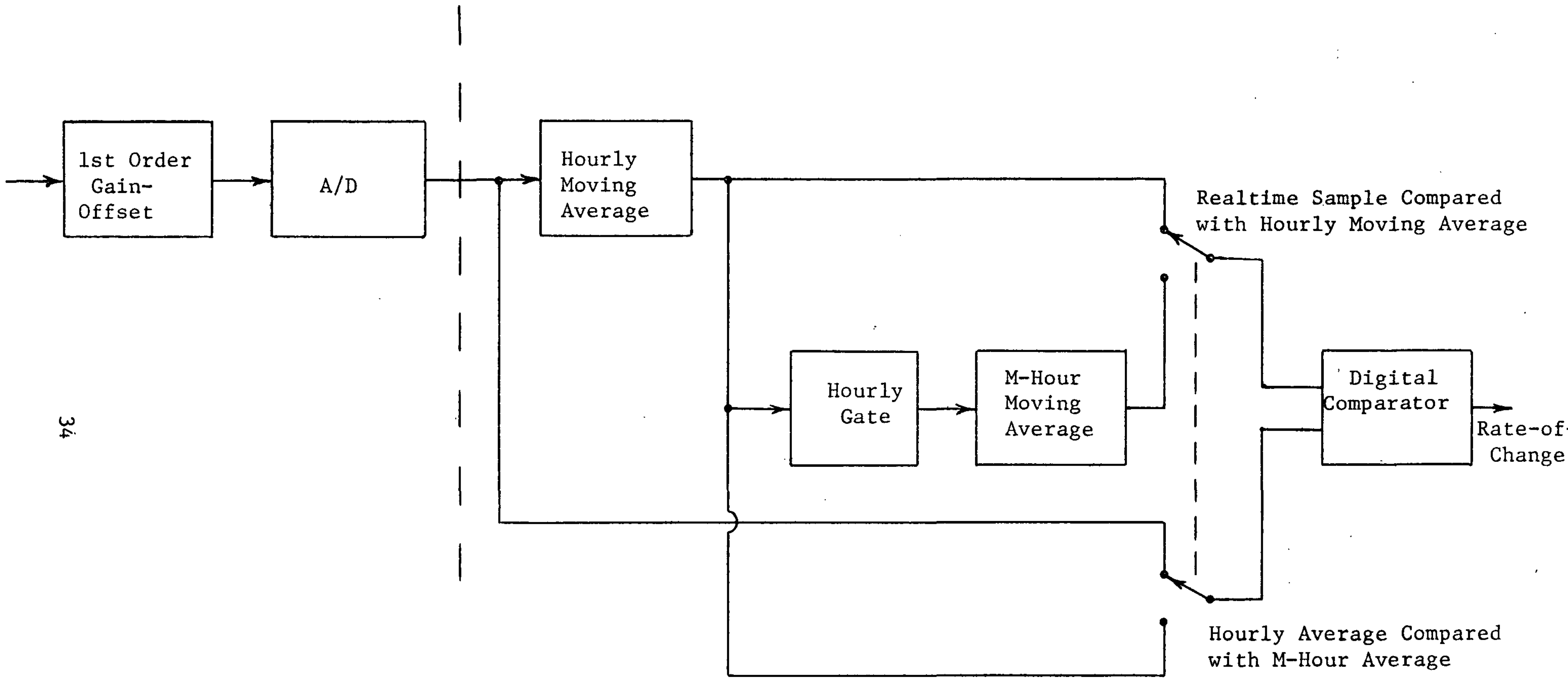

Figure 13. Digital Data Averager for Rate-of-Change Computation

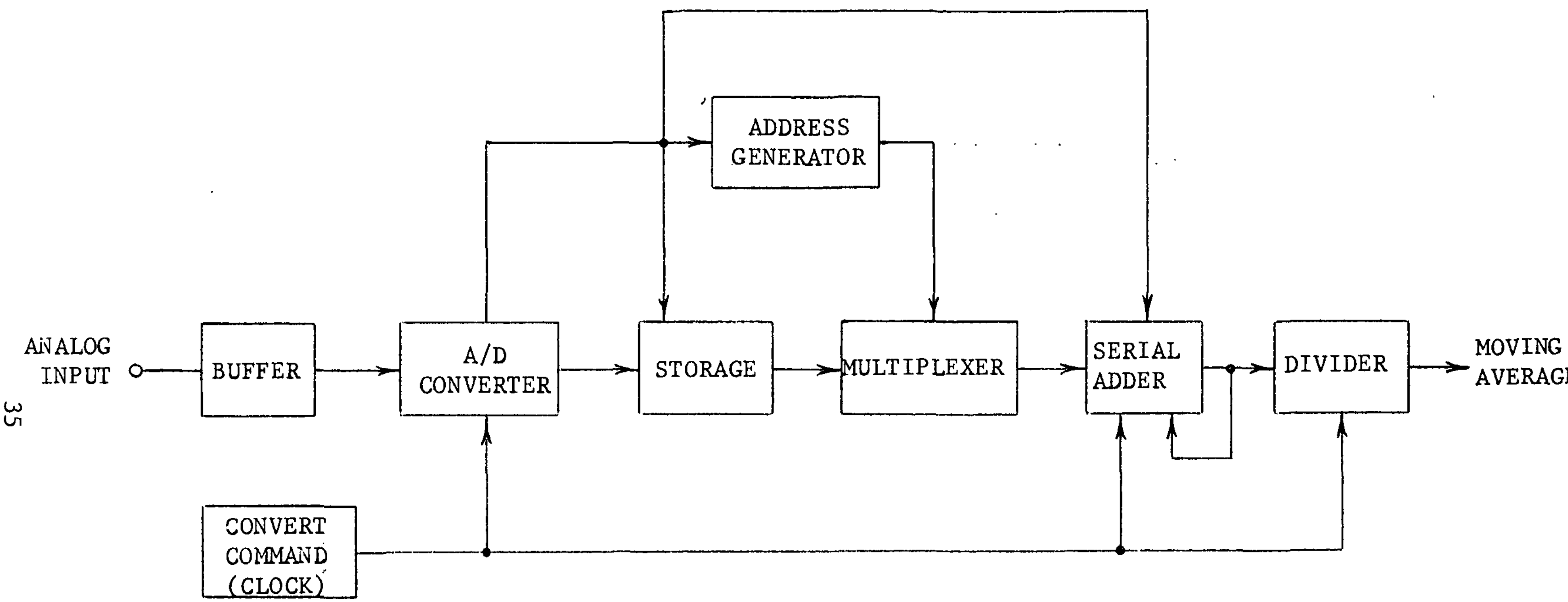

Figure 14. BLOCK DIAGRAM OF A DATA AVERAGING SYSTEM

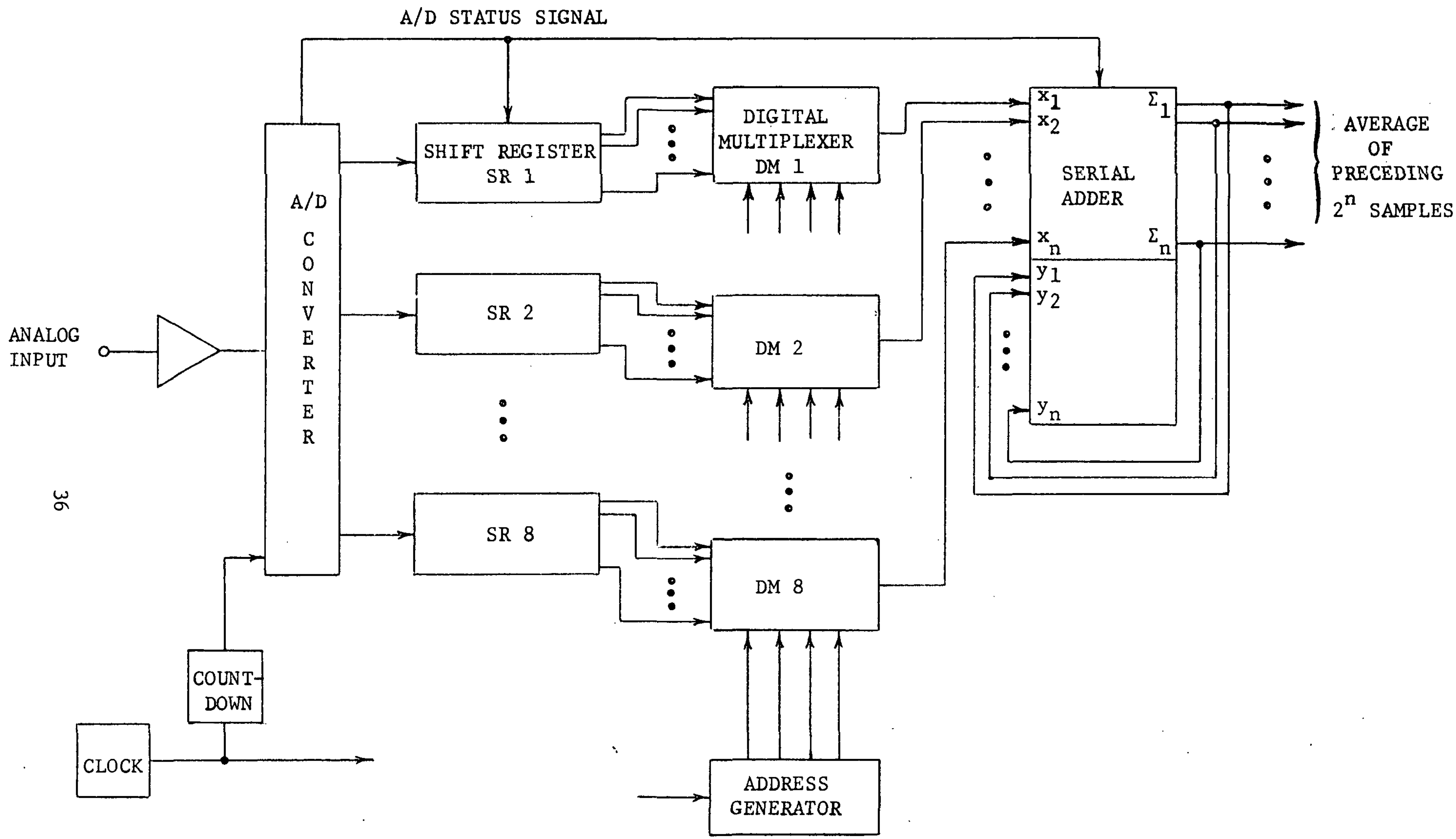

Figure 15. DIGITAL DATA AVERAGING CIRCUIT

the clock input of a number of shift registers such that after each conversion operation, the parallel output bits of the A/D converter are stored in the shift registers. The number of shift registers required equals the number of bits available from the A/D converter, and the length of each shift register determines the number of samples that can be stored. The most significant bit in each sample is stored in one shift register, e.g., SR-1 in Figure 15; successive bits in each sample are stored in other shift registers with the least significant bit in the last register, e.g., SR-8 in Figure 15. The most recent sample is always found in the first place in the several shift registers. If the registers store eight bits, for example, the seven samples preceding the most recent are stored in the registers and the eighth is shifted out of storage at the completion of each new sample/conversion cycle.

The outputs of each of the storage shift registers are supplied to a multiplexer. The multiplexer, controlled by an address generator, shifts the digitized data sequentially to a serial adder where the stored data samples are summed. The address generator will be caused to cycle at the completion of each conversion. Control signals required by the adder will depend upon the characteristics of the unit selected; but complete control can be provided by the A/D command, A/D status, and/or the address generator signals.

The sum of the eight samples appears at the output of the adder at the completion of each cycle of operation. Dividing the binary sum by an integral power of two, for example, can be accomplished by simply selecting the appropriate, significant bits from the adder. Consequently, no additional circuitry is required and the adder output is the desired moving average.

If a moving average is to be calculated from eight samples of data, for example, the circuitry in Figure 15 would have a component cost of from $450-550.

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SECTION IV

SYSTEM CONSIDERATIONS

Data management for life support systems poses numerous design and display problems because of the number of parameters that must be monitored, the critical nature of many of these parameters, and the need to design in self-checking and alarm features to facilitate timely control over the system. There are numerous data acquisition, data analysis and circuitry options open, each subject to trade-off considerations. Some of these are discussed in the following paragraphs.

The Level 1 parameters are limited in number. Those descriptive of the cabin environment number less than ten (10); however, these are significantly increased by parameters descriptive of critical conditions in the subsystems. Identification of these parameters will require the assistance of subsystem specialists, but it is anticipated that the total number of Level 1 parameters will remain small. Because of the critical nature of these parameters and because the number is manageable, these should be individually hard-wired to monitoring circuitry such as described in the preceding section. Each parameter will have an analog and a digital display of the parameter value, individual alarm displays and instrumentation alerts.

Less complex instrumentation is suggested for the other parameter levels. It is anticipated that the Level 2 parameters will be largely hard-wired to the monitoring and display equipment as described in a preceding section. These, too, will be limited to a manageably small number, e.g., a number from twenty (20) to forty (40) is assumed. The bulk of the parameters, e.g., 100 to 200, will fall in the Level 3 category. Some of these will be continuously monitored, e.g., the Level 1 parameter rates-of-change; however, most will be routinely monitored through a data acquisition system.

Data Acquisition. - Data acquisition involves the routine, periodic measurement of all parameter values of interest in the system. The numerous parameters are made available to a scanner through direct wiring or via a multiplexed path. The scanner routinely samples each parameter and interfaces with measurement and data storage units for subsequent analysis or with computer facilities for quasi real-time analysis. The block diagram of Figure 16 depicts the data management system. All parameters are monitored by either a data acquisition system or a computer facility, and many are hard-wired to individual monitors. Some additional multiplexing is likely at the Level 3 category. The distinction between internal and external cabin equipment is not as well defined as implied in Figure 16, and the interfacing of a computer facility with the data monitoring equipment is not as straightforward.

Sample Rates. - Many of the life support system parameters change very slowly. The cabin environmental parameters, for example, change slowly even if controlling subsystems are completely inoperative. As described in a preceding section, several hours would be required for the partial pressure of oxygen to reach a priority alarm level if the O_2 electrolysis subsystem was inoperative. There will be exceptions to this general rule. It is probable that some subsystem parameters will change rapidly and will be capable of irreparable damage to the subsystem. Parameters of this nature must be considered critical and monitored accordingly. These, however, would be considered Level 1 parameters and instrumented with hard-wired monitoring circuitry displays and alarms. Consequently, a nominally slow sample rate is considered adequate for the data management system, e.g., a nominal sampling period of five minutes is assumed. If significantly faster rates were used, the data acquisition would be significantly more complicated and more expensive. With a five-minute period and 200 to 300 parameters, low speed mechanical switching scanners are suitable. A crossbar scanner is the obvious choice of these because of the large

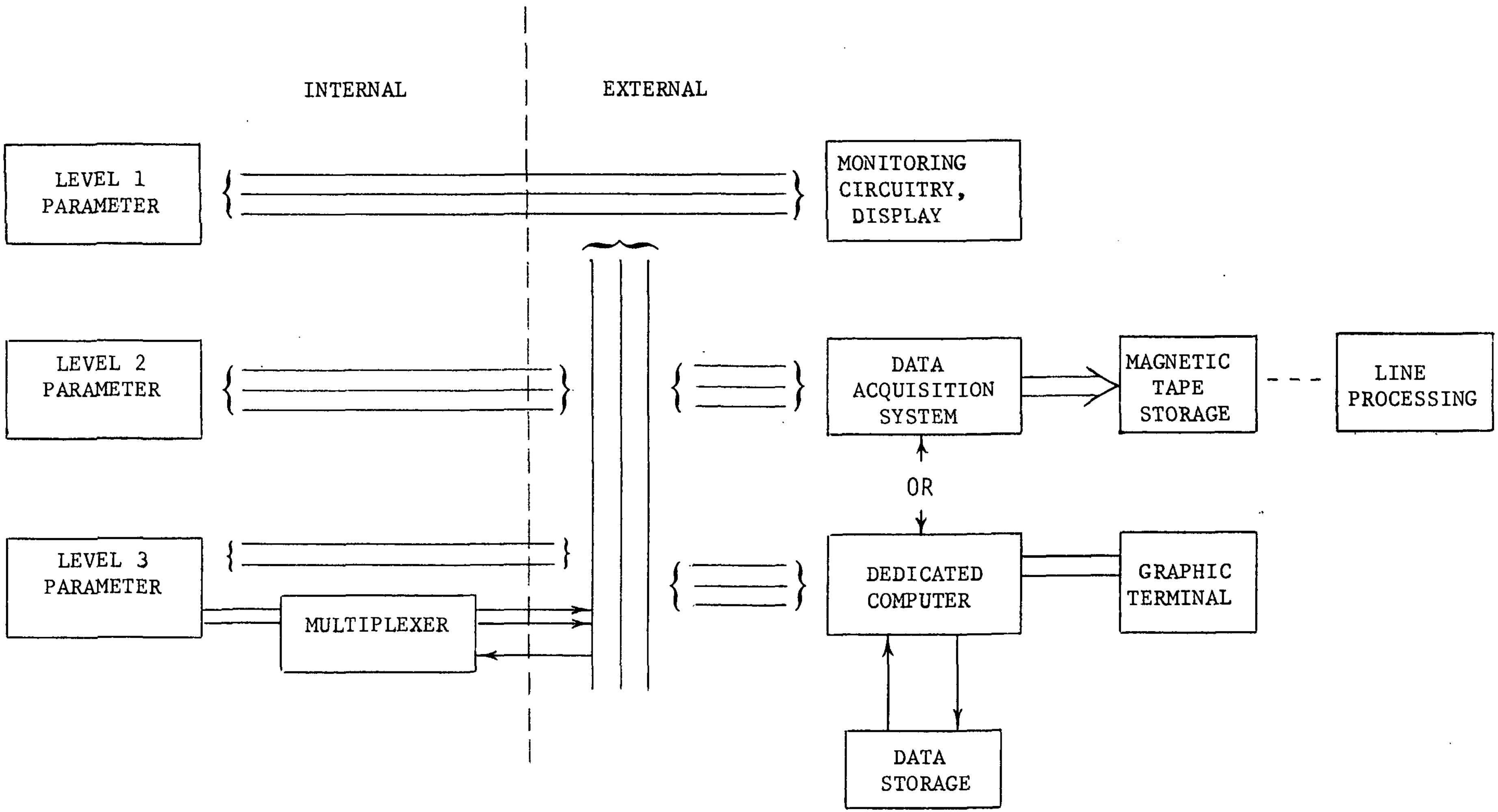

Figure 16. SOME SYSTEM CONSIDERATIONS

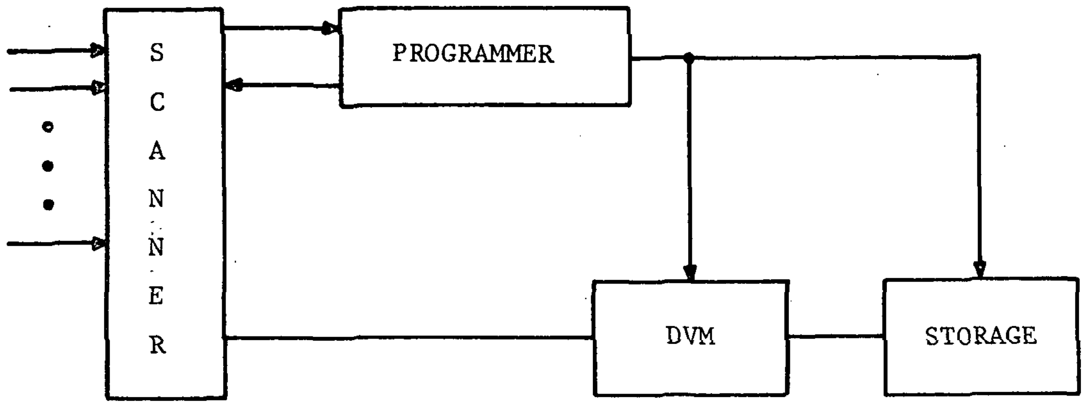

Figure 17. A Data Acquisition System

number of parameters to be monitored. Additionally, the guarded circuit design of the crossbar scanner may be advantageous.

Figure 17 is a simplified block diagram of a data acquisition system. The scanner interfaces the parameter inputs with a measuring device, e.g., a digital voltmeter. It is probably the most critical component of the data acquisition, and a principal criterion for the selection of other components is compatibility with the scanner.

Measuring Device. - A digital voltmeter (DVM) is the most frequently used measuring device and is an obvious choice for low-speed systems. Generally, moderately priced DVM's have more than adequate resolution and accuracy for data acquisition applications. It is frequently desirable for the DVM to be programmable so as to interface with a wide range of input amplitudes. An alternative to a programmable DVM is the inclusion of a programmable amplifier between the scanner and the DVM. However, if it is assumed that all of the LSS parameters to be monitored are scaled to a common voltage level at the subsystem level, the programmable feature is unnecessary.

Since a large percentage of the LSS parameters to be monitored are temperatures and are measured with thermocouples, there are advantages to utilizing one of the data acquisition systems designed especially for theromocouple applications. Systems are available to monitor thermocouples that have all of the attributes of a data acquisition system. Designed into the system are calibration and linearization capabilities, reference cold junction units, digital read-outs and binary or BCD logic outputs. These are particularly useful as data acquisition equipment for temperatures and may be a significant convenience at the subsystem level. A thermocouple system such as described, paralleled with a small system for other parameters, would be an excellent data acquisition system for the LSS.

Data Storage. - If a data acquisition system is used in lieu of interfacing with a computer facility, data must be stored for subsequent analysis. A magnetic tape recorder is an economical, computer compatible medium for storing data and an obvious choice for the large number of data channels characteristic of an LSS. A paralleled printer is also necessary to provide an on-site, quasi real-time look at the data.

Computer Facilities

The block diagram of Figure 16 illustrates a computer facility as an alternative to a data acquisition system. However, interfacing a computer facility with the LSS will require careful consideration, and a likely solution is to utilize the data acquisition system as a computer interface. A scanner and a DVM programmed or controlled by the computer constitute a reasonable approach. Design details will depend upon the characteristics of the particular computer facility utilized.

Off-line Processing. - The option of using an off-line computer facility to process LSS data previously stored on magnetic tape is realistic. It is the simplest and least expensive of the several options and should provide for satisfactory monitoring and analysis of the LSS data. The data stored on the magnetic tape can interface directly with an off-line computer facility, and the data analysis should be a simple, straightforward and reasonably fast procedure. The parameter monitors discussed in a preceding section will provide ample warning of an impending problem, circumventing the necessity of an on-line computer facility. If a computer facility is committed to data management for the LSS, a paralleled magnetic tape data storage facility would be a desirable backup. This is especially true if a time shared computer is utilized.

Computer Options. - A computer dedicated to data management and analysis and control of a LSS would offer many advantages. In addition to routine data acquisition and analysis, it would provide for on-line diagnostic routines during abnormal conditions. In the data management role, the computer could function as a programmer for optimizing the data acquisition process, i.e., the acquisition rates and the parameters monitored may be altered with the operational status of the system. In a diagnostic role, the computer could elect to monitor additional parameters that are not routinely monitored to isolate fault conditions. To function most effectively in a diagnostic role, the computer programming should be planned with the assistance of subsystem specialists. If it is utilized at all as a feedback controller, the cooperative efforts of subsystem specialists are essential. A dedicated computer facility may also provide for additional useful interfaces such as graphic terminals.

Diagnostics. - Diagnostics to detect faulty equipment in the LSS is a function to be completed before a fault occurs. Operational dependency studies completed beforehand can provide for a programmable, logical procedure to isolate faults to a replacement level. It is likely that such a study would identify the need for additional sensors in the subsystems for the sole purpose of fault isolation. Implementation of the fault isolation procedure could be done with a computer or manually with prearranged patch panels at subsystem consoles.

SECTION V

CONCLUSIONS AND RECOMMENDATIONS

This report introduces some of the considerations involved in the design of a data management and display system for a life support system. It introduces a conceptual design of the monitoring circuitry, parameter displays and alarms. Particular designs are proposed and discussed for critically important life support parameters for which instrumentation systems are well defined. These particular designs can be readily modified to accommodate many of the life support parameters. For other parameters, different designs will be required. Particular designs for all the monitor parameters would benefit from an improved technical understanding of the parameters and subsystems involved.

The particular designs discussed include both analog and digital instrumentation for a Level 1 parameter. These designs include considerable redundancy, perhaps beyond the point of diminishing returns. However, it is complete in the sense that a single failure anywhere in the added instrumentation would be detected and an appropriate alarm signaled.

A data averager concept is introduced which would be a significant asset to the data management system. It provides a moving average of the parameter values that is not influenced by spurious changes in the parameter and is a particularly convenient means of detecting parameter rates-of-change.

A discussion of the system aspects of the data management system is very general. Additional study of the LSS subsystem characteristics and objectives of the data management are necessary to prepare specific recommendations for the system design.

It is recommended, therefore, that additional studies of the data management function be undertaken. This study should begin with a review of the numerous subsystems that comprise the LSS. This review would particularly benefit from an improved technical description of the subsystems and an opportunity to review their characteristics with subsystem specialists.

A particularly fruitful effort would be the fabrication of both the digital and analog circuitry discussed in Section III of this report. A simulated parameter value could be supplied to each circuit and the circuit's operation completely evaluated. This would be a relatively inexpensive, well-defined study with specific objectives. In addition to the evaluation of the design, it would yield an assessment of the parameter display, an evaluation of the desired redundancy and valuable experience with the data management system.

REFERENCE

[1] ANON: Trade-off Study and Conceptual Designs of Regenerative Advanced Integrated Life Support Systems (AILSS). NASA CR-1458 United Aircraft Corporation, Windsor Locks, Conn., January 1970.