[redacted]

OFR 1975-43

PB-242 488

MINE AIR MONITOR

David Collins, et al

Texas Instruments, Incorporated

Prepared for:

Bureau of Mines

17 June 1974

DISTRIBUTED BY:

NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

[redacted]

KEEP UP TO DATE

Between the time you ordered this report—which is only one of the hundreds of thousands in the NTIS information collection available to you—and the time you are reading this message, several *new* reports relevant to your interests probably have entered the collection.

Subscribe to the **Weekly Government Abstracts** series that will bring you summaries of new reports *as soon as they are received by NTIS* from the originators of the research. The WGA's are an NTIS weekly newsletter service covering the most recent research findings in 25 areas of industrial, technological, and sociological interest—invaluable information for executives and professionals who must keep up to date.

The executive and professional information service provided by NTIS in the **Weekly Government Abstracts** newsletters will give you thorough and comprehensive coverage of government-conducted or sponsored research activities. And you'll get this important information within two weeks of the time it's released by originating agencies.

WGA newsletters are computer produced and electronically photocomposed to slash the time gap between the release of a report and its availability. You can learn about technical innovations immediately—and use them in the most meaningful and productive ways possible for your organization. Please request NTIS-PR-205/PCW for more information.

The weekly newsletter series will keep you current. But *learn what you have missed in the past* by ordering a computer **NTISearch** of all the research reports in your area of interest, dating as far back as 1964, if you wish. Please request NTIS-PR-186/PCN for more information.

WRITE: Managing Editor
5285 Port Royal Road
Springfield, VA 22161

Keep Up To Date With SRIM

SRIM (Selected Research in Microfiche) provides you with regular, automatic distribution of the complete texts of NTIS research reports *only* in the subject areas you select. SRIM covers almost all Government research reports by subject area and/or the originating Federal or local government agency. You may subscribe by any category or subcategory of our WGA **(Weekly Government Abstracts)** or **Government Reports Announcements and Index** categories, or to the reports issued by a particular agency such as the Department of Defense, Federal Energy Administration, or Environmental Protection Agency. Other options that will give you greater selectivity are available on request.

The cost of SRIM service is only 45¢ domestic (60¢ foreign) for each complete microfiched report. Your SRIM service begins as soon as your order is received and processed and you will receive biweekly shipments thereafter. If you wish, your service will be backdated to furnish you microfiche of reports issued earlier.

Because of contractual arrangements with several Special Technology Groups, not all NTIS reports are distributed in the SRIM program. You will receive a notice in your microfiche shipments identifying the exceptionally priced reports not available through SRIM.

A deposit account with NTIS is required before this service can be initiated. If you have specific questions concerning this service, please call (703) 451-1558, or write NTIS, attention SRIM Product Manager.

This information product distributed by

NTIS U.S. DEPARTMENT OF COMMERCE
National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22161

BuMines OFR 43 75

PB242488

USBM Contract No. HO 122044

Mine Air Monitor

Report by

Arnold F. Stalder
David H. Collins

Prepared by

Texas Instruments Incorporated
Equipment Group

USBM Contract Final Report (Contract No. HO 122044)

29 March 1974

Revised 17 June 1974

Bureau of Mines Open File Report 43-75

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies or recommendations of the Interior Department's Bureau of Mines or of the U. S. Government.

Department of the Interior
Bureau of Mines
Washington, D.C.

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
US Department of Commerce
Springfield, VA. 22151

BIBLIOGRAPHIC DATA SHEET

1. Report No. BuMines OFR 43-75

2\.

PB 242 488

4\. Title and Subtitle

Mine Air Monitor

5\. Report Date

June 17, 1974

6\. Performing Organization Code

7\. Author(s)

David Collins, Arnold Stalder

8\. Performing Organization Rept. No. Not assigned as yet

9\. Performing Organization Name and Address

Texas Instruments, Inc.
P. O. Box 6015
Dallas, Texas 75222

10\. Project/Task/Work Unit No.

11\. Contract/Grant No.

H0122044

12\. Sponsoring Agency Name and Address

Bureau of Mines, Pittsburgh Mining and Safety Research Ctr.
4800 Forbes Avenue
Pittsburgh, Pa. 15213

13\. Type of Report & Period Covered Final

6/19/72 to 6/17/74

14\. Sponsoring Agency Code

15\. Supplementary Notes

Approved for release by Director, Bureau of Mines, December 17, 1975.

16\. Abstracts

This report summarizes the work performed under the contract to design and build two portable, battery-powered, breathing air monitors for the toxic gases CO and NO_2 and for oxygen deficiency for use in working places in underground mines including coal mines. The device used commercially available electrochemical transducers, features audible and visual alarms with adjustable threshold levels, selectable digital readout of gas concentrations, alarm level set points, and battery condition. It can run continuously for 30 hours from batteries before recharging is necessary. This report details the design effort including electrochemical cell characterization of response versus temperature, and contains portions of operation and instruction manual.

17\. Key Words and Document Analysis. 17a. Descriptors

Toxic Agent Alarms
Carbon Monoxide
Nitrogen Dioxide
Oxygen
Instrumentation
Gas Detection

17b. Identifiers/Open-Ended Terms

Portable Instruments
Mine Breathing Air Monitor and Alarm
Electrochemical Gas Detectors

PRICES SUBJECT TO CHANGE

17c. COSATI Field/Group 1312 Gas Detection, 1402 Gas Analysis, 0809 Mine Ventilation

18\. Distribution Statement

Release Unlimited by NTIS.

19\. Security Class (This Report) UNCLASSIFIED

20\. Security Class (This Page) UNCLASSIFIED

21\. No. of Pages

FOREWORD

This report was prepared by Texas Instruments, Inc., Equipment Group, Dallas under USBM Contract No. HO 122044. The contract was initiated under the Coal Mine Health and Safety Research Program and the Metal and Nonmetal Health and Safety Research Program. It was administered under the technical direction of the Pittsburgh Mining and Safety Research Center with Dr. George Schnakenberg acting as the technical project officer. Mr. Dean Priddy was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period 19 June 1972 to 28 March 1974. The draft of the report was submitted by the authors on 29 March 1974. This report was revised for final submittal on 17 June 1974.

MINE AIR MONITOR

FINAL REPORT

TABLE OF CONTENTS

INTRODUCTION

The measurement of various gas concentrations in the atmosphere at a particular location has become a problem of considerable importance. Levels that need to be monitored vary from the range of percent for constituents such as oxygen to parts per million levels for gases like nitrogen dioxide. In particular, mine air can become contaminated with noxious or toxic gases from several sources: fires within the mine, diesel-powered equipment, and explosive sources. The contaminants that result are carbon monoxide (CO), carbon dioxide (CO_2), and oxides of nitrogen (NO and NO_2). Additionally, oxygen (O_2) may be depleted. Thus, the workman can be exposed to potentially toxic or asphyxiating atmospheres. A device was needed that will continuously monitor the mine air in working areas and provide warning of hazardous atmospheres.

The Mine Air Monitor was conceived as being a portable, rugged instrument capable of measuring the concentration of the various atmospheric constituents in the mine environment. The unit was to provide both warning signals and quantitative measurements when hazardous contaminants existed at too high a level, or when the oxygen was being depleted. The initial concept involved optical sensors for all of the contaminating gases to be measured, namely CO, CO_2, CH_4, and NO_2, and an electrochemical cell to monitor O_2. When the explosion proof requirements of Schedule 2-G made the concept appear to be unfeasible from the standpoint of weight and portability, the program was redirected and a three channel monitor employing electrochemical sensors was adopted. In this case the gases to be monitored were O_2, CO and NO_2. The remainder of the program was oriented towards obtaining good, commercially available electrochemical sensors for the above gases, testing them, reducing deficiencies noted during these tests, and making the necessary modifications to integrate the three sensors into a Mine Air Monitor suitable for the mine environment.

NON-DISPERSIVE OPTICAL MINE AIR MONITOR

The original concept for the Texas Instruments Mine Air Monitor involved a sensor for five gases, O_2, CO_2, CO, CH_4, and NO_2. The O_2 sensor was proposed to be an electrochemical cell, while the other constituents were to be sensed optically. The optical sensing was to be carried out in the visible as well as infrared region of the spectrum, using a common tungsten filament source and two detectors, one for the visible (NO_2) channel and one for the infrared (CO, CO_2, CH_4) channel. The method of sensing was to be a simple absorption technique, using narrow-bandpass filters to isolate absorption regions peculiar to the various gases.

The absorption wavelengths were .4880 or .4358 µm (NO_2), 3.4 µm (CH_4), 4.6 µm (CO), and 4.3 µm (CO_2). The optical system was single beam, and to obtain an absorption free reference in the visible and infrared additional filters at .6328 µm and 3.9 µm were chosen. The various filters were mounted on a single rotating chopper assembly. The detector amplifiers were led to several sample-and-hold amplifiers gated by the chopper assembly, allowing voltage signals proportional to the optical transmission at each pass band to be monitored. Since the absorption signals measured in this instrument were not expected to be related to the gas concentrations by any simple linear or log type relationship, special circuits were to be employed to linearize the relationship and allow the use of digital displays. Preliminary experiments indicated that sensitivities $\leq$ 0.5 ppm should be attainable for all of the gases measured optically.

The evolution of the design of the Non-Dispersive Optical System indicated that severe problems existed when the explosion proof requirements of Schedule 2-G were examined closely. The problems were centered mainly around weight, which became quite excessive and exceeded 150 lbs before this approach was abandoned in favor of the electrochemical Mine Air Monitor.

ELECTROCHEMICAL MINE AIR MONITOR

The idea of an electrochemical monitoring device is desirable from the standpoint of weight, power, and intrinsic safety. The weight of commercial electrochemical sensors is quite low and power requirements are small enough to allow battery operation. The voltage and current requirements of the devices, including a small sampling pump, allow careful design to yield a battery operated device that is intrinsically safe. Intrinsic safety removes the burdensome weight requirements of Schedule 2-G, applied to explosion proof devices.

The development program oriented around an electrochemical Mine Air Monitor was divided into three distinct phases to allow the Bureau of Mines to assess the progress at various stages and formulate modified program plans after each phase was completed. The first phase of the program was oriented toward selection and testing of commercially available instruments designed to measure CO, NO_2 and O_2. The results of the testing were to be analyzed, to determine which, if any, modifications would be required to make the devices suitable for the mine application. The second phase of the program involved developing and designing the necessary circuit modifications and new circuits needed to yield the portable, intrinsically safe, multigas instrument. The third phase of the program involved the detailed design and construction of the Mine Air Monitors. In practice, the separation between the second and third phases was less distinct than originally conceived. Table 1 summarizes the performance of the Mine Air Monitors that were developed and delivered.

TABLE 1
ELECTROCHEMICAL MINE AIR MONITOR
GENERAL INFORMATION AND TYPICAL VALUES

Gases Monitored and Ranges	
O_2	0 - > 190 mm
CO	0 - > 250 ppm
NO_2	0 - > 25 ppm
Specified Electronic Accuracy	
O_2	±5.0 mm
CO	±4.0 ppm
NO_2	±0.5 ppm
Display	3 1/2 digit (LED)
Alarm Threshold Ranges	
O_2	104 - 171 mm
CO	9.5 - 67 ppm
NO_2	1.2 - 6.8 ppm
Alarm Type	LED's for each gas plus pulse Mini-Sonalert and LED master alarms
Sample Flow Rate	0.5 - 1.2 liter/min.
Batteries Used	2 6V EP675A solid-gel lead a
Power (at 6V), Total	351mA (2.11W)
Pump	320mA (1.92W)
Electronics	13.3mA (0.08W)
DPM Function	18mA (0.11W)
Operating Time (on single charge)	40 hrs.
Operating Life (of cells)	≈ 4 months
Temperature Range	40 - 100°F
Size (basic case)	13.7" x 11.2" x 9.3"
Weight (with batteries)	27 lb.
(without batteries)	20 lb.

PHASE I

A. Commercial Sensor Selection

The commercial electrochemical sensors chosen to be used in the Mine Air Monitor program are noted below:

1. Oxygen Analyzer - IBC Oxygen Analyzer, Model 170-P
   Serial Nos. 13,255 & 13,259
   Manufactured by: International Biophysics Corp.
   2700 DuPont Dr.
   Irvine, Calif. 92664
   A.C. 714-833-3300
2. Carbon Monoxide Analyzer - Exolyzer, Model 2100
   Serial Nos. 0105, 0128
   Manufactured by: Energetics Science, Inc.
   4461 Bronx Blvd.
   New York, N.Y. 10470
   A.C. 212-994-5145
3. Nitrogen Dioxide Analyzer - Theta Sensors, Model
   LS-400AN02, Serial Nos. 40120,
   40121
   Manufactured by: Theta Sensors, Inc.
   1015 North Main St.
   Orange, Calif. 92667
   A.C. 714-639-4302

The oxygen analyzer chosen was the same one picked early in the program for use with the non-dispersive optical system. It is battery operated and uses a small inexpensive probe with an easily replaceable electrochemical cell. The replaceable rather than rechargeable feature of the cell made it very attractive for the mine application.

The carbon monoxide analyzer was chosen because it was the only one readily available, and phone conversations with instrument users indicated that its performance was very good.

Three possible domestic suppliers of electrochemical NO_2 analyzers were considered. These were Theta Sensors, Dynasciences and Envirometrics. At the time that the choice was made, the only vendor that appeared capable of delivering a device sensitive in the low ppm concentration range was Theta Sensors. These devices had been used by the California State Air Resources Board with some degree of success prior to January, 1973. Envirometrics had delivered a device designed to monitor fairly high levels of NO_2 in a stack to a division of Texas Instruments prior to the Mine Air Monitor application, and the performance of this device even at fairly high concentration levels was questionable. In addition to this, a representative of Envirometrics stated in late 1972 that their instruments were not capable of reliably measuring ppm levels of NO_2. Dynasciences, on the other hand, had failed to quote on an NO_2 analyzer for the Texas State Department of Health, and no reliable user information could be obtained pertaining to the performance of their devices in low level applications. The only choice open for the Mine Air Monitor project in January, 1973 appeared to be Theta Sensors.

B. Instrument Test Results

IBC Oxygen Analyzer - Testing the IBC analyzer was concerned mainly with the instrument span stability vs time, temperature, and humidity. The span stability was better than $\pm 0.2\%$ O_2 for operating periods of 48 hours. The span linearity was found to be within $\pm 0.5\%$ O_2 between 15-21% O_2. The effects of humidity seemed only to interfere with operation on one instrument, and was attributed to inadequate coating on the circuit boards. The performance was checked over temperatures ranging from 40-100^{O}F and deviations > ±0.5% O_2 were found to exist at the extremes of that range.

Improvement in temperature compensation over the 40-100^{O}F range, better humidity protection and circuit modification to allow the use of slightly different power supply voltages and for proper system interfacing were the changes needed for the O_2 circuity.

Ecolyzer - The test matrix for the CO and NO_2 sensors was expanded to include instrument response time and the effects of interfering gases. The CO analyzers were found to give 90% response ≃ 30 seconds after the introduction of a sample and > 99% after 3-5 min. The instruments were found to respond to both NO and NO_2 out of a test matrix of NO, NO_2, SO_2, CO_2, and CH_4. The response to NO was found to be about the same as that for CO, while in the case of NO_2 it was reduced to ≃ 25% of the CO response. The zero drift over a two day period operating under fairly constant conditions was found to be < 1.0 ppm. The span drift under the same conditions and measured with a 35 ppm sample was also < 1.0 ppm. Span linearity was better than ± 4 ppm out to a level of 100 ppm. The effect of humidity was negligible, until condensation occurred. Zero drift over the 40-100^{O}F temperature range was > 20 ppm for both units as tested. (The units had been modified to extend the maximum range to 500 ppm. This modification affected the zero compensation, and at least partially accounts for the extensive drift over temperature). The pan drift over the same temperature range was 20-30%, tested at 35 ppm level.

These units required extensive circuit modifications (in Phase II) which improved both zero and span temperature compensation and provided for proper system interfacing.

Theta Sensor - The Theta Sensors tested exhibited serious problems when considered for the mine application. The major problem, and one inherent in the electrochemical cell was the response time. After 3-5 min. a 90% response was achieved, but it took ≃ 30 min. to exceed 99%. Interference tests were run using the test matrix of SO_2, CO, CO_2, NO, and CH_4. These tests were run using a factory installed scrubber, designed to eliminate SO_2. The response to NO was 50 times less than to NO_2, and the response to CO was 400 times less. Removal of the SO_2 scrubber should make the instrument respond to SO_2 as well as it does to NO_2, according to the manufacturer. The zero drift in two days was < 0.3 ppm, while the span drift was about the same over that period, measured at 5 ppm. The span linearity from 0-10 ppm was better than ±0.5 ppm. Humidity, short of actual condensation, had no effect on the instruments. Span drift over the temperature range 40-100°F was < ±1 ppm at 10 ppm. Zero drift over the same range was found to ≃ 5 ppm, with most of the change occurring above 70°F.

These instruments required extensive circuit modifications (in Phase II) which improved both zero and span temperature compensation over the 40-100°F range. In addition the circuits, which were designed to operate with a 115V a.c. source, had to be changed to allow low voltage dc operation and proper system interfacing.

C. Summary

While the electrochemical cells were somewhat slow to respond to a change in their environment, the major problem associated with all of the devices tested was inadequate temperature compensation. The instrument performance of the O_2 analyzer was in general quite good. The CO analyzer performed well during most tests, but on occasions erratic results were observed. The NO_2 analyzers were the least satisfactory, and it is questionable that even with circuit modifications these units can provide the necessary measurement capability.

PHASE II

The effort required in Phase II expanded to include significant detailed electrical design as a result of the Phase I commercial gas analyzer evaluation. Phase II effort was increased still further when it became apparent the CO electronics would have to be redesigned also.

Phase II included:

Characterization of Theta Sensor NO_2 cells and Energetics Science CO cells.

Redesign of NO_2 and CO cell electronics

Selection of major system components

Electrical and mechanical system designs

A. Electrochemical Cell Characterization

Early in the Phase II program, tests were run on a CO Ecolyzer to see if a modification suggested by its vendor would improve its temperature compensation. Temperature characteristics were not improved and CO electronics redesign was added to the Phase II program.

Proper design of the cell electronics was dependent on a thorough knowledge of cell transfer characteristics. Information was acquired from the cell vendors, a cell testing program, and from theoretical data. Cell testing provided the most information but its applicability to the average cell was limited by the number of cells and time available for testing. Also, data taken over temperature had considerable scatter and poor repeatability.

B. Electrochemical Cell Electronics Redesign

In the cell electronics redesign it was decided to use ±2.5V power supplies, hold capacitor values down, and avoid all inductors. These steps were taken for intrinsic safety considerations. Power requirements were kept low to extend continuous operating time. Accuracy was a major consideration throughout the design. Since the cell test data had the problems noted above, however , the temperature compensation circuits designed were ones that would compensate the apparent average of the most consistant normalized cell test characteristics. The range compensated was 40°F to 100°F.

C. Selection of Major System Components

After tests determined the cell pressure drops and the sample air filter was selected, the system plumbing design was completed. The most important factor in the plumbing was the sampling pump. It effectively sets the power requirements of the system. The Spectrex AS-120 pump was chosen due to its relatively high flow capacity at the desired voltage (5V) at reasonable current.

The rechargeable batteries selected for Mine Air Monitor use were two Elpower EP675A 6V, 7 1/2 amp-hour, solid-gel lead acid types. Lead acid was selected over nickel cadmium due to the higher per cell voltage and lower cost of lead acid batteries.

The digital panel meter selected for use was a Datascan 820. It was selected due to its high accuracy, small size, and very low power requirements.

D. Electrical and Mechanical System Designs

The electrical and mechanical system designs as they were finalized are discussed in Appendix A, B, and C. Here, it will only be noted that intrinsic safety, size, weight and environmental constraints were major factors in the design.

PHASE III

Phase III of the Mine Air Monitor program consisted of O_2 cell characterization and O_2 electronics redesign, detailed electrical and mechanical system designs, system fabrication and testing, and generation of the Installation and Maintenance Manual and Final Report.

A. O_2 Cell Characterization

The O_2 electrochemical cells were tested over the 40°F to 100°F temperature range. Generally, the results were more consistant than those for the CO and NO_2 cells.

B. O_2 Electronics Redesign

The first step in the O_2 electronics redesign was to calculate the basis for temperature compensation currently used in the IBC Oxygen Analyzers. Comparing this compensation to the measured cell characteristics, it was determined there was little room for improvement. Therefore, the existing compensation was used in the redesign. One improvement made, however, was to reduce by a factor of five variations in temperature compensation which resulted from different span adjustment settings. Other changes made reduced the operating voltage to ±2.5V and provided the proper output signal level for system integration.

C. O_2 Threshold Level

A question arose regarding the alarm threshold level. A threshold level set at 19.5% O_2 at sea level corresponds to $P_{O_2} = 148.2$ mm. If this value of P_{O_2} is to remain the threshold level for all operating altitudes, men cannot work above 2000 ft. above sea level. If we digress to the requirement for

19.5% O_2 regardless of the total pressure, altitudes above 2000 ft. at 100° RH, give an unsuitable environment. It is interesting to note that 100°F, 100% RH, is a marginal environment under any circumstances, if 19.5% O_2 is required.

D. Detailed Electrical and Mechanical Design

The detailed system design was completed during Phase III. This design is outlined in Appendix A, B, and C. Special efforts included in this area were the testing of major purchased components, modification of the digital panel meter and creation of a separate five volt regulator for its power, and improvement in the CO electronics designed in Phase II.

E. System Fabrication and Test Results

The completed system and system test results are discussed in Appendix A, B, and C which correspond respectively to Sections I, II, and III of the Installation and Maintenance Manual.

F. Conclusion

Previous results from Phase II indicate the state of the art of electrochemical cells may be below the desired level. Tests on the Mine Air Monitor electronics, however, show the electronics are highly stable and accurate. The systems have been specifically engineered for the mine environment. The small, portable Mine Air Monitors should provide the U. S. Bureau of Mines with a flexible instrument for the evaluation of mine electrochemical multi-gas sensing.

APPENDIX A

(Section I from the Installation and Maintenance Manual)

I. PRINCIPLE OF OPERATION

General information about the Mine Air Monitor is given in Table I-1 on the next page. The system uses electrochemical cells to monitor the concentration of oxygen, carbon monoxide, and nitrogen dioxide. It features a single digital display that can be switched to read the concentration of any of the gases, alarm threshold levels, voltage regulator adjustment, or battery condition. Independent light emitting diodes for each gas indicate if the adjustable alarm threshold for that gas has been exceeded. Case-mounted audible and visible alarms give a warning signal when any of the three threshold detectors indicate an unsafe condition. A sample air flowmeter indicates if the flow through the system is adequate for proper operation.

The Mine Air Monitor is operated from rechargeable batteries and has been designed to be intrinsically safe for Class 1, Group D atmospheres.

A. Electrochemical Cells

The electrochemical cells used in the Mine Air Monitor are built by the following manufacturers:

O_2 cell - International Biophysics
CO cell - Energetics Science
NO_2 cell - Theta Sensors

Cell operation is complex, but basically, a fixed reference voltage is applied to each cell (-0.72V, O_2; -0.153V, CO; 0.800V, NO_2) and the cell current is then monitored. Except for an offset, the cell current monitored is proportional to the gas concentration for a given temperature. Both cell sensitivity and offset current vary with temperature, however, and require

TABLE I-1
ELECTROCHEMICAL MINE AIR MONITOR GENERAL INFORMATION AND TYPICAL VALUES

Gases Monitored and Ranges	
O_2	0 - > 190 mm
CO	0 - > 250 ppm
NO_2	0 - > 25 ppm
Display	3 1/2 digit (LED)
Alarm Threshold Ranges	
O_2	104 - 171 mm
CO	9.5 - 67 ppm
NO_2	1.2 - 6.8 ppm
Alarm Type	LED's for each gas plus pulsed Mini-Sonalert and LED master alarms
Sample Flow Rate	0.5 - 1.2 liter/min.
Batteries Used	2 6V EP675A solid-gel lead aci
Power (at 6V), Total	351mA (2.11W)
Pump	320mA (1.92W)
Electronics	13.3mA (0.08W)
DPM Function	18mA (0.11W)
Operating Time (on single charge)	40 hrs.
Temperature Range	40 - 100°F
Size (basic case)	13.7"x11.2"x9.3"
Weight (with batteries)	27 lb.
(without batteries)	20 lb.

compensation. Generally, the electrochemical cell characteristics are the limiting factors for system response time, temperature range, maintenance period, accuracy, and repeatability.

It should be noted that operation at high relative humidities extends the life of the O_2 and CO cells.

B. Flow System

The CO and NO_2 electrochemical cells require a forced sample air flow system for operation. The Mine Air Monitor uses a small sampling pump to supply the needed air flow. Since this pump is the primary power drain on the system, the required pump flow rate is minimized by using a single flow path. Also, needless pressure drops in the system have been eliminated. The sample air flow is first filtered through glass fibers to remove dust that could damage the pump or chemical cells. The pump should not be operated without a filter. (The filter can be observed through the inlet). Table I.B.-1 shows the flow sequence.

TABLE I.B.-1

Flow Path Sequence

1	Inlet Filter
2	Pump
3	NO_2 cell
4	Scrubber
5	CO cell
6	A9 battery cover
7	A8 battery cover
8	Flowmeter
9	Outlet screen

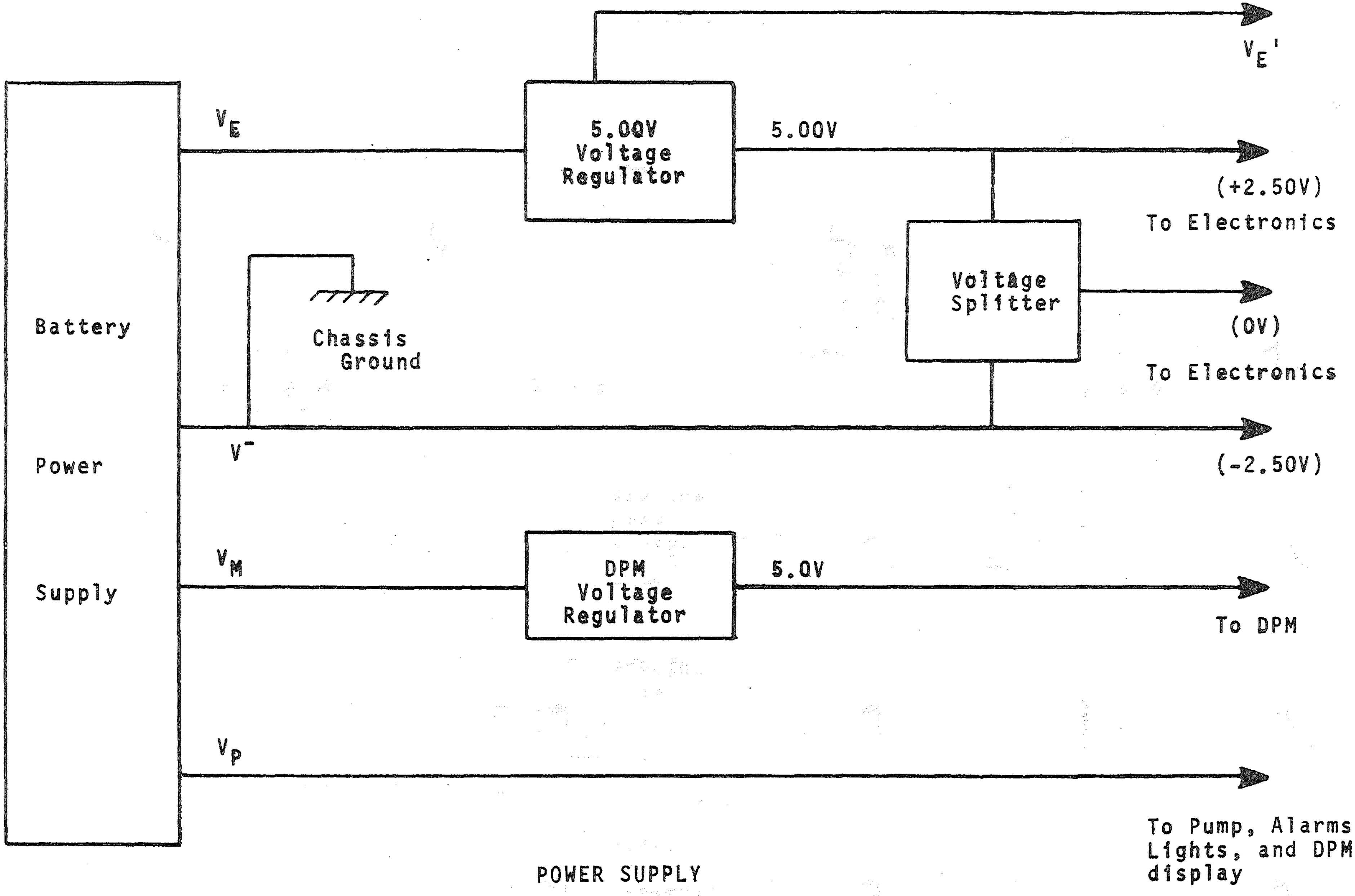
The tubing between the inlet, pump, and NO_2 cell is teflon to reduce NO_2 absorption. All other tubing is tygon for mechanical flexibility. A scrubber is located immediately before the CO cell to eliminate interfering gases. The air flow is also routed through the battery covers to remove any hydrogen that may come from the batteries. The sample air finally passes through a flowmeter before exiting through the protective outlet filter screen. Only the flowmeter scale corresponding to 0.5 to 1.2 liter/min. is viewable from the control panel. When the flowmeter ball can be seen in this range it indicates the battery covers are installed and there is an adequate air flow.

The O_2 cell is not part of the flow system but is exposed to the atmosphere through a protective screen on the front of the fiberglass case.

C. Electrical System

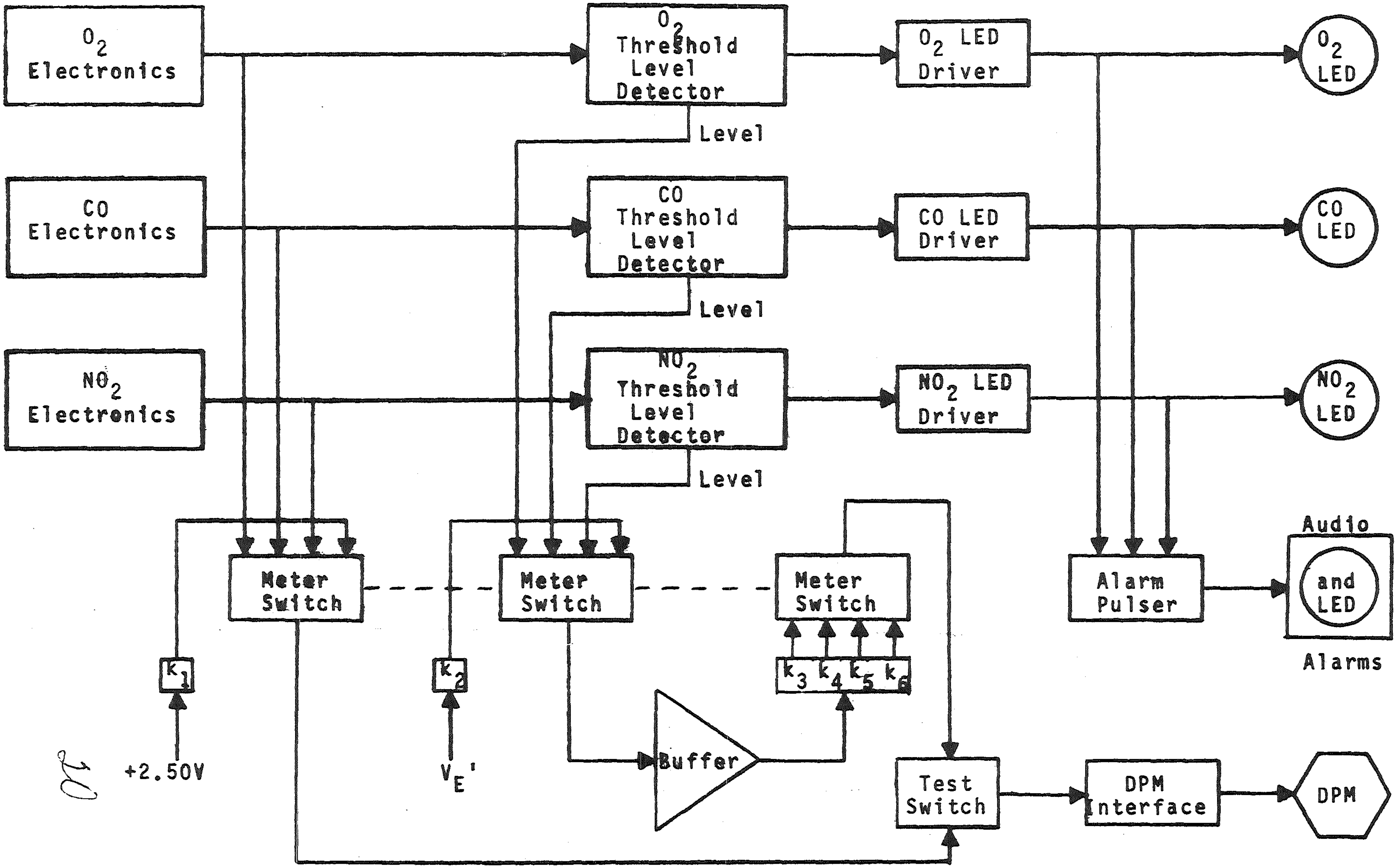
The basic electrical system is shown in Figures I.C.-1 and I.C.-2. The electrical design is heavily influenced by intrinsic safety considerations. Power supply voltages, current limits, regulator characteristics, circuit interfacing, and grounding systems are effected. Also, components used such as fuses, inductors, capacitors, indicators, the alarms, and the pump are related to the design for intrinsic safety. (See Appendix F). Mechanical design is affected indirectly because of these considerations as can be seen in the battery case design, chassis mounted insulators (for wire wound resistors), and special routing of wiring.

Power for the system comes from two solid-gel, rechargeable lead acid batteries. Three separated, individually resistor current limited power systems are derived from the battery supply. Chassis ground is connected to the common return



POWER SUPPLY

FIGURE I.C.-1



ELECTRONICS

line of these power systems. Since battery voltage drops during discharge and combined with this there is a current-dependent voltage drop across the limiting resistors, it is necessary to regulate the voltage used in the electronics. A sophisticated 5.00V regulator is used in conjunction with a precision voltage splitter to generate ± 2.50V supplies for the electronics. The accuracy of these supplies allows all necessary reference voltages to be derived from the ± 2.50V lines. The system reference in the 5.00V regulator is a highly stable mercury battery composed of two Mallory Certified cells. Regulator control is maintained with input (V_E) down to 5.10V. Figure I.C.-1 shows the power system.

Power for the digital panel meter (DPM) comes from the V_M supply. It too is regulated but with simpler circuitry. The DPM utilizes a pulsed current system to conserve power. This pulsed current through the limiting resistor causes large excursions in the V_M voltage. The regulator eliminates both the effects of changing battery voltage and pulsed current. It supplies the DPM with 5.0V at low impedance. To ease loading of the V_M supply and regulator, DPM display power is derived from the V_P system.

The V_P system also supplies power for the pump, gas threshold indicators, alarms, and flowmeter light.

The system electronics shown in Figure I.C.-2 consists of three primary sections; analog, alarm, and test. The amplified, compensated analog signal representing each gas concentration goes to the meter function switch. If not bypassed by the test push button, the signal selected in the meter function switch is applied to the DPM interface. Since the DPM references its input to the negative supply (V^-) and the analog signal is referenced to 0V, the interface is necessary. It is a precision controlled current source. The interface output is applied to the DPM which is a milliamp meter, i.e., 1000 displayed equals 1 mA. The first position of the meter function switch is OFF; the next three, gas concentrations; and the last position checks the 5.00V regulator. Actually, a constant function of the +2.50V is monitored with respect to 0V. Since both the voltage splitter and DPM interface circuits are highly precise, however, this is equivalent to monitoring the complete 5.00V supply.

The analog voltage for each gas channel also goes to a threshold level detector. Here, the signal is compared with an adjustable reference level. If the gas concentration is outside this safe level, a light emitting diode for that gas is turned on. When any of the three gas threshold LED's is on it triggers the audible and visible alarms through an "OR" circuit. Both the Mini-Sonalert and LED alarms are pulsed by an oscillator to be more easily noticed. (Note that alarm power was not listed in Table I-1 because the alarms will normally be off. The current required is approximately 11 mA per indicator ON plus roughly 10 mA for the alarms).

The set threshold level for each detector also goes to the meter function switch for utilization in the test circuitry. The threshold level selected by the switch is buffered to eliminate any effect on the detector. The appropriate gain constant is then applied to the signal before it returns to the meter function switch. When the test push button is depressed, the buffered signal with the correct gain is applied to the DPM interface and displayed by the DPM. In the test mode, the first four positions of the meter function switch correspond to the same channels monitored when there is no test. In the fifth position the battery condition is monitored. A fraction of the voltage difference between V_E' (switched V_E) and V^- is buffered, gain set, and applied to the DPM through the interface. By this means, a V_E' voltage of 6.3V (approximately 6.4V at the A9 battery) is represented by a display of 100.0 (%). When V_E' has dropped to 5.1V, the regulator input limit, the display reads 00.0 (%).

Some of the lesser electronic functions are not shown in Figure I.C.-2. These include the flowmeter light function, power systems interfacing, and range change and decimal point position control. The flowmeter light is on when the test push button is depressed. (It adds approximately 46 mA when on). Power systems interfacing is related to intrinsic safety and is covered in Appendix F. The range and decimal point function is shown as well as all other circuitry in Appendix C.

D. Electronic Accuracy

Initial tests on the Mine Air Monitors indicate their electronics are highly stable and accurate. Tests at ≃77°F were made using simulated cells and each channel was first calibrated. The test results are shown in Table I.D.-1. The cells used, calibration and test levels are first shown followed by the specified accuracy. The measured electronic accuracy is then shown for both Mine Air Monitors.

TABLE I.D.-1
Electronic Accuracy at ≃77°F

Channel	Cells Used	Calibration Level	Test Level	Specified Accuracy	MAM#1 Error	MAM#2 Error
O_2	3 nA/mm	190 mm	114 mm	±5.0 mm	-0.2 mm	-0.3 mm
CO	4.5 μA/ppm	100 ppm	35 ppm	±4.0ppm	-0.2ppm	-0.1ppm
NO_2	31 nA/ppm	10 ppm	3 ppm	±0.5ppm	-0.04ppm	+0.03ppm

Initial temperature tests also indicate the electronics are highly stable. The result of tests on Mine Air Monitor S/N-2 over approximately 40°F to 100°F are shown in Table I.D.-2. All measured values were compared to their values at approximately 77°F. It is important to note that the errors shown in each row of the table are only for the function specified. Cumulative errors are not shown in the table. Errors less than or equal to 0.05% are shown as 0 in the table.

TABLE I.D.-2

Electronic Accuracy Over Temperature

Function	Error At 40°F	Error At 100°F
Hg Reference	0	+0.1%
5.00V Supply	0	0
2.50V (0V)	0	0
DPM Interface	0	0
DPM	-1.1%	+0.3%
5.0V (DPM Supply)	-0.3%	+0.2%
Threshold Levels		
O_2	0	-0.1%
CO	-0.9%	0
NO_2	-0.9%	0

It is expected that the error in the temperature compensation is approximately ± 1% over temperature.

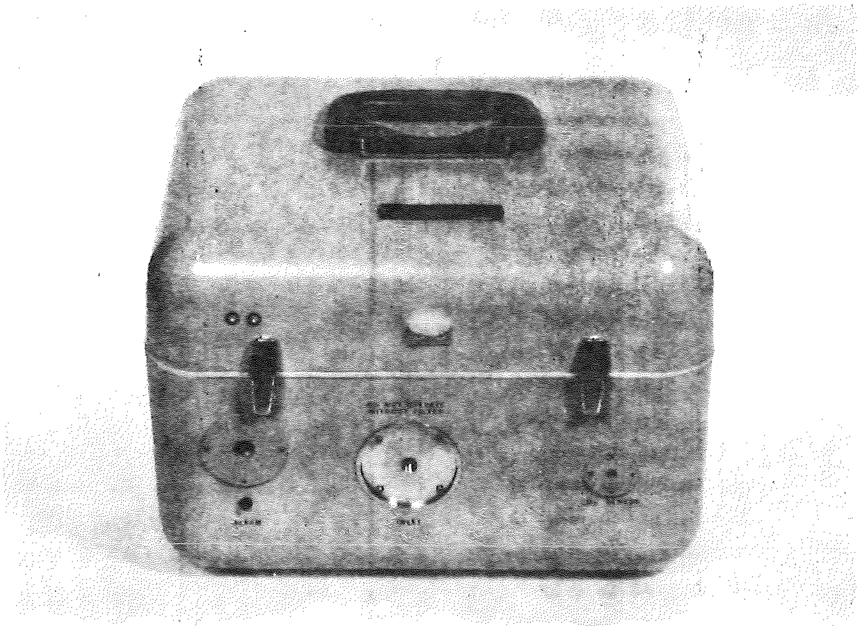
APPENDIX B

(Section II from the Installation and Maintenance Manual)

II. OPERATION

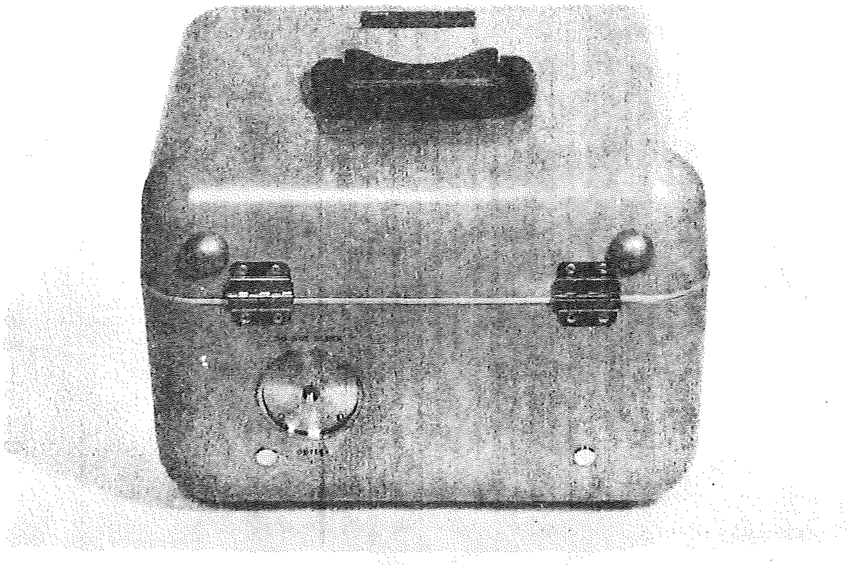
A. Control Access

Level I: With the case closed and latched, the Mine Air Monitor is in its most rugged and normal operating configuration. Both the audible and visible alarms are mounted at the case walls, as are the sample air inlet and outlet, and the O_2 cell. (The alarms are equally effective with the case open or closed.) The filter behind the inlet can be changed without opening the case. No controls are accessible at this level. Figures 1043-29 and 1043-30 show the front and back of the system respectively.



1043-29

TEXAS INSTRUMENTS
INCORPORATED

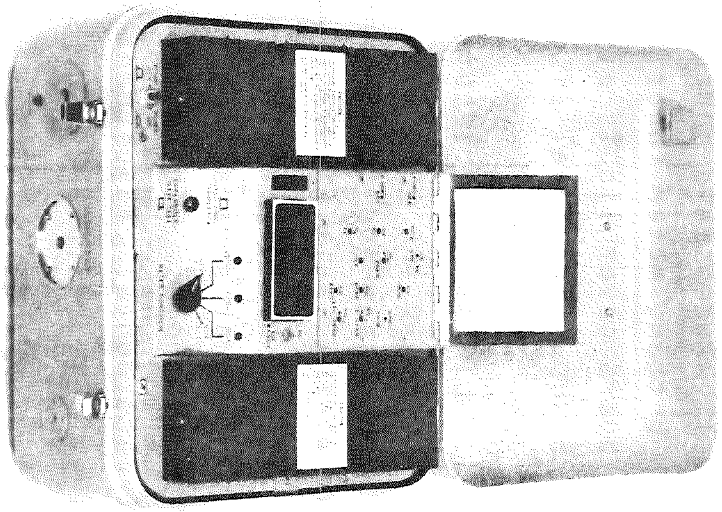


1043-30 TEXAS INSTRUMENTS INCORPORATED

Level II: Opening the case provides access to the control panel and battery covers. The digital panel meter and flowmeter prism displays, and the gas threshold indicators can be viewed at this level. Accessible controls are the pump on/off button, test push button, meter function switch, and range switch. The circuit board cover lid is also accessible at this level. Figure 1043-25 shows the Level II configuration.

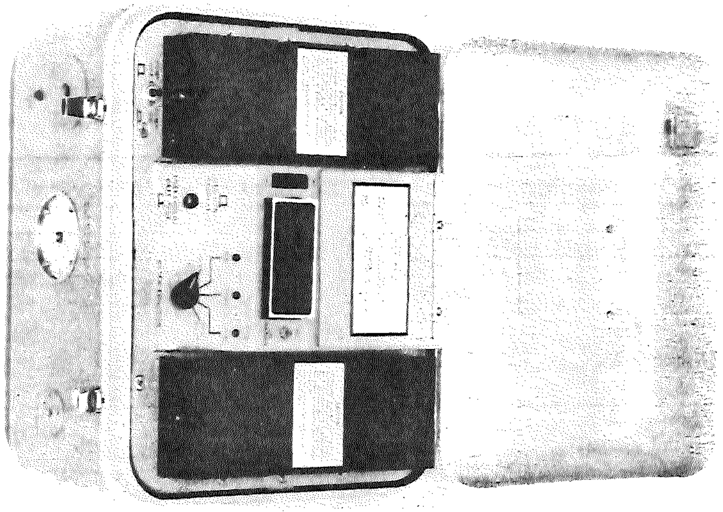
Level III: Lifting the circuit board cover lid/name plate provides access to the threshold level adjustments and adjustments for zero, span and the 5V regulator. These controls are reached with a small-bladed screwdriver through small holes in the circuit board cover. The controls are identified on the cover. Note that several controls are identified for which there are no access holes. These controls seldom require adjustment and their accidental adjustment could make system disassembly necessary. Figure 1043-24 shows Level III.

Level IV: All remaining controls are reached by first removing the circuit board cover assembly which is held by



1043-24

Texas Instruments
Incorporated



1043-25

Texas Instruments
Incorporated

eight screws. The circuit boards are also accessible at this level. The controls include adjustment trimpots for the electronics and on/off switches for the alarms, pump, and electronics (5V).

Level V: Access to the electrochemical cells, fuses, mercury battery, pump, etc. requires removal of the chassis assembly from the case. (See Section IV). There are no controls at this level.

B. Control Operation

1. Pump ON/OFF Switches

Both the pump switch on the control panel and the pump switch on Circuit Board 5 have to be on for the pump to operate. The circuit board pump switch would normally be in the on position. The pump is then controlled by the control panel pump switch. Lifting the button turns the pump off for no-flow calibration. To assure the pump is not accidentally left off, a striker plate in the case lid returns the switch to the on position when the case lid is closed. The circuit board pump switch provides a means of turning the pump off when the system is being stored or transported with the batteries installed.

2. 5V (Electronics) ON/OFF Switch

The 5V switch located on Circuit Board 3 should almost always be left in the ON position. Turning this switch off removes bias from the electrochemical cells when it kills the power for the electronics. Loss of cell bias will necessitate a recovery period of hours. The switch can be turned off when the system is being stored or transported with the batteries installed.

3. Meter Function Switch

The meter function switch controls power to the digital panel meter (DPM) and determines which channel the meter displays. In the first position, DPM power is off. It is desirable to leave the switch in this position when the DPM is not being used because the discharge period for the batteries will be extended. In the second switch position, the DPM monitors the O_2 gas concentration. The third position allows monitoring of the CO concentration and the fourth position, the NO_2 gas concentration. In the fifth position, the DPM monitors the critical 5.00V supply. The reading can be considered a percentage of the correct value. A reading of 100.0 indicates the voltage is correctly set at 5.00V. A reading of 100.2 would indicate the voltage was 0.2% high, i.e. 5.01V.

Depressing the test push button changes the meter function in all switch positions except OFF. The second, third, and fourth positions become respectively the threshold levels for O_2, CO, and NO_2. In the fifth position, the DPM indicates the condition of the batteries. Again, the reading can be considered a percentage with 100% representing freshly charged batteries and 0% representing batteries discharged to the point of system failure. Note: The battery discharge curves are non-linear; the DPM monitors the A9 battery (on the right side) more closely than the A8 battery; and the reading is somewhat dependent on loading of the batteries.

4. Test Push Button

The test push button (located to the left of the meter function switch) is used primarily for changing the DPM function as noted in Section II.B.3. It also illuminates the flowmeter scale when depressed.

5. Range Switch

The range switch changes the DPM scale by a factor of 10 for use with high gas concentrations. It is desirable, for maximum accuracy, to keep the range switch in LO whenever possible. (Except when calibrating the equipment, the least significant digit of the display should only be used to determine if the next most significant digit should be rounded up or not). When the signal to the DPM is such that the reading would be greater than 1999 (the maximum DPM reading), the digits will flash (a 1000 reading). Switching the range switch to HI will divide the signal by 10 and display the correct reading.

6. Threshold Level Controls

As stated in Section II.B.3, depressing the test push button will allow display of the threshold level for each gas. The thresholds can then be adjusted to the desired levels using the trimpots on Circuit Board 4 which are accessible through the circuit board cover. NOTE: Some hysteresis has been designed in to the threshold levels to reduce the possibility of false alarms. (See appendix H).

7. Gas Threshold Indicators

The gas threshold indicator lights are located above the meter function switch but are independent of its position. An indicator LED will illuminate when the threshold level for its particular gas is exceeded. Each indicator is independent of the other indicators, i.e. zero, one, two, or three indicators can be on at a given time. NOTE: The battery load increases slightly for each indicator that is on. During laboratory experimentation, it would be preferable at the end of the work day to set the threshold levels such that the indicators will not be left on.

8. Alarm Switch

Normally, when any indicator is triggered, the audible and visible alarms will also be triggered. The alarm switch on Circuit Board 5 provides a means of disabling the alarms without affecting the gas threshold indicators. (Disabling the alarms may be desirable during calibration or experimentation. The alarms should be enabled in the field).

9. Flowmeter Readout

The flowmeter readout (at the left of the DPM) illuminates when the test push button is depressed. If the flowmeter ball can be seen through the prism, the air flow is satisfactory for cell operation. (The pump switch can be cycled to more easily locate the flowmeter ball, if necessary). As adjusted at MAM shipment, the bottom of the display represents approximately 0.5 liter/minute. The top of the display represents a flow equal to or greater than roughly 1.2 l/m. NOTE: The flowmeter monitors the flow immediately before the outlet filter. If either battery cover is not properly in place, it may cause a no-go flow indication.

C. Battery Replacement and Charging

1. Battery Replacement

WARNING: Intrinsic safety is only maintained when the batteries are properly covered in their cases.

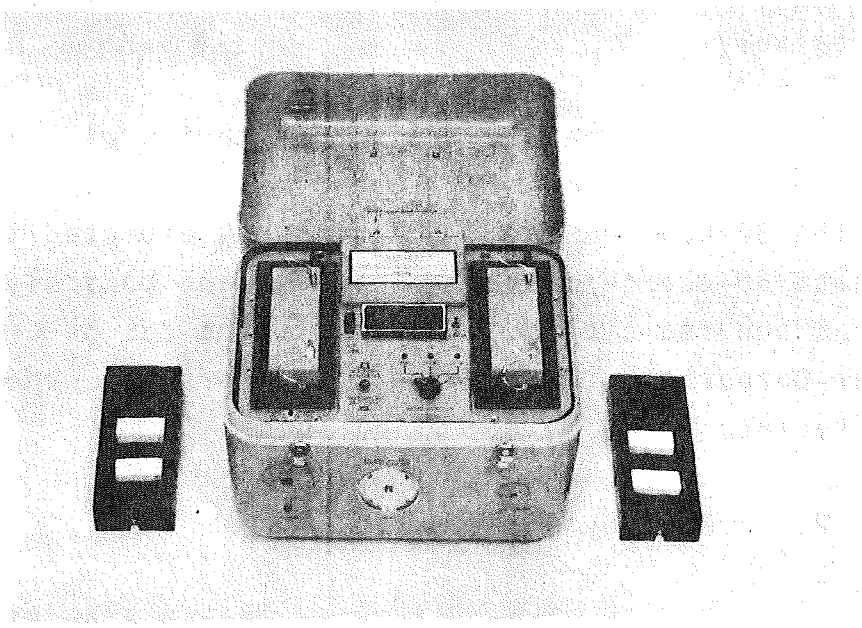
When the Mine Air Monitor batteries charge gets low, they should be replaced with fully charged batteries. Only one battery should be replaced at a time since simultaneous removal of both batteries will cause a loss of bias on the electrochemical cells and result in a substantial loss of time for restabilization of the cells.

A good procedure for battery replacement follows: (See Figure 1043-22).

a. Turn both the pump and DPM OFF.

b. Remove both battery covers by loosening the six screws on each cover and then lifting the cover off.

c. Remove both wires from the battery on the left of the system. Be careful not to excessively strain the wires or bend them at the junction to the battery clips.



1043-22 TEXAS INSTRUMENTS INCORPORATED

WARNING: Do not allow the battery clip attached to the white/red lead to short to the control panel or mounting hardware. (It can blow the fuse on the other battery case).

d. Place the 2 orange O' rings (Item 56 in the parts list) around the lower 1/3 and 2/3 of the replacement battery. (See Figure 1043-23 in Section III). These O' rings act as shock absorbers for the battery.

e. Install the replacement battery with the <u>positive terminal at the front of the system</u>. Reconnect the wires to the battery, again being careful not to strain the wires or bend the wires at the junctions to the battery clips.

WARNING: DO NOT REVERSE POLARITY. Polarity reversal may damage the electronics and will blow the fuse on at least one and possibly both battery cases.

f. Repeat steps c, d, and e for the battery on the right of the system.

g. Be sure the black O' ring (Item 57) is properly located in the O' ring groove on both battery cases.

h. Reinstall both battery covers and tighten the 6 screws on each cover. Do not tighten these screws excessively.

The Mine Air Monitor batteries will eventually degrade to the point where a full charge will not operate the system for the 30 hour period. (This is not expected to happen until at least 50 charge/discharge cycles, and possibly not until several hundred cycles.) New batteries can be ordered from Elpower Corporation, Santa Ana, California. Order only EP 675A batteries.

2. Battery Charging

The charging method recommended by Elpower is as follows:

a. Use a charging current limited to a maximum of 1.2 A until the battery voltage reaches 7.2V. Never allow the battery voltage to exceed 7.2V.

b. At 7.2V, when the charging current drops to 0.12 A, the batteries are fully charged.

c. Deeply discharged batteries should be charged for 16-20 hours.

NOTE: Dynamic Instrument Corporation sells battery chargers.

D. Filter Replacement

The inlet air filter will eventually collect so much dust that an adequate air flow can not be maintained. See Section II.B.9. Before replacing the filter, however, verify there is not another cause of the low air flow. Verify that the pump is on, the battery covers are properly installed, and the batteries have an adequate charge. If filter replacement is necessary, proceed as follows:

1. Turn the pump OFF.

   WARNING: Operating the pump without the filter may damage it or other parts in the flow path.

2. Remove the 4 screws holding the inlet filter retainer and then the retainer.

3. Replace the filter (Item 79 in the parts list). Be sure the filter support is in place prior to putting in the new filter.

4. Be sure both O' rings are properly in place before reinstalling the filter retainer.

E. Modified Operation

Mine Air Monitor operation is not limited to that described in Sections II and III or permanently constrained by the designed temperature compensation. An example is long term use as a digital oxygen monitor. In an application where only

O_2 monitoring is required and with the pump off and alarm indicators not triggered, sparing use of the DPM will certainly allow hundreds of hours of continuous operation. Time between charges may reach 1000 hours. Modification of the temperature compensation in each channel is also possible, if necessary. Appendix D describes the modification procedure.

The pulsing nature of the alarms can be changed by changing resistor R10 on Circuit Board No. 5. A steadier alarm signal should result from reducing the 3 MΩ resistor (between terminals E1 and E2) to 2.2 kΩ by the procedure in Appendix D. Do not reduce this value below 2KΩ. When the pump is on, there will still be a roughly 135 Hz component in the audible alarm output.

The Mine Air Monitor can also serve as a test base for experiments with electrochemical cells. The simplest example of this is that terminals have been provided on Circuit Board No. 2 to allow small changes in reference electrode voltage. The reference voltage is,

$$V_R = -\ 2.5\ \frac{(750\Omega)}{(750\Omega)+R7}\ \text{volts} \quad \text{or}$$

$$R7 = -\ \frac{(750\Omega)(2.5+V_R)}{V_R} \quad .$$

In changing resistor R7, the procedure in Appendix D should be followed. Also, all values $\geq$ 11.5 kΩ can be used, but values less than 11.5 kΩ are limited. Reference voltages more negative than -1.00V should never be used and a -0.3V limit is suggested. Note that the circuit will not supply counter electrode voltages more negative than ≈ -1.2V.

Maximum Mine Air Monitor flexibility is provided by the capability of completely changing a cells' electronics simply by replacing a circuit board. This can be done with any of the cells but is most efficiently accomplished with the CO board (CB2). (Changing either CB1 or CB3 for the NO_2 or O_2 channels necessitates duplication of other electronic functions. For changing the CO electronics or using a different type of electrochemical cell in place of the CO cell the following interface information is necessary:

XA2 Pin Connections

1.	+2.50V (≤ +10 mA)
2.	
3.	100 kΩ thermistor, Fenwal UUT 51J1
4.	
5.	
6.	Counter Electrode (white lead at cell)
7.	Reference Electrode (blue lead at cell)
8.	Working Electrode (orange lead at cell)
9.	DC ground, 0V (≤ +2 mA, ≥ -1 mA)
10.	
11.	
12.	2.252 kΩ thermistor, Fenwal UUA 32J3
13.	
14.	Analog Output (0.1577 μA/ppm, 805.9 μV/ppm)
15.	Output to threshold detector (1.49 mV/ppm)
16.	2.252 kΩ thermistor, Fenwal UUA 32J3
17.	
18.	-2.50V (≥ -10 mA)

The suggested current limitations and proper output levels are also shown in the above list. The output impedance to the threshold detector is not critical but 10 kΩ is desirable. The load on the analog output is 5.110 kΩ.

APPENDIX C

(Section III from the Installation and Maintenance Manual)

III. CALIBRATION

The Mine Air Monitor has been designed to electronically compensate for the general electrochemical cell temperature characteristics observed during Phase II of this contract. The designed compensation curves are included in Appendix D. The temperature sensors for this compensation (except for NO_2 cell offset) have been located such that they are in thermal contact with the cells.

The electrochemical cells require a substantial stabilization time after changes in temperature or bias. The temperature stabilization times are further increased due to comparative isolation of the cells from the environment by the fiberglass case. When considering any method of calibrating or testing the Mine Air Monitor, the factors affecting cell temperature should be given special attention. These include sample air temperature, the environment's temperature, and power dissipation. (NOTE: Most power dissipation is in the pump, roughly 2 watts). A change in any of these factors can reduce the reliability of the calibration or test results.

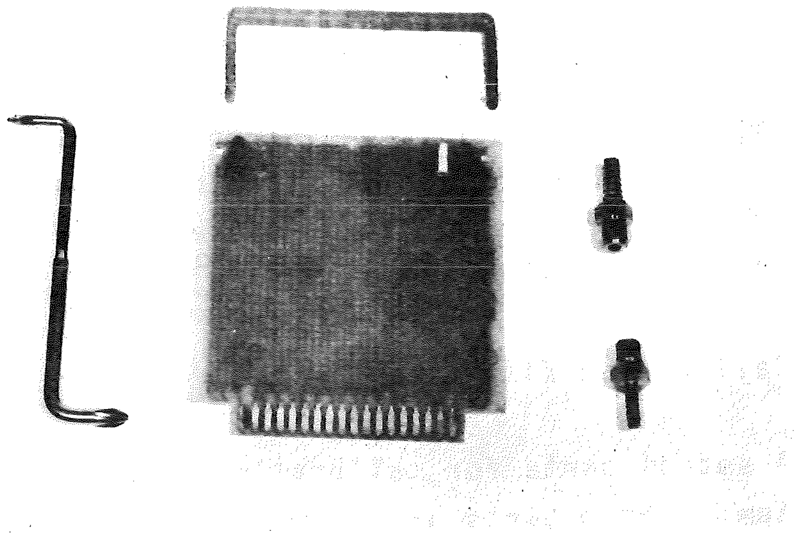
A. Calibration Kit

A set of parts for calibration has been included for each system. These parts are shown in Figure 1043-21.

Included in the calibration kit for DPM calibration is Circuit Board No. 1-CAL. A circuit board extractor and a right angle Phillips head screwdriver have also been supplied.

For cell calibration, the kit includes a 1/4 inch tube fitting for the inlet and 3/8 inch tube fitting for the outlet.

NOTE: There are basically two methods of calibration. 1. A prepared sample can be pulled into the system from the surroundings. (A bag may be used to enclose the system.) 2. A sample may be supplied from premixed tanks. In this second method, the following precautions must be observed. The pump must be running and the sample pressure at the inlet must equal the ambient pressure. Also, the back pressure in the outlet hose should be minimized. Possible damage to the pump or cells may result if the inlet pressure drops too low or the outlet pressure gets too high.



1043-21

TEXAS INSTRUMENTS
INCORPORATED

B. Electrochemical Cell Calibration

One of the best conditions for Mine Air Monitor cell calibration would be where the system is continuously operating in the same environment. Under these conditions, the environment and inlet air temperatures are very close, and the temperature rise from the power dissipation has reached steady state.

1. O_2 Cell Calibration

If an alternate (possible slow) method of oxygen measurement is available and accurate, the O_2 span control can simply be adjusted for the correct DPM reading. This adjustment should be made very slowly, however, because the time constant of the electronics has been made long to reduce noise.

If the O_2 cell is calibrated in the outside air, it should only be done after the system has thoroughly stabilized. The correct O_2 reading can then be determined from Appendix A.

2. CO Cell Calibration

With the system at steady state, the zero calibration can be accomplished by switching the inlet air to a zero CO air mixture at the same temperature and flow rate. (Using a standard air mixture except for a void of CO is probably the best method for zeroing this cell. High relative humidity of the sample is also desirable). Adjust the CO zero trimpot for roughly a 00.1 ppm reading.

NOTE: When making zero adjustments remember that <u>the DPM will not display negative numbers</u>.

A less accurate, but much simpler, method of zeroing the CO cell is to turn off the pump and make the adjustment after 5 minutes. A longer time can probably be used at low temperatures but a shorter time may be necessary at high temperatures. Long periods between pump turn-off and zero adjustment should not be used. Turning the pump off affects the thermal stability of the system and the lack of air flow probably changes the electrochemical equations in the cell.

To adjust for the CO sensitivity of the cell (after zero adjustment) change the inlet air to a calibration CO mixture at the same temperature and flow rate. (Using a standard CO in air mixture with CO increased to the level of greatest interest is probably the best method for span calibration. High relative humidity of the sample is also desirable). Adjust the CO span trimpot for a DPM reading equal to the CO concentration + 0.1 ppm.

3. NO_2 Cell Calibration

The NO_2 cell can be calibrated by a method almost identical to that for the CO cell in Section III.B.2, above. Differences are that the NO_2 zero reading and correction should be 0.01 ppm, roughly. Also, both the time constants for the NO_2 cell and electronics are much longer than those for CO. The NO_2 calibration samples must not be humidified.

C. 5.000 V Regulator Calibration

The 5.000 V regulator voltage is very critical because all reference and bias voltages created in the electronics are derived from it. Since changing this voltage affects all bias levels, adjustment should precede cell calibration by a lengthy period. Calibration is simple; adjust the 5 V trimpot for a 100.0 reading. (The best calibration will be acquired under steady state conditions).

D. Electronics Offset Calibration

The electronics offsets should be zeroed when the system is at thermal equilibrium, preferably at the normal system operating temperature. Normal operating temperature is not a necessity, however, because the electronics are probably one to two orders of magnitude more stable and accurate than the electrochemical cells. It is probable that the electronics offsets will only need to be zeroed every few months. Since removal of the cells is necessary for adjustment (and thus chassis assembly removal is necessary), it is suggested that the electronics offset adjustments be combined with cell replacement.

To prepare for adjustment, remove the chassis assembly and cells as described in Section IV. Be sure that none of the electrical connections for any of the cells are in contact with any non-insulator. Turn the pump, alarm, and DPM switches off; reinstall the batteries, and let the electronics stabilize for 15 minutes.

CAUTION: The yellow test points used in this section go directly to vunerable areas of the electronics. Caution should be exercised when using these test points. Also, the chassis assembly should be placed on an insulating surface and the high impedance millivoltmeter should be isolated. (CB3-TP2 is the negative reference for all measurements).

1. DPM Offset

a. Verify the meter function switch is OFF and turn the range switch to LO.

b. Connect a 25KΩ±5% resistor between CB1-TP6 and CB1-TP2.

c. Turn the DPM offset trimpot fully clockwise.

d. Measure the voltage at CB1-TP1 and refer to it as X. (It should be approximately 0 mV).

e. Turn the DPM offset trimpot slowly counter clockwise until the voltage at CB1-TP1 reaches (X-0.1 mV) or -0.3 mV, whichever occurs first.

f. Remove the 25KΩ resistor.

2. NO_2 Amplifier Offset

a. Turn the NO_2 span trimpot fully clockwise.

b. Adjust the NO_2 zero trimpot for 0.0 mV at CB1-TP7.

c. Short CB1-TP6 (white) to CB1-TP5 (yellow).

d. Slowly adjust the NO_2 offset trimpot for 0.0 mV at CB1-TP3.

e. Remove the jumper.

3. CO Amplifier Offset

a. Turn both CO zero and span trimpots fully clockwise.

b. Short CB2-TP4 (white) to CB2-TP5 (yellow).

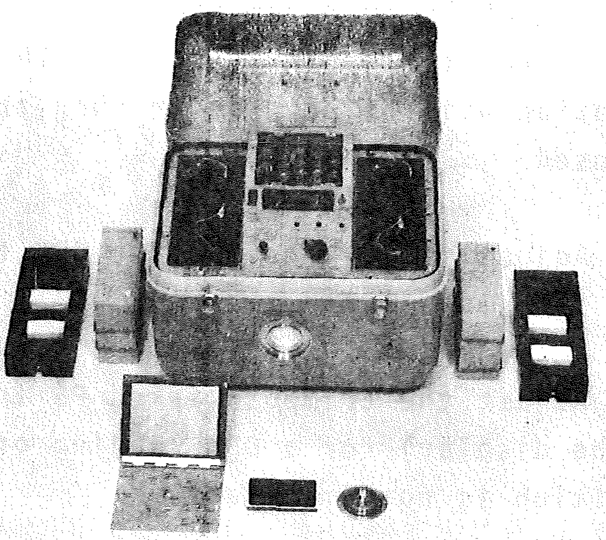
c. Adjust the CO offset trimpot for 0 mV at CB2-TP2. (The reading may drift slightly).

d. Remove the jumper.

4. O_2 Amplifier Offset

a. Turn the O_2 span trimpot fully clockwise.

b. Very slowly adjust the O_2 offset trimpot (R25) for 0 mV at CB3-TP5. (The reading may drift slightly).



1043-23 TEXAS INSTRUMENTS INCORPORATED

E. DPM Calibration

The digital panel meter may be calibrated without removing the chassis assembly. The meter should be calibrated at roughly 4 month intervals. The pump and alarm switches should be off and the meter function switch should be in any position except OFF. The system should be at thermal equilibrium, preferably at the normal system operating temperature.

1. Replace Circuit Board No. 1 with Circuit Board No. 1-CAL.

2. Carefully remove the bezel from the DPM. Do not tilt the bezel while removing it; it can damage it. (Figure 1043-23 shows the bezel removed).

3. Connect the negative lead of a high impedance, precision voltmeter to the violet test point on CB1-CAL.

Monitor the voltage at the red test point on CB1-CAL. (The yellow test point on this board can be used instead of the red test point for slightly improved accuracy, if caution is observed; it is a direct test point). NOTE: The accuracy of the DPM calibration will be no greater than the accuracy of the voltmeter used.

4. Adjust the 5 V trimpot on CB3 for a 5.000 V reading.

5. Adjust the trimpot marked FS in the DPM (to the left of the display) for a DPM reading of 1604. The decimal point position is not important.

6. Carefully reinstall the bezel and replace Circuit Board No. 1.

APPENDIX D

TECHNICAL REPORTS

Table 1 lists the technical reports that have been supplied during the contract. Major work areas have been separated for clarity. Particularly important reports in the chronological listing have been underlined. The abbreviation "MTPR" stands for "Monthly Technical Progress Report".

TABLE 1
MINE AIR MONITOR TECHNICAL REPORTS

Date	Subject	Period Covered
24 July 1972	June/July MTPR	19 June - 18 July 72
21 August 1972	July/Aug MTPR	19 July - 18 Aug 72
25 September 1972	Aug/Sept MTPR	19 Aug - 18 Sept 72
1 November 1972	Sept/Oct MTPR	19 Sept - 18 Oct 72
20 November 1972	Technology Study Report	
14 December 1972	Proposal for the Electrochemical MAM	
5 February 1973	Jan MTPR	15 - 31 Jan 73
12 March 1973	Feb MTPR	1 - 28 Feb 73
13 April 1973	Mar MTPR	1 - 31 Mar 73
10 May 1973	Phase I Report	15 Jan - 10 May 73
10 July 1973	June MTPR	1 June - 9 July 73
8 August 1973	July MTPR	10 July - 1 Aug 73
19 September 1973	Phase II Report	1 June - 20 Sept 73
9 November 1973	Oct MTPR	12 Sept - 7 Nov 73
7 December 1973	Nov MTPR	8 Nov - 6 Dec 73
21 January 1974	Dec MTPR	7 Dec 73 - 18 Jan 74
7 February 1974	Jan MTPR	19 Jan - 6 Feb 74
28 March 1974	Installation and Maintenance Manual	
29 March 1974	Final Report Draft	19 June 72 - 28 Mar 74
17 June 1974	Final Report	19 June 72 - 28 Mar 74