HDL-TM-7131

# ARMY $CO_2/O_2$ CONCENTRATION MONITOR (MODEL I)

by

Fernando Villarroel

Charles W. Ragsdale

December 1971

U.S. ARMY MATERIEL COMMAND
HARRY DIAMOND LABORATORIES
WASHINGTON, D.C. 20438

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A flueric-electronic system has been developed to continuously monitor the concentration of carbon dioxide and periodically measure the concentration of oxygen in respiratory gases. The sensor consists of two miniature flueric oscillators whose acoustic frequency depends on CO concentration; the sensor is coupled to a pressure transducer. The signal is electronically processed, and the gas concentration is indicated by a calibrated dial. The signal may also be recorded.

The system has a low sampling rate (7 cc/sec) induced by a flueric suction unit operated by low-pressure gas. The humidity and temperature of the sampled gas are controlled by a humidity control unit operated by a flueric vortex tube.

The system has been calibrated and is accurate to better than 0.3 percent carbon dioxide and 1 percent oxygen.

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# FOREWORD

This report summarizes work performed for
the Surgical Directorate
of the
USA Medical Research and Development Command

# ABSTRACT

A flueric-electronic system has been developed to continuously monitor the concentration of carbon dioxide and periodically measure the concentration of oxygen in respiratory gases. The sensor consists of two miniature flueric oscillators whose acoustic frequency depends on $CO_2$ concentration; the sensor is coupled to a pressure transducer. The signal is electronically processed, and the gas concentration is indicated by a calibrated dial. The signal may also be recorded.

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**DEPARTMENT OF THE ARMY**
HARRY DIAMOND LABORATORIES
WASHINGTON, D.C. 20438

AMXDO-AS

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TO: Recipients of HDL-TM-71-31, "Army $CO_2/O_2$ Concentration Monitor (Model 1)," December 1971.

From: Technical Reports Section, 0473

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Page 31

In figure C-1, change "Meter Projection Circuit" to "Meter Protection Circuit". Change "presure" to "pressure", and "undeteced" to "undetected".

Page 37

In para C.3.2, line 7, change "Input: noise" to "Input: no signal input".

In para C.3.2, line 8, change "Detected Output" to "Detected Output Offset".

Page 38

In abscissa of figure C-5, change "FREQUENCY (Hz)" to "FREQUENCY (kHz)".

Page 39

In para C.3.2, line 13, delete: 1.4 (about 0.18 V of signal due to dc level); add: (about 0.18 V of ac signal).

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## CONTENTS

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## ILLUSTRATIONS

## TABLES

## 1. INTRODUCTION

An instantaneous means of quantitatively and continuously analyzing the carbon dioxide exhaled during the respiratory cycle is desirable for a number of medical reasons. Several methods have been developed that monitor the composition of the expired gases.[1,2] One of these methods is based on the principle that the resistance of a wire depends on its temperature. If an electrically heated wire is placed in a tube where the gas sample is flowing, the wire cools. Since the cooling capacity of a gas depends upon its velocity and composition, its composition can be determined by the wire conductivity. Other methods are the classical fractional sampling of the expired gas, mass spectrometers, the spectro-photometric method which involves ionization and photoelectric measurements, the thermal conductivity method, optical gas analyzer (in particular infrared absorption), and the interferometric method, which is based upon the difference in the refractive index of the gases. The paramagnetic properties of oxygen have also been utilized to measure oxygen concentration since other gases do not have this property.

The concentration sensor described in this report utilizes two high-frequency fluidic oscillators. The frequency of the oscillators depends on certain physical properties of the gases flowing through them. This device is inexpensive, has a fast response, and is rugged.

The Army $CO_2/O_2$ Concentration Monitor is a differential gas analyzer that compares the sampled gas with pure air to determine the concentration of carbon dioxide or oxygen. The present model has the capability of continuously measuring the concentration of only one gas; it is used mostly to measure the exhaled carbon dioxide (breath to breath) but is periodically used to check the concentration of the oxygen in the inhaled gas. Both gases could be monitored continuously simply by using another sensor.

This report describes Model I of the Army Carbon Dioxide/Oxygen Concentration Monitor (fig. 1), its theory of operation, calibration, and use.

## 2. THEORY OF OPERATION OF THE SENSOR

The flueric oscillators[3] used as sensors are of the jet-edge resonator type shown schematically in figure 2. In this type of oscillator, the jet-edge frequency couples with the cavity resonant frequency. The jet-edge frequency $f_e$ is given approximately by

$$f_e = 0.466 \frac{u}{h} \tag{1}$$

where

u = velocity of the jet

h = distance from jet outlet to edge.

The fundamental cavity frequency $f_n$ (for the cavity mode n = 1) is given by the expression

---

[1] Rossier, P., Bühlmann, A., and Wiesinger, K., "Respiration," The C. V. Mosby Co., St. Louis, Mo., 1960.

[2] Fenn, W. O., Otis, A. B., and Rahn, H., Air Force Technical Report No. 6528, 1951, U. S. Air Force, Wright Air Development Center, Wright-Patterson A.F.B., Ohio.

[3] Gaylord, W. and V. Carter, "Flueric Temperature Sensing Oscillator Design," HDL-TR-1428, Harry Diamond Laboratories, Washington, D. C., April 1969.

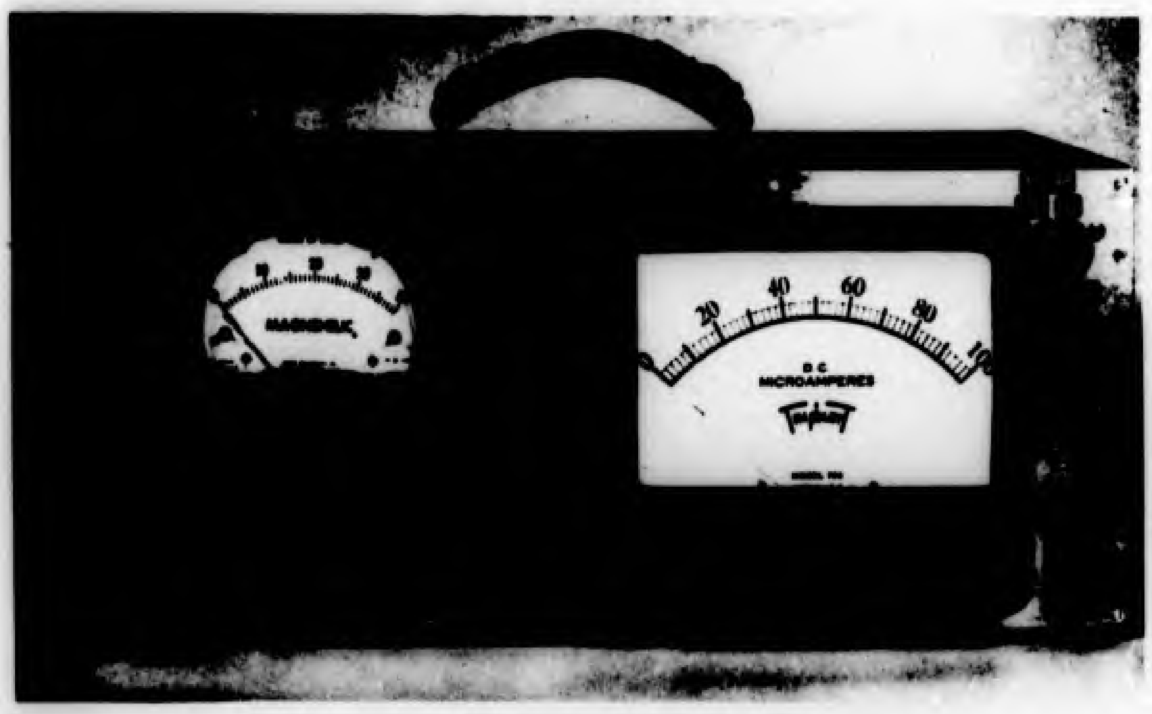

Figure 1a. Front View of the Army $CO_2/O_2$ Concentration Monitor (Model I).

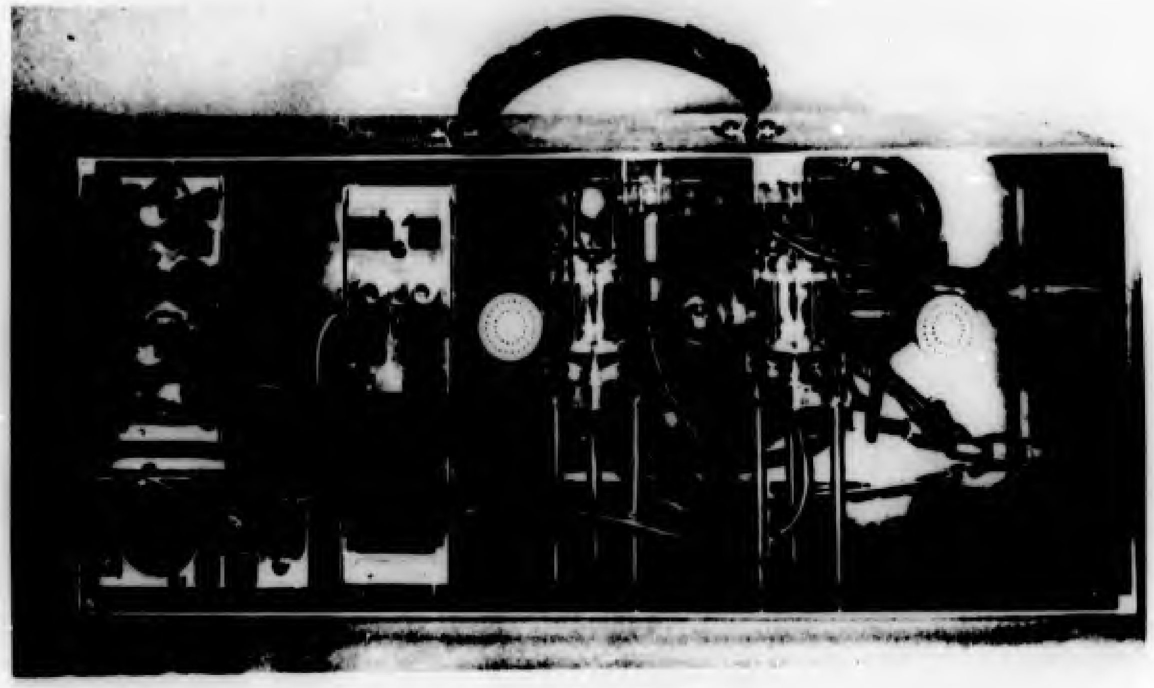

Figure 1b. Rear View of the Monitor.

$$f_1 = \frac{[\gamma RT]^{1/2}}{K} \tag{2}$$

where

$\gamma$ = ratio of specific heats

R = ideal gas constant

T = absolute temperature

K = constant depending on the geometry of the oscillator.

The constant K can be computed accurately enough for design purposes by using the following equation

$$K = 2\left\{\left[L^2 + \left(b - \frac{h}{2}\right)^2\right]^{1/2} + L + \left(b - \frac{h}{2}\right)\right\} \tag{3}$$

where L, b, and h are geometrical parameters described in figure 2.

When the cavity frequency is approximately equal to the jet-edge frequency, these frequencies couple, and the oscillator operates at its maximum wave amplitude.

The velocity at which the maximum wave amplitude can be expected may be calculated by equating (1) and (2), and the threshold pressure drop $\Delta p_t$ yielding this velocity can be computed for low operating pressures by using incompressible flow theory. The resulting approximation is equation (4). Details of its derivations are given in appendix A.

$$\Delta p_t = \frac{h^2 (1 + \alpha^2) \gamma \bar{p}}{0.4343 K^2} \tag{4}$$

where

$\bar{p}$ = average pressure between inlet and outlet of oscillator

$\alpha$ = ratio of inlet nozzle area to outlet nozzle area.

For the oscillator geometry to be used, the calculated threshold pressure drop is 2.1 $kN/M^2$ (0.3 psid).

From equation (2), it is clear that the output frequency is a function of the properties of the gas flowing through the oscillators if the geometry and temperature are maintained constant. For gas mixtures, the values of $\gamma$ and R are given by the following equations

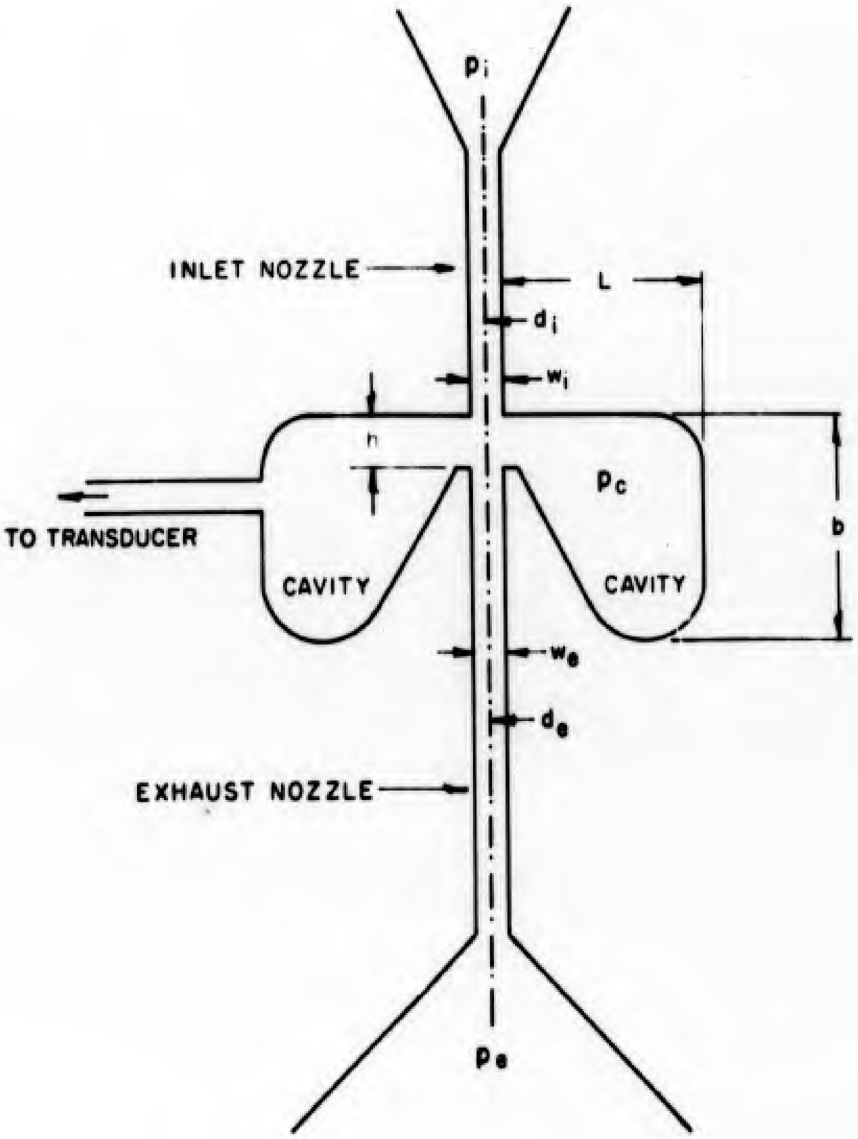

Figure 2. Flueric Oscillator.

$$\gamma_m = \frac{\sum\left\{\left(\frac{P_i}{z_i}\right)\left(\frac{c_{pi}}{R_i}\right)\right\}}{\sum\left\{\left(\frac{P_i}{z_i}\right)\left(\frac{c_{vi}}{R_i}\right)\right\}} \tag{5}$$

$$R_m = \frac{\sum\left\{\frac{P_i}{z_i}\right\}}{\sum\left\{\left(\frac{P_i}{z_i}\right)\left(\frac{1}{R_i}\right)\right\}} \tag{6}$$

where

$\gamma_m$ = ratio of the specific heat of the mixture

$R_m$ = ideal gas constant of the mixture

$P_i$ = partial pressure of component i

$z_i$ = compressibility factor of component i

$R_i$ = ideal gas constant of component i

$c_{pi}$ = specific heat at constant pressure of component i

$c_{vi}$ = specific heat at constant volume of component i.

Details of the development of these equations are given in appendix B, and the value of the physical parameters are given in table I.

## 3. SENSING UNIT

The sensing unit consists of two parallel oscillators exhausting to a common chamber as shown in figure 3. The critical dimensions of these units are given in table II. The gases are drawn through these oscillators by applying a constant suction to the exhaust chamber. A transmission line connects the cavities of the two oscillators, and a transducer placed in this line monitors the beat frequency of the two oscillators. The signal is electronically processed (appendix C) and converted to an indication of carbon dioxide concentration or oxygen concentration.

The change in percent difference frequency is nearly proportional to the percent change in the square root of the absolute temperature (0.17 percent per °C), and temperature changes could complicate the calibration and use of a one-oscillator sensor. The two-oscillator system was chosen primarily because it makes the effect of the gas temperature insignificant.

The frequency of the reference oscillator (with air) computed using equations (2) and (3) and the data given in tables I and II is $f_R$ = 30,056 Hz. On the other hand, the sampling oscillator with air has a computed frequency of $f_s$ = 29,823 Hz. The oscillator pair is designed with this minimum frequency difference (233 Hz) because it has been experimentally

**Table I. Physical Properties of the Gases at 290°K.(1)(2)**

| Gas | $R \times 10^{-6} \dfrac{cm^2}{sec^2\ °K}$ | $\gamma$ | M | $\dfrac{c_p}{R}$ | $\dfrac{c_v}{R}$ | z |
|---|---|---|---|---|---|---|
| Air | 2.8704 | 1.4020 | 28.966 | 3.4989 | 2.4956 | 0.9996 |
| $N_2$ | 2.9677 | 1.401 | 28.016 | 3.5025 | 2.5000 | 0.9997 |
| $O_2$ | 2.5982 | 1.396 | 32.000 | 3.5288 | 2.5278 | 0.9928 |
| $CO_2$ | 1.8892 | 1.299 | 44.010 | 4.4208 | 3.4032 | 0.9944 |
| $H_2O$ | 4.615 | 1.330 | 18.016 | 4.0343 | 3.0344 | 0.968 |

Air composition: $N_2$ 78.09 percent
$O_2$ 20.95 percent
Ar 0.93 percent
$CO_2$ 0.03 percent

(1)Tables of Thermal Properties of Gases, Circular 564, NBS (1955)
(2)Gas Tables, Keenan & Kaye, 1948

**Table II. Critical Dimensions of the Sensing Units.**

| Parameter | Sensing Oscillator | | Reference Oscillator | |
|---|---|---|---|---|
| | Dimension | | Dimension | |
| | (cm) | (in.) | (cm) | (in.) |
| L | 0.1778 | 0.070 | 0.1753 | 0.069 |
| b | 0.1778 | 0.070 | 0.1778 | 0.070 |
| h | 0.0406 | 0.016 | 0.0406 | 0.016 |
| $d_i$ | 0.0762 | 0.030 | 0.0762 | 0.030 |
| $w_i$ | 0.0254 | 0.010 | 0.0254 | 0.010 |
| $d_e$ | 0.0381 | 0.015 | 0.0381 | 0.015 |
| $w_e$ | 0.0254 | 0.010 | 0.0254 | 0.010 |
| K | 1.1455 | 0.45098 | 1.1366 | 0.44748 |

demonstrated that the measured signal becomes quite unstable when the difference frequency is too close to zero.

During the respiratory cycle, oxygen is consumed, and carbon dioxide is produced. The ratio between the percent carbon dioxide produced and the percent oxygen consumed is is called respiratory quotient (RQ). The average value of the respiratory quotient for humans

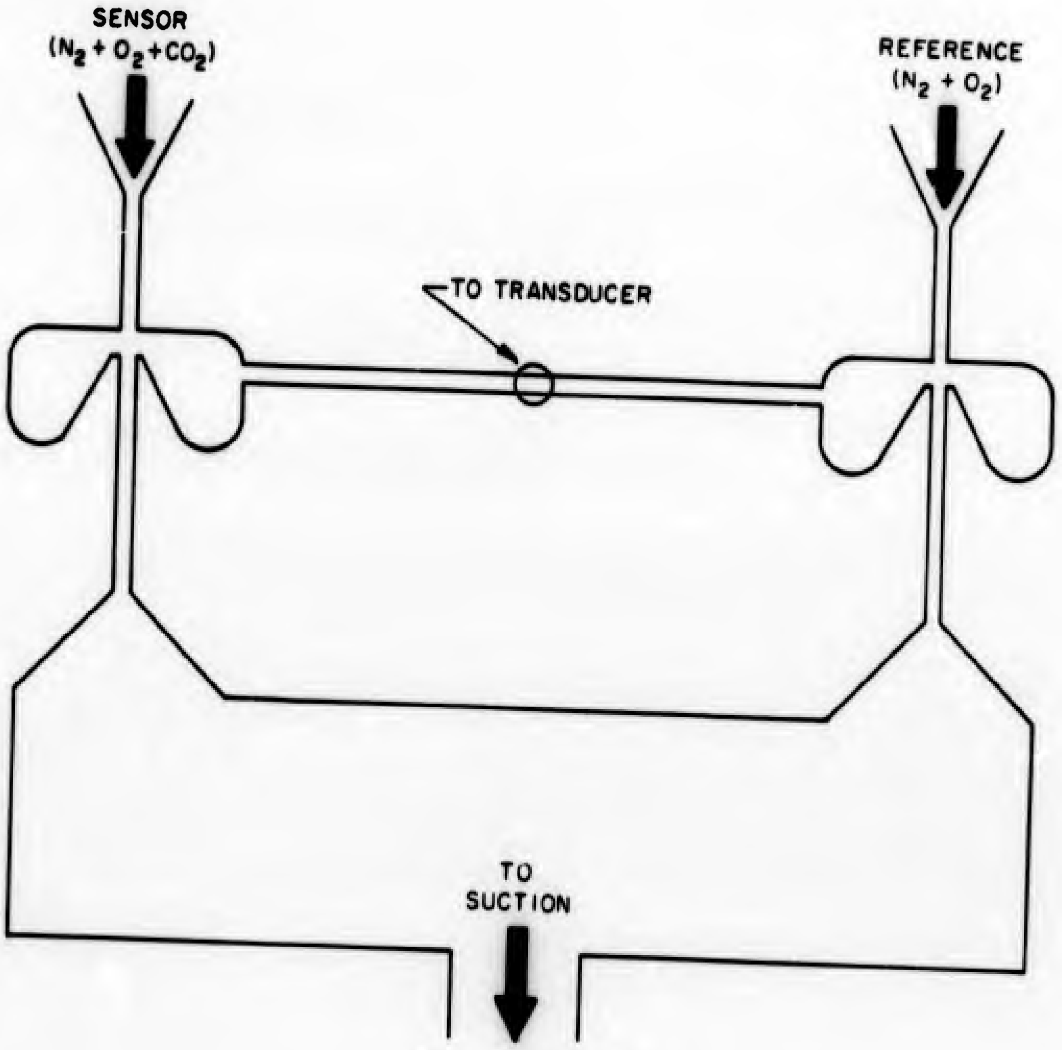

Figure 3. Sensing Unit.

is 0.85.[4] The change in frequency observed when exhaled gas is compared with air is not only due to the carbon dioxide added to the exhaled gas mixture but also to a decrease in oxygen concentration. The first phenomenon decreases the frequency of the sampling oscillator, and the second increases it; however, the sensing unit is about three times more sensitive to carbon dioxide than it is to oxygen. Therefore the error introduced in the measurement of the carbon dioxide concentration due to variation in the respiratory quotient is not significant.

## 4. CONCENTRATION MONITORING SYSTEM

### 4.1 Flueric Circuitry

A block diagram of the Army $CO_2/O_2$ Concentration Monitor (Model I) is shown in figure 4.

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[4] Handbook of Biological Data, William S. Specter (Editor), WADC Technical Report 56-273, AD 110501 (1956).

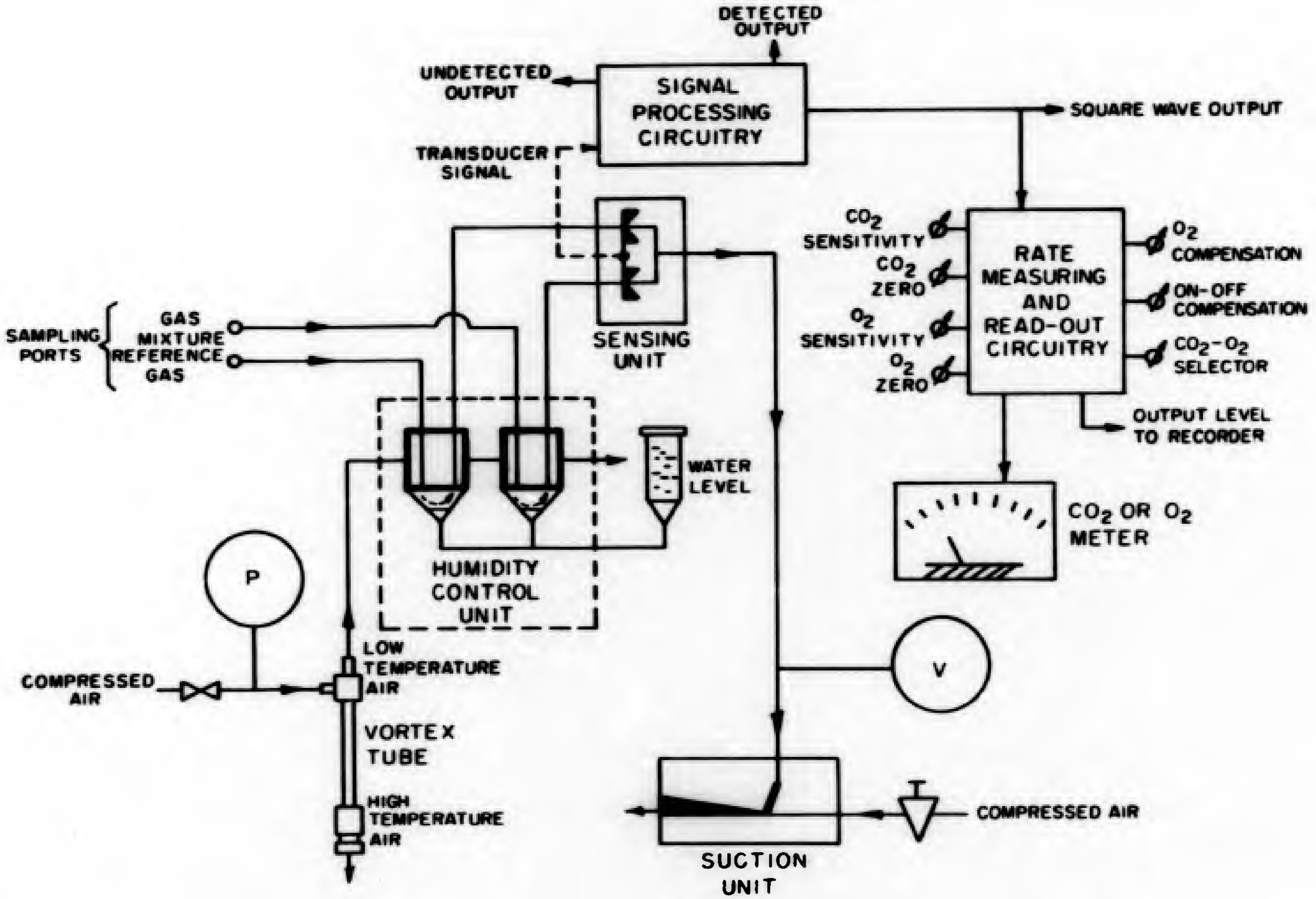

Figure 4. Block Diagram of the Monitor.

A small sample of the expired gases and the reference gas (air or the inhaled mixture of oxygen and nitrogen) is aspirated through the sampling ports. Both gas samples are independently drawn through a humidity control unit consisting of two small Plexiglas units (fig. 5). Each unit contains two independent chambers; cold air supplied by a vortex tube shown in figure 4 flows continuously through the upper chamber. An air pressure of 283 kN/m$^2$ (41 psig) is applied to the vortex tube. The estimated gas flow is 30 s ℓ/min. The lower chamber contains water at ambient temperature. The gas coming from the sampling port enters the system at the top through one of the brass tubes shown in figure 5. These tubes are maintained at the temperature of the cold air circulating through the upper chamber. The gas flows through the lower chamber and exhausts through the other brass tube flowing toward the flueric oscillator. The gas exhausting from the humidity control unit is saturated with water vapor and is at the temperature of the air circulating through the upper chamber of the unit. Water vapor is either removed from the gas as in the case of the sample taken from exhaled gases or put in the gas as in the case of a dry reference gas. In this way, both oscillators receive gas at the same temperature and relative humidity. The lower chamber is connected to a water-level control tube installed in the front of the monitor for easy visual checking. The two gas samples are drawn from the humidity control unit to the sensing unit where the signal is picked up by a transducer and supplied to the signal processing circuitry. The signal is ultimately converted to carbon dioxide or oxygen percentage and indicated on a meter. The processed signal can also be supplied to a recorder if so desired.

The gases are moved through the system by a small aspirator (suction unit) shown in figure 6. An air pressure of approximately 38 kN/m$^2$ (5.5 psig) is applied at the input port (A). The air exhausts through port (C). The geometrical characteristics of the aspirator causes a suction of 8.3 kN/m$^2$ (33 in. of water) at port (B) which is connected to the output of the sensing unit.

## 4.2 Electronic Circuitry

The Army $CO_2/O_2$ Concentration Monitor electronics accepts a low-level signal from a pressure transducer, processes the signal (which is essentially a mixture of two frequencies), detects the beat frequency that is present, produces a voltage level that is proportional to this

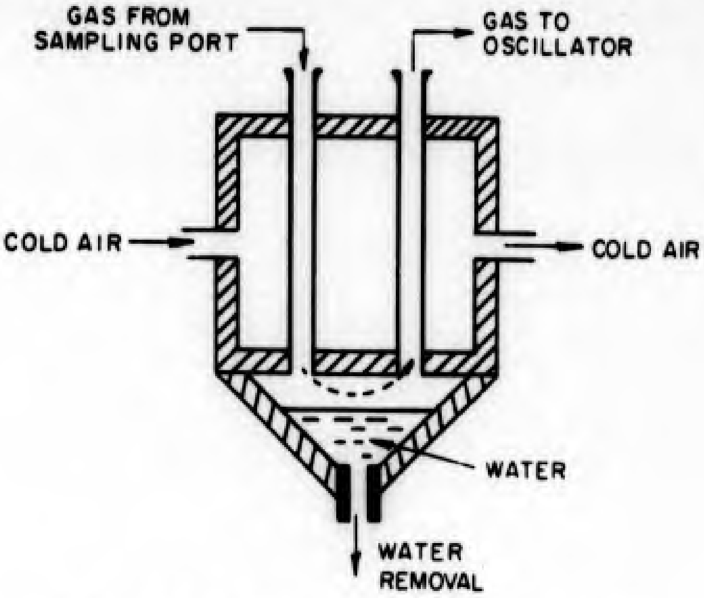

Figure 5. Water Condenser of the Humidity Control Unit.

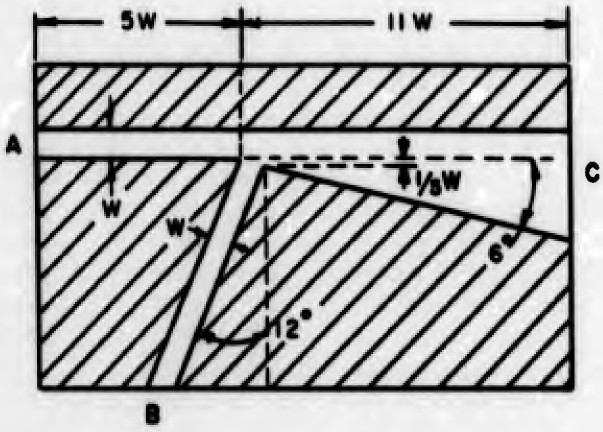

Figure 6. Suction Unit (W = 0.051 cm).

beat frequency, and displays the voltage on a meter. The electronic system is described in detail in appendix C. Since the beat frequency produced by the mixture of the two flueric-sensor outputs (and sensed by the pressure transducer) is almost proportional to the amount of carbon dioxide, it can be read directly on a linear scale of 0 to 10 percent on the system meter when the carbon dioxide range is being used. An oxygen range is provided so that the percent oxygen in the inhaled gas can be read directly on a scale of 0 to 100 percent. Zero adjustments for both the oxygen and carbon dioxide ranges are provided on the rear and can be set when both oscillators are receiving the same gas; likewise, sensitivity adjustments (also on the rear) for both ranges allow adjustment for any changes in the characteristics of the flueric oscillators and allow the use of a flueric oscillator with different characteristics.

In addition, if $CO_2$ is to be measured in a concentration of nitrogen and oxygen that is different from that of air, an oxygen compensation adjustment (on the front panel) permits the meter to be rezeroed for this new gas mixture keeping the same electronic sensitivity to carbon dioxide. Furthermore, the electronics provides outputs (undetected, detected, and square wave) for measurement or for operating other equipment, contains a power supply for operation using alternating current, provides an input for operating from an external power supply such as a battery pack, and provides a rate output from which the dc level (proportional to gas concentration) can be recorded. The power requirements of the electronics are low enough so that a 4.0 A-hr battery pack should operate the system continuously for over five days.

## 5. LABORATORY CALIBRATION

### 5.1 Calibration Setup

The calibration setup is shown in figure 7. Nitrogen, oxygen, and carbon dioxide are combined in the gas mixing apparatus (appendix D) to obtain the desired gas mixture. The concentration of each gas is determined from the manometer readings. The gas mixture is passed through a small sampling chamber and exhausted to atmosphere. The pressure in the sampling chamber is practically equal to the ambient pressure. An input flow to the chamber approximately 1-1/2 times the sampling rate (7 cc/sec) is used to insure that the gas sample is not contaminated with the outside air.

### 5.2 Argon Correction

Air is a mixture of 20.9 percent oxygen, 78.0 percent nitrogen, 0.9 percent argon, and small quantities of other gases. For medical applications, to obtain a desired oxygen-rich

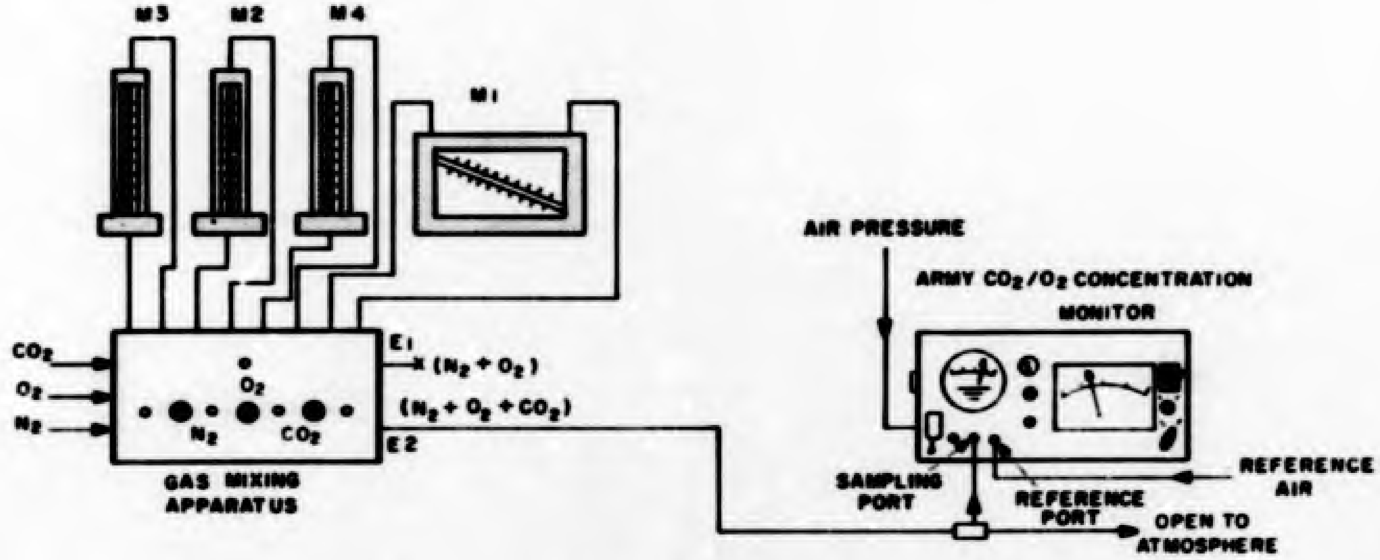

Figure 7. Calibration Setup.

atmosphere, air is mixed with oxygen. This oxygen-rich gas contains a certain amount of argon provided by the air. The gas mixing apparatus (appendix D) supplies an argon-free gas mixture. If a 20.9 percent oxygen-nitrogen mixture were compared with air using the Army $CO_2/O_2$ Concentration Monitor, the observed beat frequency (or meter indication) would be different from that obtained in comparing air with air. To compensate for this difference, the percent of oxygen in the argon-free gas mixture can be increased by an amount equivalent to the concentration of argon that would be present if air and oxygen are mixed to obtain the desired gas mixture. The physical characteristics of argon are such that the effect of small amounts of argon can be simulated by the addition of the same amount of oxygen to the gas mixture. An oxygen concentration of 21.88 percent is equivalent to 20.95 percent oxygen and 0.93 percent argon. This equivalence was confirmed by setting the carbon dioxide scale to zero (higher sensitivity) with air and rechecking the zero with a 21.9 percent oxygen-nitrogen mixture. A 20.95 percent oxygen-nitrogen mixture gives a meter indication below zero.

Since the ratio of the argon to nitrogen should stay constant for gas mixtures made by adding oxygen to air, the oxygen concentrations with air or pure nitrogen that produce the same beat frequency are related as follows:

$$(\%\,O_2)_{AO} = (\%\,O_2)_{NO} - 0.93\,\frac{(\%\,N_2)}{78} \tag{7}$$

where

$(\%\,O_2)_{AO}$ is the concentration of oxygen in a gas mixture made from air and oxygen

$(\%\,O_2)_{NO}$ is the concentration of oxygen in a gas mixture made from nitrogen and oxygen (argon free)

$(\%\,N_2)$ is the concentration of nitrogen.

### 5.3 Scale Setting

The differential pressure across the sensing unit was set to 33 in. of water (indicated by the front differential gage). Operation of the sensing unit seems most stable at this setting. The pressure at the input of the vortex tube (humidity control unit) was set at 41 psig; this pressure corresponds to a cooling air temperature of 6°C. The carbon dioxide zero adjustment and sensitivity adjustment (back of the monitor) were adjusted to read zero with pure air and 5 percent with a mixture of 5 percent carbon dioxide and a concentration of oxygen equivalent to that of dry (saturated at 6°C) exhalation gas with 5 percent carbon dioxide when the inhaled gas is pure air (respiratory quotient of 0.85). The oxygen scale was adjusted in a similar way to read 18 percent oxygen with pure air and 101 percent oxygen with pure oxygen. This setting allows a balanced error in the oxygen indication of less than 1 percent oxygen for the upper 2/3 of the scale and a maximum of 2.8 percent oxygen in the lower end of the scale.*

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*Later recalibrations have shown that a more suitable oxygen scale may be obtained by setting the lower end of the scale (air) to 20 percent and the upper end of the scale (pure oxygen) to 99 percent. This setting allows an error of 1 percent at any point of the scale.

### 5.4 Calibration

The calibration data obtained using the setup shown in figure 7 are given in tables III and IV. Table III gives the data obtained for respiratory quotients of 0.85 and 1.0 for 0 and 5 percent carbon dioxide. The column entitled "% $O_2$ in $O_2$ - $N_2$ mix," represents the oxygen content of the calibration gas mixture before mixing with carbon dioxide. The oxygen content at zero concentration of carbon dioxide represents the inhaled gas concentration in an argon-free mixture. The oxygen concentration in the presence of argon yielding the same beat frequency may be obtained from equation (7). The oxygen concentration in the calibration gas mixture before mixing with carbon dioxide was computed using equation (8). Equation (8) corrects the concentration of oxygen presumed to be inhaled for the oxygen loss due to the consumption of oxygen in the lungs (given by the carbon dioxide concentrations divided by the respiratory quotient) and the effect of the addition of carbon dioxide to the initial oxygen-nitrogen mixture. The equation relating these concentrations is as follows:

$$(\%\,O_2) = \frac{100}{100 - (\%\,CO_2)}\left[(\%\,O_2)_0 - \frac{\%\,CO_2}{RQ}\right] \qquad (8)$$

where

$(\%\ O_2)$ is the concentration of oxygen in the oxygen-nitrogen mixture in the gas mixer,

$(\%\ O_2)_0$ is the concentration of oxygen in the oxygen-nitrogen mixture presumed to be inhaled,

$(\%\ CO_2)$ is the concentration of carbon dioxide in the final ternary mixture to be used for calibrating the analyzer, and

RQ is the respiratory quotient.

Figure 8a is a plot of the correction factor for the carbon dioxide scale due to the effect of the oxygen concentration. The solid lines are the theoretical correction factors obtained in appendix E, and the points are computed from the data given in table III for RQ = 0.85. Figure 8b is a plot of a correction that should be added to the indicated oxygen percentage to obtain the real oxygen concentration. The points plotted in this figure were computed using the data given in table III, and the solid line indicates the theoretical correction from appendix E. Figure 8c is a plot of the oxygen compensation dial indication versus the percent oxygen inhaled. The data points were taken from table III and the solid line is the best fit to the data.

The data in table III shows that (as expected from the theoretical analysis in appendix E) the effect of the respiratory quotient is insignificant.

The data in table IV were obtained to determine the linearity of the carbon dioxide scale at different inhaled oxygen levels. The column labeled "% $CO_2$ CORRECTED" was obtained by multiplying the column immediately before by the carbon dioxide scale correction factor obtained from figure 8a. The table shows that the device is linear as expected from the theoretical considerations (appendix E).

Table III. Calibrations of the Monitor.

| Respiratory Quotient | % $O_2$ in $O_2$-$N_2$ Mix | $\Delta P(M2)$ (Oxygen) | $\Delta P(M3)$ (Nitrogen) | % $CO_2$ | $\Delta P(M4)$ ($O_2$ + $N_2$) | $\Delta P(M1)$ (Carb. Diox.) | Oxygen Compens. | % $O_2$ Indicated | % $CO_2$ Indicated |
|---|---|---|---|---|---|---|---|---|---|
| – | 21.8* | 2.50 | 8.30 | 0 | – | – | 0 | 18 | 0 |
| 0.85 | 16.7 | 1.75 | 8.00 | 5 | 6.38 | 2.57 | 0 | – | 5.00 |
| 1.0 | 17.7 | 1.87 | 8.00 | 5 | 6.38 | 2.57 | 0 | – | 5.20 |
| – | 32.0* | 4.40 | 8.59 | 0 | – | – | 72 | 30.5 | 0 |
| 0.85 | 27.5 | 3.26 | 7.90 | 5 | 7.20 | 2.88 | 72 | – | 4.80 |
| 1.0 | 28.4 | 3.40 | 7.90 | 5 | 7.20 | 2.88 | 72 | – | 4.90 |
| – | 50.0* | 8.00 | 7.35 | 0 | – | – | 183 | 49.5 | 0 |
| 0.85 | 46.4 | 5.64 | 6.00 | 5 | 7.55 | 2.93 | 183 | – | 4.80 |
| 1.0 | 47.3 | 7.20 | 7.39 | 5 | 7.55 | 2.93 | 183 | – | 4.80 |
| – | 75.0* | 10.00 | 3.06 | 0 | – | – | 339 | 75.5 | 0 |
| 0.85 | 72.8 | 10.00 | 3.04 | 5 | 7.50 | 2.81 | 339 | – | 4.80 |
| 1.0 | 73.5 | 10.00 | 3.03 | 5 | 7.50 | 2.81 | 339 | – | 4.80 |
| – | 90 * | 10.00 | 1.05 | 0 | – | – | 431 | 91.0 | 0 |
| 0.85 | 88.6 | 10.00 | 1.03 | 5 | 7.50 | 2.75 | 431 | – | 4.50 |
| 1.0 | 89.3 | 10.00 | 1.04 | 5 | 7.50 | 2.75 | 431 | – | 4.50 |
| – | 100.0* | – | – | 0 | – | – | 487 | 101.0 | 0 |
| 0.85 | 100.0 | – | – | 5 | 7.0 | 2.53 | 487 | – | 4.50 |
| 1.0 | 100.0 | – | – | 5 | 7.0 | 2.53 | 487 | – | 4.50 |

*Theoretical inhaled oxygen concentrations including argon correction

Cooling Gas Temperature . . . . . . . . . . . . . . . . 6.5 ± 0.5°C

Vortex Tube Pressure . . . . . . . . . . . . . . . . . . 41 ± psig

Differential Pressure Across Sensor . . . . . . . . 33 inches of water

Table IV. Linearity Check of the Monitor.

| % $O_2$ in $O_2 - N_2$ Mix | $\Delta P(M2)$ Oxygen | $\Delta P(M3)$ Nitrogen | % $CO_2$ | $\Delta P(M4)$ $(O_2 + N_2)$ | $\Delta P(M1)$ Carb. Diox. | Oxygen Compens. | % $CO_2$ Indicated | % $CO_2$ Corrected | Error |
|---|---|---|---|---|---|---|---|---|---|
| 21.8* | 2.50 | 8.30 | 0 | – | – | 0 | 0 | 0 | 0 |
| 19.9 | 2.14 | 8.00 | 2.5 | 6.50 | 1.22 | 0 | 2.50 | 2.5 | 0 |
| 16.7 | 1.75 | 8.00 | 5.0 | 6.38 | 2.57 | 0 | 5.00 | 5.0 | 0 |
| 14.8 | 1.51 | 8.00 | 7.5 | 6.20 | 3.86 | 0 | 7.60 | 7.6 | +0.1 |
| 50.0* | 6.52 | 6.00 | 0 | – | – | 187 | 0 | 0 | 0 |
| 47.0 | 5.81 | 6.00 | 2.5 | 7.09 | 1.32 | 187 | 2.30 | 2.4 | -0.1 |
| 46.4 | 5.64 | 6.00 | 5.0 | 7.55 | 2.93 | 187 | 4.80 | 5.0 | 0 |
| 42.1 | 3.34 | 4.20 | 7.5 | 5.00 | 2.95 | 187 | 7.20 | 7.50 | 0 |
| 100.0* | – | – | 0 | – | – | 491 | 0 | 0 | 0 |
| 100.0 | – | – | 2.5 | 7.50 | 1.32 | 491 | 2.20 | 2.4 | -0.1 |
| 100.0 | – | – | 5.0 | 7.00 | 2.53 | 491 | 4.40 | 4.9 | -0.1 |
| 100.0 | – | – | 7.5 | 5.20 | 2.89 | 491 | 6.60 | 7.3 | -0.2 |

*Theoretical inhaled oxygen concentration including argon correction

Cooling Gas Temperature . . . . . . . . . . . . . . . . 6.5 ± 0.5°C
Vortex Tube Pressure . . . . . . . . . . . . . . . . . . 41 ± 1 psig
Differential Pressure Across Sensor . . . . . . . . . 33 inches of water
Respiratory Quotient . . . . . . . . . . . . . . . . . . . 0.85

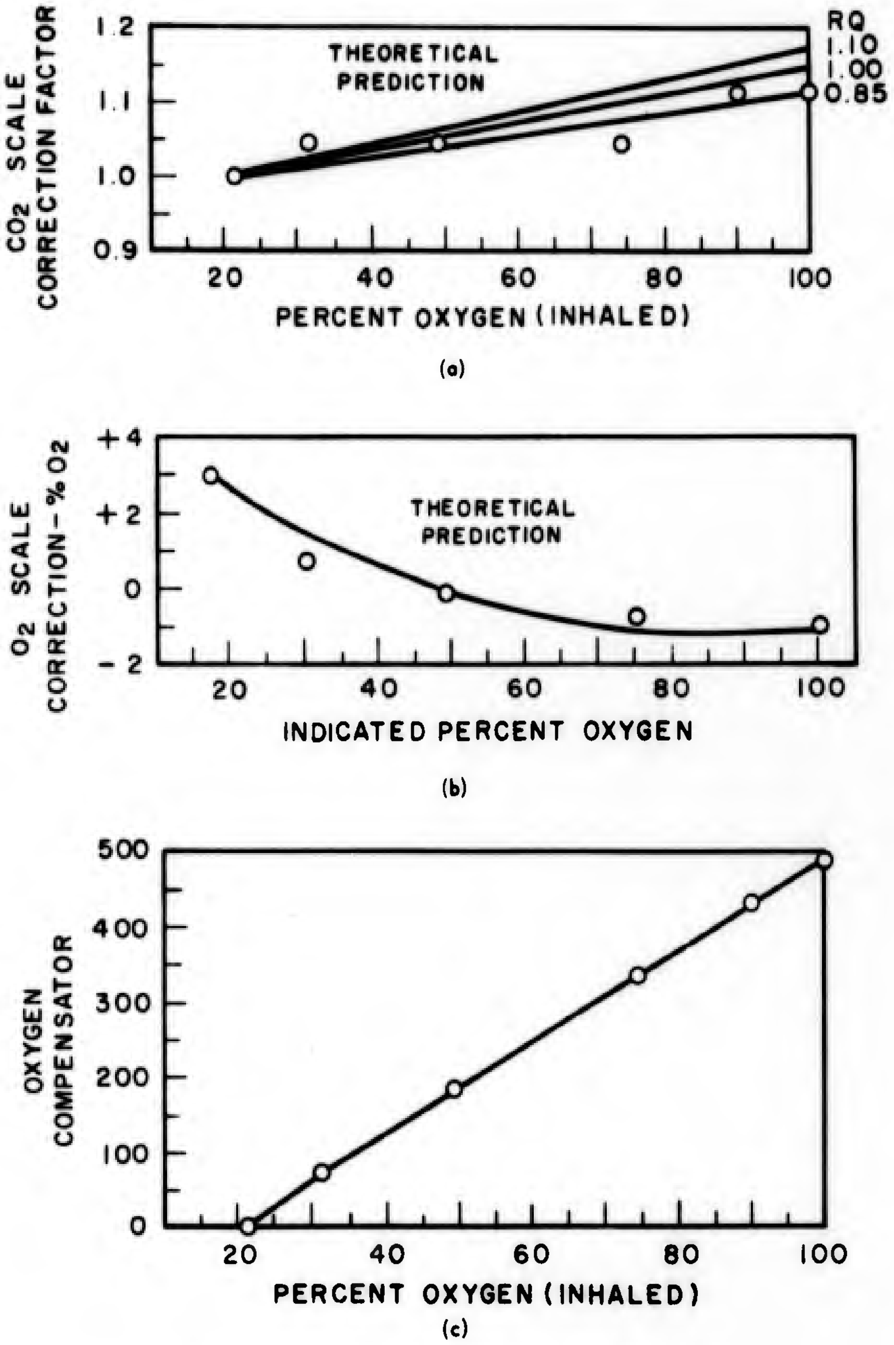


Figure 8. Calibration Data and Theoretical Predictions.

## 6. OPERATION AND MAINTENANCE

### 6.1 Sampling Technique

### 6.1.1 Sampling During Operation

The Army $CO_2/O_2$ Concentration Monitor has two sampling ports located in the front of the monitor immediately under the differential pressure gage of the sensor. The right port (R) should be kept open to sample the reference ambient air continuously. The left port (G) is used to sample the unknown gas mixture. The use of these ports is not interchangable since they are connected to oscillators with different characteristics.

The monitor may be used in conjunction with a respirator or with a simple breathing mask and breathing valve, as the one shown in figure 9. During inhalation, the gas is supplied to the individual through port B. The small vacuum produced by the lungs is enough to open the check valve in port B and close the check valve in port A. During exhalation, the process reverses, and the exhaled gases exhaust through port A. The valve is connected to the breathing mask at port C. Port A is always connected directly to atmospheric pressure through a few inches of tubing with insignificant pressure drop. Port (a) is connected to the sampling port of the monitor. Port B is open to the local atmosphere (ambient air or oxygen tent). If the inhaled oxygen concentration is unknown, it can be measured by connecting the sampling port to port (b) of the breathing mask.

### 6.1.2 Sampling During Calibration

The calibration sampling chamber is shown in figure 7. It consists of a tee to be connected to the sampling port (G). The calibration gas flows through the tee at a rate of approximately 12 cc/sec exhausting to atmosphere through a few inches of tube. The pressure inside the sampling chamber remains at the normal ambient pressure since the pressure drop across the exhaust tube is insignificant.

### 6.2 User Calibration

Two calibrated gases are needed in addition to ambient air: pure oxygen and a suitable mixture of oxygen, nitrogen, and carbon dioxide equivalent to dry exhaled air with a

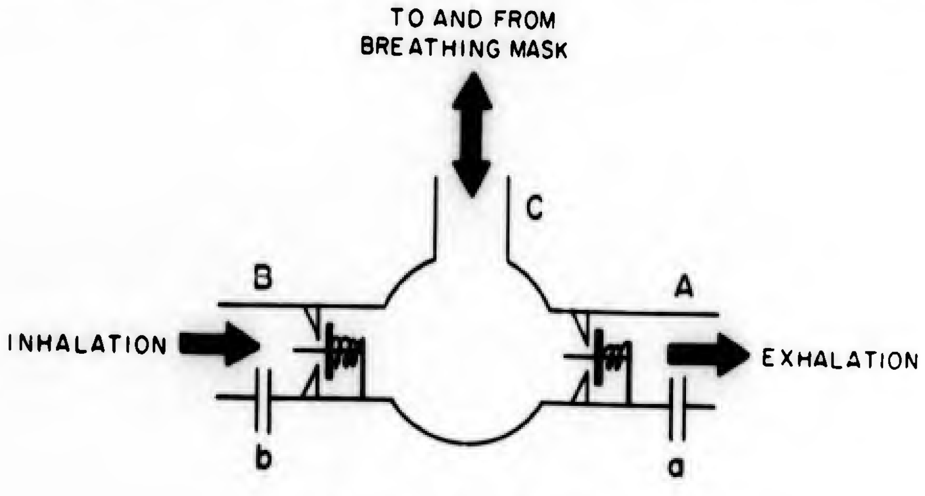


Figure 9. Breathing Valve.

concentration of carbon dioxide between 5 and 10 percent and a concentration of oxygen given by equation (9)

$$(\%\,O_2) = 21.9 - (\%\,CO_2)/0.85. \qquad (9)$$

These gases are used to set the carbon dioxide and oxygen scales by adjusting the zero adjustment and the sensitivity for each gas in the back of the monitor. The following procedure should be followed:

### 6.2.1 Calibration of the Carbon Dioxide Scale

The carbon dioxide scale is calibrated as follows:

(a) Activate the power supply (either ac or battery) and turn the power switch on.

(b) Adjust the vortex tube pressure to 41 psig and wait five minutes to obtain the desired gas temperature (6 to 7°C).

(c) Adjust the differential pressure across the sensing unit to 33 in. of water.

(d) Set the TC switch (back of the monitor) to S.

(e) Set the range switch to $CO_2$.

(f) Make sure that the $O_2$ compensation is off and set its dial to zero.

(g) Sampling pure air, set the dial to zero with "$CO_2$ ZER" adjustment.

(h) Sampling the calibrated oxygen-nitrogen-carbon dioxide gas mixture, set the dial to the appropriate reading of carbon dioxide adjusting the "$CO_2$ SN" (sensitivity) adjustment.

(i) Repeat steps (g) and (h) until scale is set, and lock the carbon dioxide controls in the back of the monitor.

### 6.2.2 Calibration of the Oxygen Scale

(a) Set the range switch to $O_2$.

(b) Sampling pure air, adjust the "$O_2$ ZER" control (back of the monitor) to 18 percent. The nonlinearity of the sensor introduces a small error in the oxygen scale. This error should be corrected using the correction chart during operation. The error is less than 1 percent oxygen in the upper 2/3 of the scale. (See footnote on page 18.)

(c) Sampling pure oxygen, adjust the "$O_2$ SN" (sensitivity) control to 101 percent.

(d) Repeat steps (b) and (c) until scale is adjusted, and lock the oxygen controls in the back of the monitor.

## 6.3 Typical Use (AC-Line Operation)

To operate from the ac line, the line cord should be plugged in and attached to the ac receptacle at the rear of the monitor. The switch next to the ac receptacle should be set at "ACPWR." The power switch should be switched ON, and the pressure control to the vortex tape (humidity control unit) should be set to 41 psig. If calibration is necessary, refer to section 6.2. Also, before the monitor can be used, the shorting switch on the rear of the meter should be placed in the up position.

Providing the system is calibrated, and, if carbon dioxide in air is to be measured, switch the range switch to $CO_2$ and set the "$O_2$ compensation" to OFF. After a few minutes to allow the humidity control unit to reach temperature equilibrium, turn the control regulator of the sensing unit to read 33 in. of water in the front differential gage. This should cause the concentration meter to read near zero when pure air is being sampled. Adjust the zero reading with the "$CO_2$ ZER" control in the back of the monitor. Calibration should be checked periodically.

If a fast meter response is desired, set the TC (time constant) switch to S (short). Slight variations in the meter position due mainly to oscillator variations can often be reduced by setting the TC switch to L (long). This doubles the time constant of the rate measuring circuit.

After the previous initial adjustments, changes in the percent of carbon dioxide in air should cause a corresponding indication on the meter on the 0- to 10-percent scale. If carbon dioxide is to be measured in some other concentration of oxygen and nitrogen, sample the new oxygen-nitrogen mixture (with no carbon dioxide), turn the "$O_2$ compensation" switch ON, and adjust the "$O_2$ compensation" adjust dial until the meter reads zero percent. Lock the "$O_2$ compensation" adjust dial and make the carbon dioxide measurements as in the case of air. Do not turn the compensation switch OFF if the dial reads higher than 900. Correct the carbon dioxide reading by multiplying the reading by the correction factor given in figure 8a.

If oxygen is to be measured, assuming calibration has been made (see sect. 6.2), switch the range switch to $O_2$. Sampling pure air, the meter should read near 18 percent (due to the small nonlinearity of the sensing unit). Adjust the meter reading to 18 percent using the "$O_2$ZER" control in the back of the monitor. After the 18 percent reading is obtained, changes in the oxygen concentration in oxygen-nitrogen mixtures should cause a corresponding indication of oxygen concentration on the 0- to 100-percent scale. As for carbon dioxide measurements, the time constant of the average-rate circuit can be doubled by switching the TC switch to L. Correct the oxygen indication using figure 8b.

If an external counter is to be used, attachment can be made to the detected-signal output jack on the back of the monitor. The input impedance of any device attached to this point should not be less than 1.0 MΩ. A recorder may be connected to the rate output jack in the rear of the monitor if a written record of gas concentration changes is desired. Full meter protection is not in effect for the rate output, so care should be taken to keep from overdriving the recorder or other measuring instruments that may be used. The input impedance of any device attached to the rate output jack should be no less than 20 kΩ.

If one wishes to measure the undetected output, attachment can be made to the appropriate jack on the preamplifier in the back of the monitor. The input impedance of any device attached to this jack (e.g., oscilloscope) should not be less than 1.0 MΩ. A square-wave output is provided, with a frequency the same as that of the beat frequency measured at the detected output. However, any device attached to the square-wave output should have an input impedance of not less than 10 MΩ shunted by a capacitance of no more than 8.0 pF. A X10 oscilloscope probe can be used as an interface between the square-wave output and some other device whose input impedance is lower than that required, providing the device can tolerate the reduction in signal. Signal levels at the various preamplifier outputs typically are approximately as follows:

undetected output - 8 V p-p,

detected output - 3 V peak,

square-wave output - 10 V peak.

If battery operation or operation from some other power supply is desired, refer to section 6.4. Battery operation or operation from a low-ripple power supply may reduce meter pointer variations slightly.

### 6.4 Operation from an External Supply

An external supply can be attached to the plug labeled "Batt" (battery) on the rear of the monitor. Connections to the plug can be determined from the power supply schematic given in figure C-2. Switching the selecting switch in the back of the monitor to "BATT PWR," the monitor can be operated as previously described. Typically, after being fully charged, the battery-pack voltages should measure ±10.5 V. Do not allow the voltages of the battery pack to drop below 9.0 V of either polarity. Since the drop between 10.0 and 9.0 V is somewhat rapid and the concentration sensor works best in the 10.5- to 10.0-V range, a cut-off voltage of 10.0 V might be used.

Other external supplies may be used, but, for any external supply, care must be taken to apply the correct polarity of voltage and not to exceed 12-V of either polarity. If these precautions are not followed, the concentration sensor electronics may be damaged. The concentration sensor will operate with an imbalance in the two power supply voltages (in a ±9-V to ±12-V range), but best operation (little change in meter position) is obtained when the two supplies are at the same voltage.

### 6.5 Transporting the System

Whenever the system is to be moved more than a short distance, the shorting switch on the meter board (meter rear) should be placed in the down position to protect the meter movement. This will keep the meter pointer from swinging quite so wildly. Care should be taken when reaching for the switch that the wires in the vicinity of the switch are not moved. Whenever the electronics is to be used, the shorting switch should be placed in the up position.

## 7. CONCLUSIONS

A flueric concentration monitor with an electronic output (meter or recorder) has been built. The system is able to measure carbon dioxide and oxygen in respiratory gases continuously with an accuracy of 1 percent oxygen and better than 0.3 percent carbon dioxide. Results with the monitor were in good agreement with the theoretical prediction obtained with the help of a computer. The system is inexpensive, easy to clean if necessary, is rugged, and can be miniaturized if so desired.

## Appendix A. Threshold Differential Pressure

The term threshold describes the condition at which the cavity frequency of the oscillator becomes coupled with its jet-edge frequency. Parameters that may be used to characterize this condition are the velocity of the jet, the flow, and the differential pressure across the oscillator. Theoretically, the amplitude of the pressure wave is maximum at this point and is more easily detectable by the transducer. It is for this reason that a simple way to predict the threshold point is desirable.

The threshold differential pressure can be obtained by equating expressions (1) and (2)

$$f_e = f_1 \tag{A-1}$$

$$0.446 \frac{u}{h} = \frac{[\gamma RT]^{1/2}}{K} . \tag{A-2}$$

The velocity u may be obtained using incompressible flow theory, assuming a low pressure drop across the oscillator, as follows.

$$Q_i = A_1 \, [2(p_i - p_c)/\rho_i]^{1/2} \tag{A-3}$$

$$Q_e = A_e \, [2(p_c - p_e)/\rho_e]^{1/2} \tag{A-4}$$

where

$Q$ = is the volumetric flow

$A$ = is the area of the nozzle

$\rho$ = is the density of the gas

subscripts

$i$ = input

$c$ = cavity

$e$ = exit.

The average cavity pressure, $p_c$, may be obtained by equating (A-3) and (A-4) since $Q_i = Q_e$ for incompressible flow. Also for this case $\rho_i = \rho_e$. Then

$$A_i \, (p_i - p_c)^{1/2} = A_e \, (p_c - p_e)^{1/2} \tag{A-5}$$

or rearranging

$$p_c = \frac{a^2 p_i + p_e}{a^2 + 1} \qquad \text{(A-6)}$$

where

$$a = A_i / A_e$$

From equation (A-3) we obtain

$$u = \frac{Q_i}{A_i} = \left[\frac{2 (p_i - p_c)}{\rho_i}\right]^{1/2} \qquad \text{(A-7)}$$

or, substituting equation (A-6) into (A-7)

$$u = \left[\frac{2 (p_i - p_e)}{\rho (1 + a^2)}\right]^{1/2} \qquad \text{(A-8)}$$

where the subscript i has been dropped from $\rho$.

Substituting the value of u from equation (A-8) into equation (A-2) and rearranging yields

$$\Delta p_t = \frac{\gamma RT \rho h^2 (1 + a^2)}{0.4343 K^2} \qquad \text{(A-9)}$$

where

$$\Delta p_t = p_i - p_e .$$

Substituting into equation (A-5) the average density $\rho$ by $\bar{p}/RT$, where $\bar{p}$ is the average pressure between $p_i$ and $p_e$, yields

$$\Delta p_t = \frac{h^2 (1 + a^2) \gamma \bar{p}}{0.4343 K^2} . \qquad \text{(A-10)}$$

For the oscillator dimensions given in table II and using the value of $\gamma$ given in table I, the threshold differential pressure is 2.1 kN/M$^2$ (0.3 psig).

## Appendix B. Predictions of $\gamma$ and R for Gas Mixtures

The value of the ratio of the specific heat and ideal gas constant of the gas mixture may be obtained using the following equations

$$\gamma_m = \frac{c_{pm}}{c_{vm}} = \frac{\sum m_i c_{pi}}{\sum m_i c_{vi}} \tag{B-1}$$

$$R_m = \frac{\sum m_i R_i}{\sum m_i} \tag{B-2}$$

where

$c_p$ = specific heat at constant pressure

$c_v$ = specific heat at constant volume

$m$ = partial mass occupied by a specie in the total gas volume

subscript $i$ = component i

subscript $m$ = mixture

$\gamma$ = ratio of the specific heat

$R$ = ideal gas constant.

The partial mass $m_i$ occupied by a specie i in the total volume of the gas is its partial density

$$m_i = \frac{P_i}{z_i} \frac{1}{R_i T} \tag{B-3}$$

where $z_i$ is the compressibility factor of component i.

Substituting equation (B-3) into (B-1) and (B-2) and eliminating the temperature T yields

$$\gamma_m = \frac{\sum \left\{ \left( \frac{P_i}{z_i} \right) \left( \frac{c_{pi}}{K_i} \right) \right\}}{\sum \left\{ \left( \frac{P_i}{z_i} \right) \left( \frac{c_{vi}}{R_i} \right) \right\}} \tag{B-4}$$

and

$$R_m = \frac{\sum \left\{ \frac{P_i}{z_i} \right\}}{\sum \left\{ \left( \frac{P_i}{z_i} \right) \left( \frac{1}{R_i} \right) \right\}} \tag{B-5}$$

# Appendix C. Electronic System

## C.1 GENERAL DESCRIPTION

A block diagram of the system is given in figure C-1. A commercial pressure-sensitive transistor (Pi-Tran) is used as the pressure transducer and was selected mainly because of its low price. Biasing is provided for the transducer, and its output is ac-coupled to the amplifier and filtering. The ac coupling removes the large dc component produced by the large bias pressure that the mixed oscillator signal is riding on.

The preamplification and filtering provides a maximum gain of 1670 which is controlled by the automatic gain control (AGC) voltage. Quadruple roll-off filtering is also provided so that the preamplifier has a maximum gain at 22.5 kHz and rolls off rapidly on either side of this frequency at a rate approaching 80 dB/decade. The base frequency of the flueric oscillators is about 30 kHz, and this really should be the frequency of maximum amplification. However, the operational amplifiers used in the preamplifier are also rolling off rapidly at 30 kHz, and design limitations resulted in the 22.5 kHz frequency. Nevertheless, at 30 kHz, the preamplifier output has only decreased about 10 percent. The preamplifier supplies the undetected-output jack on the rear and also supplies the signal to a half-wave rectifier.

The half-wave rectifier allows only positive portions of the undetected signal to be applied to the low-pass filter. Without this rectification, the filtering of the high-frequency signal with the low-pass filter would result in essentially a zero filter output. However, low-pass filtering of the rectified signal removes high-frequency components and results in the beat frequency of the original mixed signal. The low-pass filter allows passage of signals in the 0- to 3000-Hz range and provides for over 40-dB/decade roll-off at higher frequencies. The detected beat-frequency signal is applied to the detected-output jack and is also applied to the Schmitt trigger.

The Schmitt trigger changes state when its input exceeds about +2.5 V. When the threshold is exceeded, the AGC control voltage (produced by the AGC circuit) decreases in an exponential fashion (about 0.2-sec time constant) and acts to reduce the preamplifier gain so that the detected output exceeds the Schmitt-trigger threshold by a lesser amount. Because of the time constant and exponential decay of the AGC circuit, the Schmitt-trigger threshold is always exceeded by peaks of the detected signal. Hence, the Schmitt-trigger's square-wave output consists of pulses whose frequency of occurrence is the same as that of the detected-signal peaks. This square wave is applied to the square-wave output jack and also triggers the monostable multivibrator.

The monostable multivibrator produces a constant-width, constant-amplitude pulse. The amplitude of this pulse can be modified by the sensitivity adjustments (separate adjustment potentiometers are selected by the range switch), and the adjusted pulse is applied to the average-rate circuit. The average-rate circuit produces an output voltage that is proportional to the average rate of occurrence of the monostable-multivibrator pulses, the height of the monostable-multivibrator adjusted pulses and the setting of the zero-adjust (separate adjustment potentiometers are selected by the range switch) and/or oxygen-compensation-adjust controls. The average-rate-circuit output is applied to the rate output (for recording on a strip-chart recorder or an instrumentation tape recorder) and also to the meter-protection circuit.

The meter-protection circuit begins to operate if an input to the meter-protection circuit drives the meter above a full-scale deflection or below zero. Such conditions, which may result if the zero-adjust controls are improperly set, the oxygen compensation is changed, or the flueric oscillators change their frequency characteristics (as might occur if

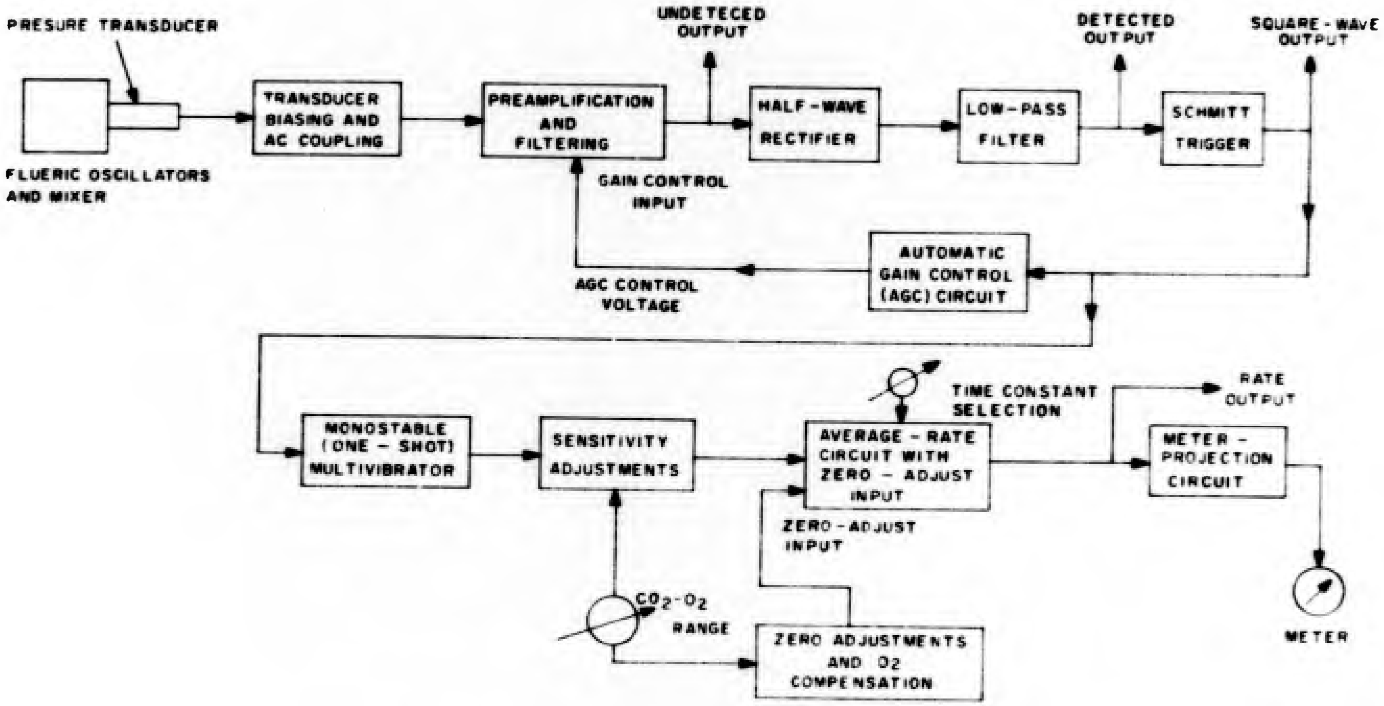


Figure C-1. Block Diagram of the Electronic Circuitry.

moisture is taken-in), might damage the meter as its pointer goes off scale. Hence, the protection circuit prevents the pointer from touching the stop when a large, negative-going, rate-circuit output attempts to drive the meter pointer below zero. Also, the meter pointer will just touch the stop and rest there when a large, positive, rate-circuit output is produced. Hence, the meter gives an indication proportional to the beat frequency of the flueric oscillators when this frequency is within the range of the meter; otherwise, the meter indicates above full-scale or below zero.

## C.2 CIRCUIT DIAGRAMS

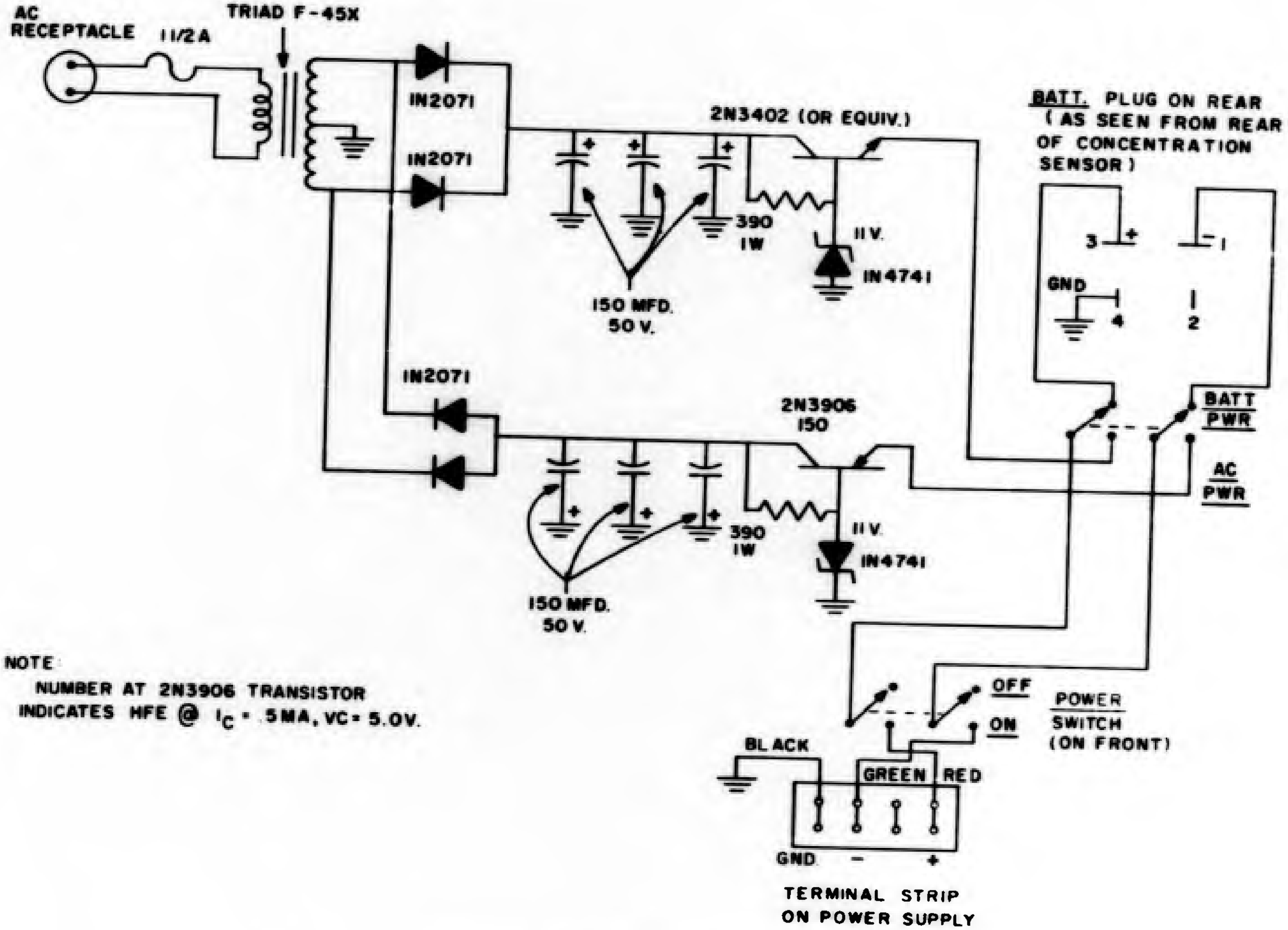
The power supply schematic is shown in figure C-2. Whenever the ac line cord is plugged-in and attached, the power supply is on and produces +10.5 and -10.3 V (about 5-mV ripple). However, these voltages are not applied to the system electronics unless the switch on the power supply rear is turned to AC PWR and the power switch on the front of the system is turned ON. If battery operation is desired, the switch on the rear should be set to BATT PWR, and a battery pack supplying ±10.5 V (no more than ±12 V and no less than ±9.0 V) should be attached by means of the appropriate pins to the battery plug on the rear. The power switch on the front still controls the distribution of power to the system electronics. The ac power supply consists of two series regulator circuits, and, if the supply is inadvertently shorted to ground, either or both of the transistors used as regulators may be burned out.

Figure C-3 shows the preamplifier schematic, and the various circuits are labeled according to figure C-1. The transistor pressure transducer is shielded as shown. Biasing for the base circuit is provided by R3 and R4 through R5. Relatively fixed bias is supplied, incorporating R2 in the emitter circuit. However, R2 is shunted by C1 which essentially provides a short for the 30-kHz frequencies to be detected, thereby increasing the gain of the transducer. C2 provides ac coupling to the preamplification and filtering section.

The field effect transistor Q2 acts with R6 to produce a voltage-controlled attenuator. When the control voltage is over 4.0 V, little attenuation results. However, if the control voltage becomes zero, at least a 50:1 increase in attenuation results. C3 and R7 act to provide low-frequency roll-off of 20 dB/decade. The operational amplifier feedback circuit, made-up of C4, C5, R9, R10, and R11, acts to provide an initial high-frequency roll-off of 40 dB/decade. C8, R15 and C9, and R16 act to provide a 40-dB/decade low-frequency roll-off, and C14 acts with R24 to provide another 20 dB/decade of low-frequency roll-off. Hence, the preamplifier provides 80 dB/decade of low-frequency roll-off. Since R18, R19, R20, C10, and C11 initially provide an additional 40 dB/decade of high-frequency roll-off, the preamplifier incorporates a roll-off at high frequencies of 80 dB/decade. Each operational amplifier circuit provides a gain (at 22.5 kHz) of over 40 (first stage has more gain than the second stage), so that the total gain is about 1670, at 22.5 kHz. R8 and R17 will adjust the midband gain. Each operational amplifier power-supply input is decoupled from the power supply (by means of 100-Ω resistors and 100 μF capacitors) and incorporates a 470-Ω trim resistor to reduce individual amplifier dc offset.

Q3 and R25 form an emitter follower whose quiescent output voltage helps compensate for the forward voltage of D1, in the half-wave rectifier. R27 and C15 provide initial low-pass filtering and are followed by a low-pass filter (made-up of Q4, Q5, R28-R31, and C16-C18) which has a high-frequency roll-off approaching 40 dB/decade.

R32 and R33 can be varied to adjust the threshold of the Schmitt trigger (Q6-Q8; R32-R38, and D2), though R33 should be made no larger than the value shown. Q6 compensates for the $V_{BE}$ of Q7, and D2 helps set the inherent Schmitt-trigger threshold and provides low hysteresis.



NOTE:
NUMBER AT 2N3906 TRANSISTOR INDICATES HFE @ $I_C$ = .5MA, VC= 5.0V.

Figure C-2. Power Supply Schematic.

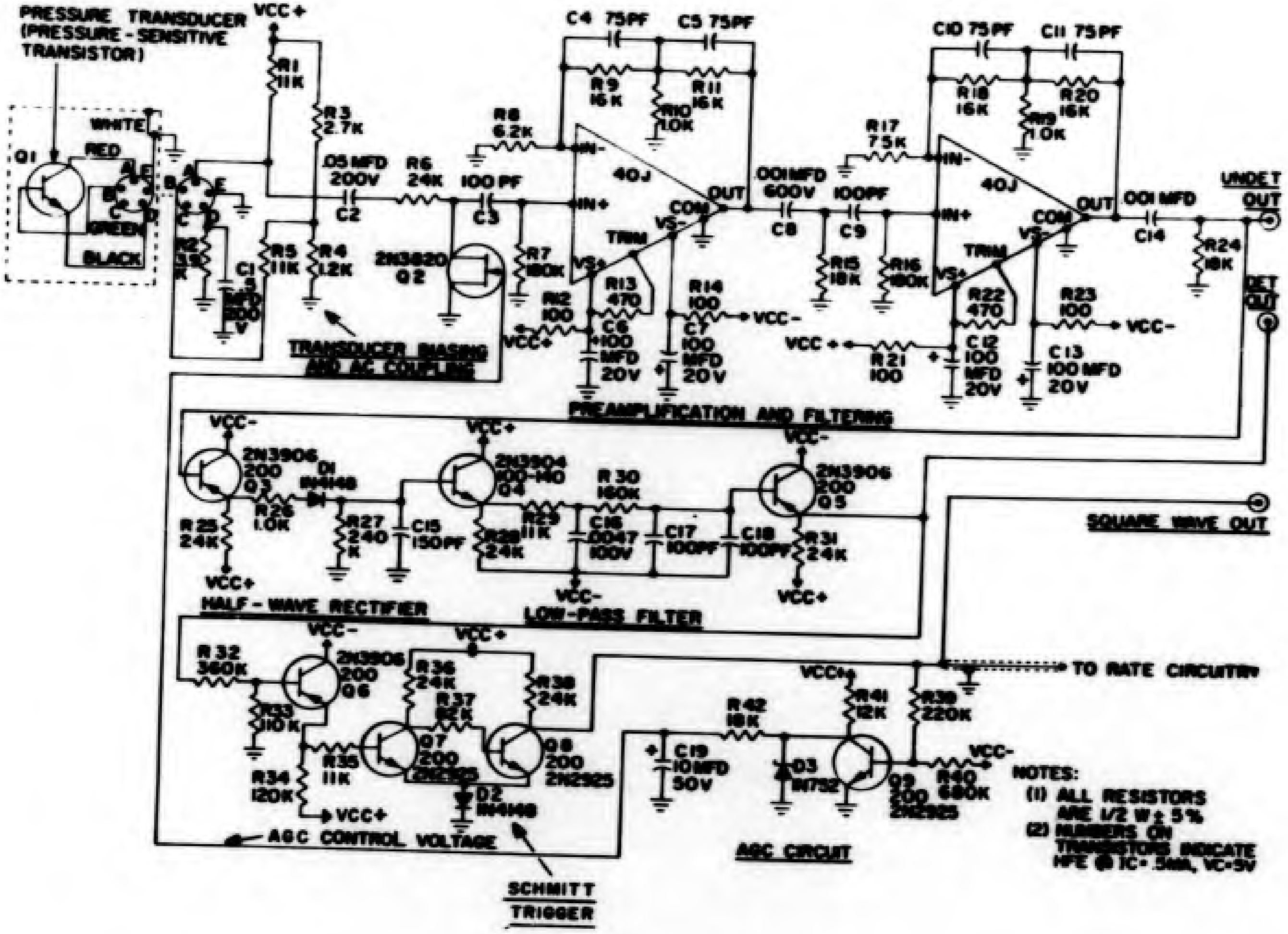


Figure C-3. Preamplifier Schematic.

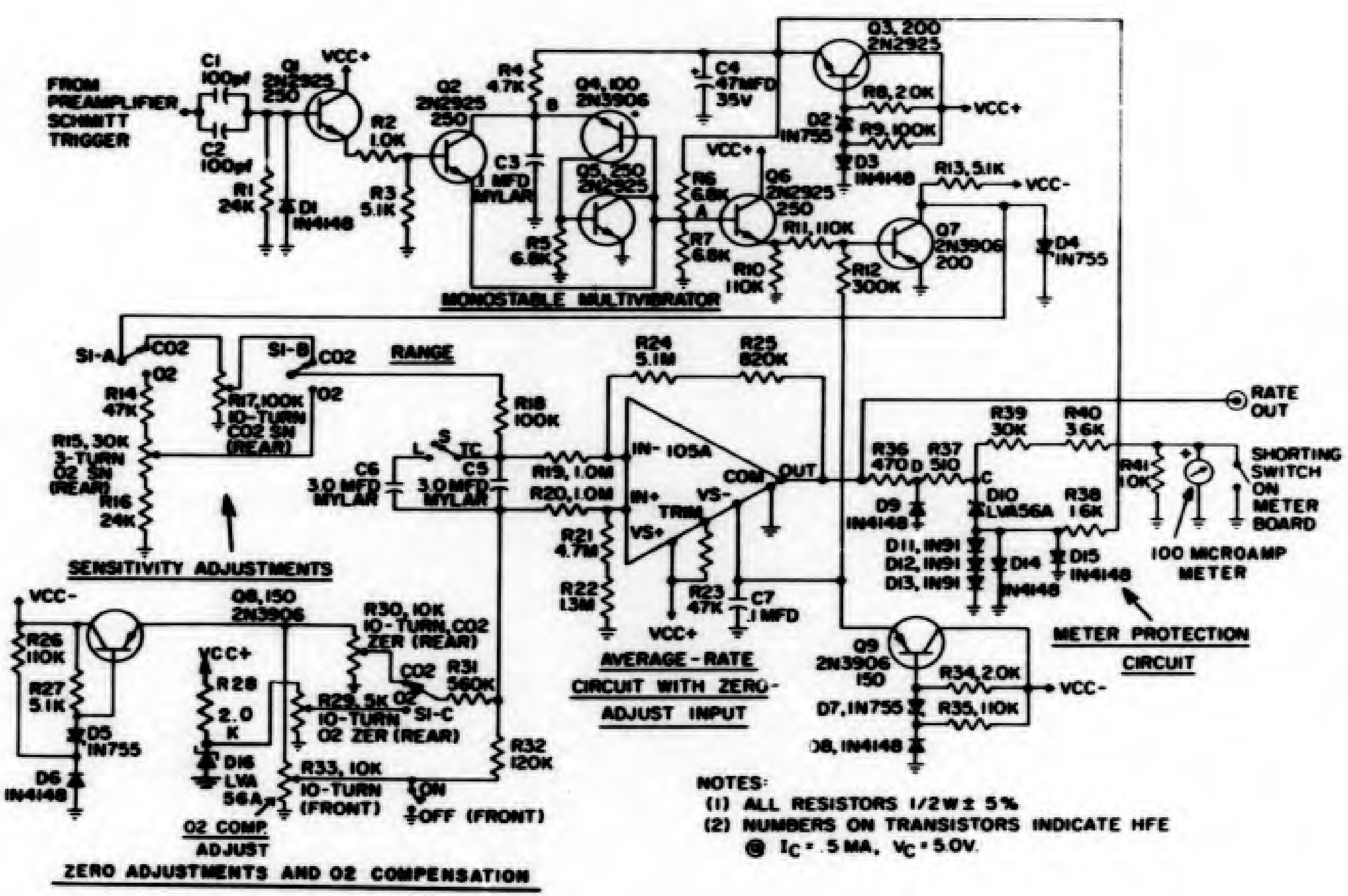
The collector of Q8 goes positive when the Schmitt-trigger threshold is exceeded, and this causes Q9 to saturate. C19 discharges through R42, and, when the voltage across C19 (AGC control voltage) becomes low enough (preamplifier gain decreases), the Schmitt-trigger input remains above the threshold for a shorter period of time, and Q9 remains unsaturated for a longer period of time. Hence, C19 can charge to a higher voltage (regulated by D3 and R41 for changes in the power supply voltage) thereby increasing the preamplifier gain. A point is reached at which the system eventually stabilizes, and the Schmitt trigger provides output pulses that trigger the rate circuitry.

Figure C-4 shows the rate circuitry where the various circuits are labeled according to the block diagram of figure C-1. Incoming pulses from the Schmitt trigger are differentiated by C1, C2, and R1 and are dc-restored by D1. Q1 and Q2 act to discharge C3 in a very short period of time, and when the voltage across C3 drops low enough, Q4 and Q5 are held off. When this occurs, the voltage at A rises to one half of the voltage supplied by the regulated supply in Q3 (to prevent power supply variations from affecting the monostable multivibrator pulse width). Since the differentiated pulse must turn-on Q1 and Q2, the pulse is attenuated by R1, and the 24-kΩ collector resistor at the Schmitt-trigger output. If the voltage at A is high, Q2 is held off, and further incoming pulses from the Schmitt trigger will not be effective while Q4 and Q5 are off. C3 charges with a time constant determined by R4 and C3, until the voltage at B is higher than the voltage at A by $V_{BE_{Q4}}$. Then, Q4 and Q5 regenerate, rapidly discharging C3, until the voltage at B is ($V_{BE_{Q4}} + V_{SAT_{Q5}}$). Q4 and Q5 remain on until another pulse from the Schmitt trigger starts the process over again. Hence, the circuit acts as a monostable multivibrator and provides a constant-width output pulse. Q6 reduces loading of following stages, and Q7 provides inversion of the pulse from Q6. D4 provides regulation and allows the monostable multivibrator to produce a constant-amplitude output pulse.

The pulse from Q7 is applied to the sensitivity adjustments which vary the attenuation of the monostable multivibrator pulse by means of R15 or R17 depending on the position of the range switch. The attenuated pulse is applied to one input of the average-rate circuit, which is mainly a differential amplifier. When the pulse is first applied, both amplifier inputs receive essentially equal signals as a result of C5 (and C6 if the TC switch is on L). Eventually, however, with a time constant dependent upon R18, C5 (and C6 if the TC switch is on L), and the resistances of the zero adjustments and oxygen-compensation circuit, the capacitor(s) charge-up to the average value of the incoming pulses. Since the incoming pulses are of fixed width and amplitude, their average value corresponds to their rate of occurrence. Hence, a potential difference develops between the two inputs to the differential amplifier, and this potential is amplified and appears at the average-rate-circuit output.

The dc level of the rate-circuit output can be varied by inputs from the zero adjustments (controlled by R29 or R30, depending on the position of the range switch) and the $O_2$ compensation (R33). The $CO_2$ zero adjustment and the $O_2$ compensation are supplied with a regulated voltage (Q8), and Q8 is temperature-compensated by D6 (in the same fashion as D3 compensates Q3 and D8 compensates Q9). The $O_2$ zero-adjust potentiometer (R29) is also supplied by a regulated voltage (produced by R28 and D16). The use of a positive voltage in the adjustment of the $O_2$ zero was necessary since the particular flueric oscillators used required it. If other flueric oscillators were used, a negative voltage (derived from the emitter of Q8) might have been supplied (through a 4.7-kΩ resistor) to R29, in place of the voltage supplied by R28 and D16. An improvement in the system would be the incorporation of a switch to make the change rapidly. The regulated voltages further increase the stability of the system with power supply variations. The negative power-supply input to the operational amplifier in the average-rate circuit is also regulated to further increase stability.

The output of the average-rate circuit is supplied to the rate output and also to the meter-protection circuit. D10 acts with D11-D15 (forward-biased by R38 and the regulated supply of



NOTES:
(1) ALL RESISTORS 1/2W ± 5%
(2) NUMBERS ON TRANSISTORS INDICATE HFE @ $I_C$ = .5 MA, $V_C$ = 5.0V.

Figure C-4. Rate Circuitry Schematic.

Q3) to limit the voltage at C to about +6.0 V. R40, R39, and R41 limit the current in the meter to a little above a full-scale deflection when the voltage at C is about 6.0 V. R41 provides a low-impedance path across the meter to stabilize the meter movements. When the average-rate-circuit output goes to zero, D10 is almost forward-biased by D11-D15, so that a small negative average-rate-circuit output is limited by D10. However, if the rate-circuit output went too far negative, the current in D10 would oppose the bias current of D11-D15. Hence, R36 and D9 limit the voltage at D to about -0.7 V. At this voltage, the bias current in D11-D15 is not exceeded. Hence, the meter is protected against large negative and positive voltages.

## C.3 LABORATORY DATA

### C.3.1 Preamplifier and Filter

Characteristics of the preamplification and filtering circuit were measured by providing appropriate inputs and monitoring the undetected outputs. The characteristics were as follows:

Gain: 1670 at 22.5 kHz
(2.4-mV p-p input gives 4.0-V p-p output at 22.5 kHz)
Noise Output: 0.07-V p-p with no input at 10.5-V power supply voltages
Frequency Response: Figure C-5
Temperature Characteristics: In breadboard form, the preamplifier worked well at temperatures from 0° to +130°F.

### C.3.2 Halfwave Rectifier and Low-Pass Filter

The detected output of the halfwave rectifier and low-pass filter was measured with no preamplifier input, with a 50-mV p-p mixed sinewave preamplifier input of 30-kHz base frequency and 500-Hz beat frequency at various power supply voltages and with a mixed signal input of 30-kHz base frequency to various beat frequencies.

Results were as follows:

Input: noise

| Power Supply (V) | Detected Output (V) |
|---|---|
| +10.5, -10.5 | 0.5 |
| +12, -12 | 0.5 |
| + 8, -12 | 0.4 |
| + 8, - 8 | 0.45 |
| +12, - 8 | 0.6 |
| + 9, - 9 | 0.45 |

Input: 50-mV p-p mixed sinewave, 30-kHz base frequency, 500-Hz beat frequency

| Power Supply (V) | Peak Detected Output (V) |
|---|---|
| +12, -12 | 4.0 |
| + 9, -12 (below +9 V, clipping starts) | 4.0 |
| + 9, - 8 | 4.0 |
| + 8.5, - 8 (no clipping) | 3.98 |
| +12, - 8 | 4.0 |

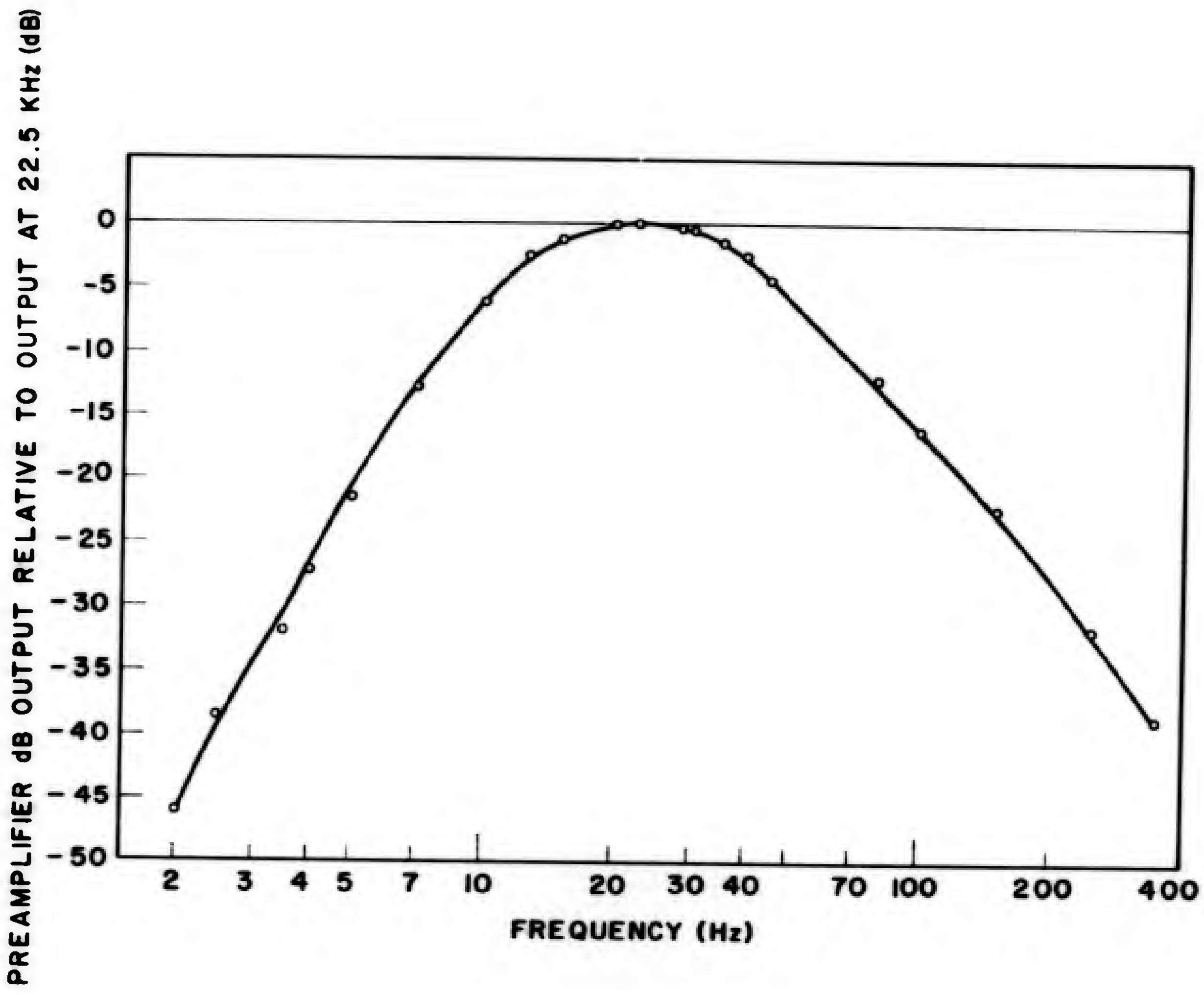


Figure C-5. Frequency Respose of the Preamplifier.

Input: Mixed signal. 30 kHz base frequency, AGC not operating since input signal was too low.

| Beat Frequency (Hz) | Peak Detected Output (V) |
|---|---|
| 100 | 2.0 |
| 200 | 2.0 |
| 500 | 2.0 |
| 1,000 | 1.95 |
| 2,000 | 1.85 |
| 3,330 | 1.70 |
| 7,500 | 1.414 |
| 10,000 | 1.4 (about 0.18 V of signal due to dc level) |

### C.3.3 Schmitt Trigger

The mixed preamplifier input was varied, and the detected output that just caused the beginning of Schmitt triggering was noted.

| Power Supply (V) | Peak Detected Output Triggering Schmitt (V) |
|---|---|
| +12, - 12 | 2.5 |
| + 8, - 12 | 2.5 |
| +12, - 8 | 2.5 |
| +10.5, - 10.5 | 2.5 |
| + 9, - 9 | 2.5 |
| + 8, - 8 | 2.5 |

### C.3.4 Average-Rate Circuit

A mixed-signal preamplifier input of above 10 mV p-p was applied, and the detected output frequency was measured by a counter. As the beat frequency of the preamplifier input was varied, the system electronics' meter indication was compared with the counter indication (taken as the actual frequency) at various settings of sensitivity, oxygen compensation, and $CO_2$-$O_2$ range. All of the data was taken while operating from the ac power supply, and the results are given below.

#### C.3.4.1 Carbon Dioxide Section

0-500 Hz Sensitivity

| Actual Frequency (Hz) | Indicated Frequency (Hz) |
|---|---|
| 500 | 500 |
| 0 | 0 |
| 448 | 449 |
| 393 | 394 |
| 347 | 348 |

| Actual Frequency (Hz) | Indicated Frequency (Hz) |
|---|---|
| 301 | 301 |
| 250 | 252 |
| 198 | 199 |
| 149 | 149.5 |
| 100 | 100 |
| 50 | 50 |

$O_2$ compensation set at 195.5; 500 Hz equals essentially zero on the meter

| | |
|---|---|
| 500 | 500 |
| 1000 | 999 |
| 950 | 949 |
| 901 | 900 |
| 851 | 850 |
| 800 | 800 |
| 751 | 751 |
| 701 | 701 |
| 651 | 650 |
| 602 | 600 |

$O_2$ compensation set at 391.5

| | |
|---|---|
| 1000 | 1000 |
| 1499 | 1496 |
| 1452 | 1450 |
| 1403 | 1400 |
| 1353 | 1354 |
| 1302 | 1300 |
| 1251 | 1249 |
| 1202 | 1200 |
| 1150 | 1148 |
| 1102 | 1099 |

$O_2$ compensation set at 586

| | |
|---|---|
| 1500 | 1501 |
| 1999 | 1998 |
| 1951 | 1950 |
| 1900 | 1899 |
| 1851 | 1850 |
| 1798 | 1798 |
| 1749 | 1749 |
| 1700 | 1700 |
| 1651 | 1649 |
| 1599 | 1597 |

$O_2$ compensation set at 778

| Actual Frequency (Hz) | Indicated Frequency (Hz) |
|---|---|
| 2000 | 2002 |
| 2500 | 2501 |
| 2450 | 2450 |
| 2399 | 2399 |
| 2350 | 2350 |
| 2300 | 2301 |
| 2247 | 2249 |
| 2200 | 2201.5 |
| 2148 | 2150 |
| 2099 | 2101 |

0-450 Hz Sensitivity

| | |
|---|---|
| 450 | 452 |
| 404 | 406 |
| 359 | 360 |
| 314 | 315.5 |
| 268 | 270 |
| 223.5 | 225 |
| 178 | 179.5 |
| 134 | 135 |
| 91 | 90 |

$O_2$ compensation set at 194.5

| | |
|---|---|
| 450 | 451 |
| 901 | 901 |
| 853 | 855 |
| 809 | 810 |
| 764 | 765 |
| 719 | 720 |
| 673 | 675 |
| 628 | 630 |
| 584 | 585 |
| 540 | 540 |

$O_2$ compensation set at 390

| | |
|---|---|
| 900 | 901 |
| 1349 | 1350 |
| 1303.5 | 1305 |
| 1259 | 1260 |
| 1214 | 1215 |
| 1168.5 | 1170 |
| 1123 | 1125 |
| 1079 | 1080 |
| 1035.5 | 1036 |
| 990 | 990 |

$O_2$ compensation set at 587

| Actual Frequency (Hz) | Indicated Frequency (Hz) |
|---|---|
| 1350 | 1351 |
| 1800 | 1798 |
| 1755 | 1753 |
| 1711 | 1709 |
| 1666 | 1664 |
| 1620 | 1618.5 |
| 1577 | 1575 |
| 1531 | 1529 |
| 1488 | 1485 |
| 1443 | 1440 |

$O_2$ compensation set at 781

| | |
|---|---|
| 1800 | 1801 |
| 2250 | 2248 |
| 2205 | 2203 |
| 2160 | 2158 |
| 2117 | 2115 |
| 2071 | 2070 |
| 2026 | 2025 |
| 1981.5 | 1980 |
| 1935 | 1934 |
| 1892 | 1890 |

$O_2$ compensation set at 973

| | |
|---|---|
| 2250 | 2251 |
| 2430 | 2426 |
| 2385 | 2382 |
| 2340 | 2338 |

0-650 Hz Sensitivity

| | |
|---|---|
| 650 | 651 |
| 584 | 585 |
| 519 | 519 |
| 456 | 455 |
| 391 | 391 |
| 324 | 325 |
| 260 | 260 |
| 196 | 195 |
| 132 | 130 |

$O_2$ compensation set at 196

| Actual Frequency (Hz) | Indicated Frequency (Hz) |
|---|---|
| 650 | 651 |
| 1300 | 1302 |
| 1231 | 1235 |
| 1167 | 1170 |
| 1101 | 1100 |
| 1039 | 1041 |
| 971 | 975.5 |
| 907 | 910 |
| 842 | 845 |
| 780 | 785 |

$O_2$ compensation set at 396

| | |
|---|---|
| 1950 | 1950 |
| 1884 | 1885 |
| 1819 | 1820 |
| 1755 | 1755 |
| 1688 | 1689 |
| 1624 | 1625 |
| 1560 | 1560 |
| 1496 | 1495 |
| 1432 | 1430 |

$O_2$ compensation set at 594

| | |
|---|---|
| 1950 | 1951 |
| 2470 | 2469 |
| 2407 | 2404.5 |
| 2341 | 2340 |
| 2274 | 2275 |
| 2210 | 2210 |
| 2146 | 2145 |
| 2081 | 2079.5 |

### C.3.4.2 Oxygen Section

**0-1000 Hz Sensitivity**

| | |
|---|---|
| 1000 | 1000 |
| 900.5 | 900 |
| 800 | 802 |
| 700 | 699 |
| 599 | 599 |
| 499 | 499.5 |
| 400 | 399 |
| 303 | 300 |
| 205 | 200 |
| 107 | 100 |

0-1400 Hz Sensitivity

| Actual Frequency (Hz) | Indicated Frequency (Hz) |
|---|---|
| 1400 | 1400 |
| 1259 | 1260 |
| 1121 | 1120.5 |
| 981 | 980 |
| 839 | 840 |
| 700 | 701 |
| 561 | 560.5 |
| 421 | 419.5 |
| 282 | 280 |
| 144 | 139 |

0-1700 Hz Sensitivity

| | |
|---|---|
| 1700 | 1700 |
| 1529 | 1530 |
| 1362 | 1360 |
| 1193 | 1190 |
| 1021 | 1020 |
| 852 | 851 |
| 681 | 680 |
| 513.5 | 510 |
| 346 | 340 |
| 181 | 170 |

### C.3.5 Current Drain of the Electronics

Positive Supply: 28 mA at +10.8 V.
Negative Supply: 22 mA at -10.8 V.

# Appendix D. Gas Mixing Apparatus

## D.1 DESCRIPTION

Preliminary testing and laboratory calibration of the concentration monitor requires a source of a low-pressure mixture of oxygen, nitrogen, and carbon dioxide. The partial pressure (or concentration) of each gas in the mixture must be accurately known. Buying calibrated gas mixtures was considered impractical, because of the number and quantity of gas mixtures required to conduct the necessary tests. The alternative chosen was a gas mixing apparatus capable of manufacturing any gas mixture in the desired range from a supply of the three individual gases.

A schematic drawing of the gas mixing system is shown in figure D-1. The gases are supplied to the system through three supply ports (S2, S2, S3). They are filtered (F1, F2, F3), and their temperatures are equalized to ambient temperature in coils C1, C2, and C3. At this point, the pressure of each gas is regulated by three pneumatic regulators (R1, R2, R3); the flow is controlled by needle valves (V1, V2, V3) and is measured by three linear gas flowmeters (FM1, FM2, FM3). The flow indication is given by manometers (M1, M2, M3). After the flowmeter the oxygen and nitrogen flows are mixed together and pass through coil C4 which has sufficient length to allow perfect mixing. After coil C4 the oxygen-nitrogen mixture is divided into two streams. The stream flowing through flowmeter FM4 is mixed with the flow of carbon dioxide coming from flowmeter FM1. The gases are allowed to mix properly in coil C5, and the mixture of nitrogen, oxygen, and carbon dioxide exhausts through the exhaust port E1. Valve V4 is a bleeding valve that controls the flow through E1.

The second stream of the oxygen-nitrogen mixture flows through flowmeter FM5. The only purpose of this flowmeter is to balance both flow circuitries. The purpose of valve V5 is similar to that of valve V4. If valves V4 and V5 are closed, the flow through E1 and E2 will be closely balanced, and only a very small adjustment of valve V4 may be needed to account for the extra carbon dioxide flow introduced after FM4. The exhaust port E2 is a mixture of oxygen and nitrogen with the same ratio of oxygen and nitrogen as is contained in the ternary mixture flowing through E1. If port E1 is closed, valve V5 could be used to increase the mixing range between the oxygen-nitrogen mixture and the carbon dioxide.

## D.2 CALIBRATION OF THE LINEAR FLOWMETERS

The linear gas flowmeters were purchased uncalibrated and were calibrated using a positive displacement deadweight calibrator. The flowmeters are installed in the system to be used to exhaust to pressures close to ambient pressures. In this case, the equation relating the output flow of the meters to the differential pressures across the taps is

$$\Delta P = b \mu Q \tag{D-1}$$

where

$\Delta P$ = is the differential pressure across the flowmeter taps

$b$ = is the flowmeter constant

$\mu$ = is the viscosity of the gas

$Q$ = is the output volumetric flow

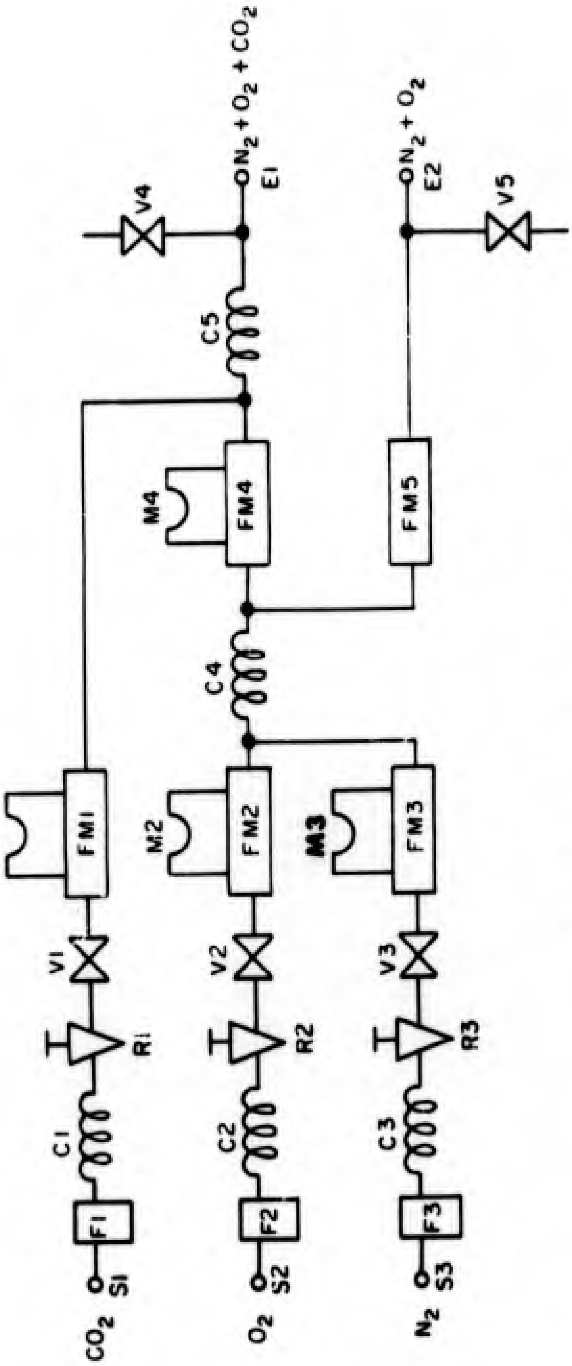


Figure D-1. Gas Mixing System Schematic.

The flowmeters were calibrated using bottled air. The temperature of the gas was carefully measured to determine the viscosity[1] of the air. The calibration accuracy is estimated to be 1/2 percent of the flow at any point where the manometer indication can be read to 1/2 percent or better. The results of the calibration are given in table (D-1). All the flowmeters used in the system have a maximum nominal differential pressure of 10 in. of water.

Table D-I. Calibration of Flowmeters

| Symbol in Figure D-1 | Manufacturer Serial No. | Maximum Nominal Flow-LPM | Gas | Flowmeter Constant b |
|---|---|---|---|---|
| FM 1 | 5302 | 0.1 | $CO_2$ | 0.536 |
| FM 2 | 5303 | 1.0 | $O_2$ | 0.0528 |
| FM 3 | 5304 | 1.0 | $N_2$ | 0.0561 |
| FM 4 | 5305 | 1.0 | $N_2 + O_2$ | 0.0559 |

## D.3 DETERMINATION OF THE VISCOSITY OF OXYGEN-NITROGEN MIXTURES

The gas flowing through FM4 is a mixture of oxygen and nitrogen. The viscosity of a gas mixture may be obtained from known equations[2] or measured using the laminar flowmeters already calibrated.

Flowmeters FM2 and FM3 were connected in parallel exhausting to FM4. FM2 was connected to an oxygen source, and FM3, to nitrogen. FM4 was passing the mixture of oxygen and nitrogen supplied by the other two units. Since all the flowmeter constants (b) were already determined, the flow and composition of the gas flowing through FM4 was known, and from equation (D-1) the viscosity of the gas mixture could be determined. The resulting viscosity curve is given in figure D-2.

## D.4 DETERMINATION OF THE OXYGEN AND CARBON DIOXIDE CONCENTRATIONS

The oxygen concentration may be directly determined from the ratio of the oxygen and nitrogen manometers. Equations (D-2) and (D-3) describe the relation between the flow and manometer differential pressures for the oxygen and nitrogen network

$$\Delta P_{O_2} = b_{O_2} \mu_{O_2} Q_{O_2} \tag{D-2}$$

$$\Delta P_{N_2} = b_{N_2} \mu_{N_2} Q_{N_2} \tag{D-3}$$

Dividing equation (D-2) by equation (D-3) and rearranging yields

$$\frac{Q_{O_2}}{Q_n} = \frac{b_{N_2} \mu_{N_2}}{b_{O_2} \mu_{O_2}} \frac{\Delta P_{O_2}}{\Delta P_{N_2}} . \tag{D-4}$$

---

[1] American Institute of Physics Handbook, McGraw Hill, 1957.

[2] Condon E., and H. Odishaw, Handbook of Physics, McGraw Hill, 1958.

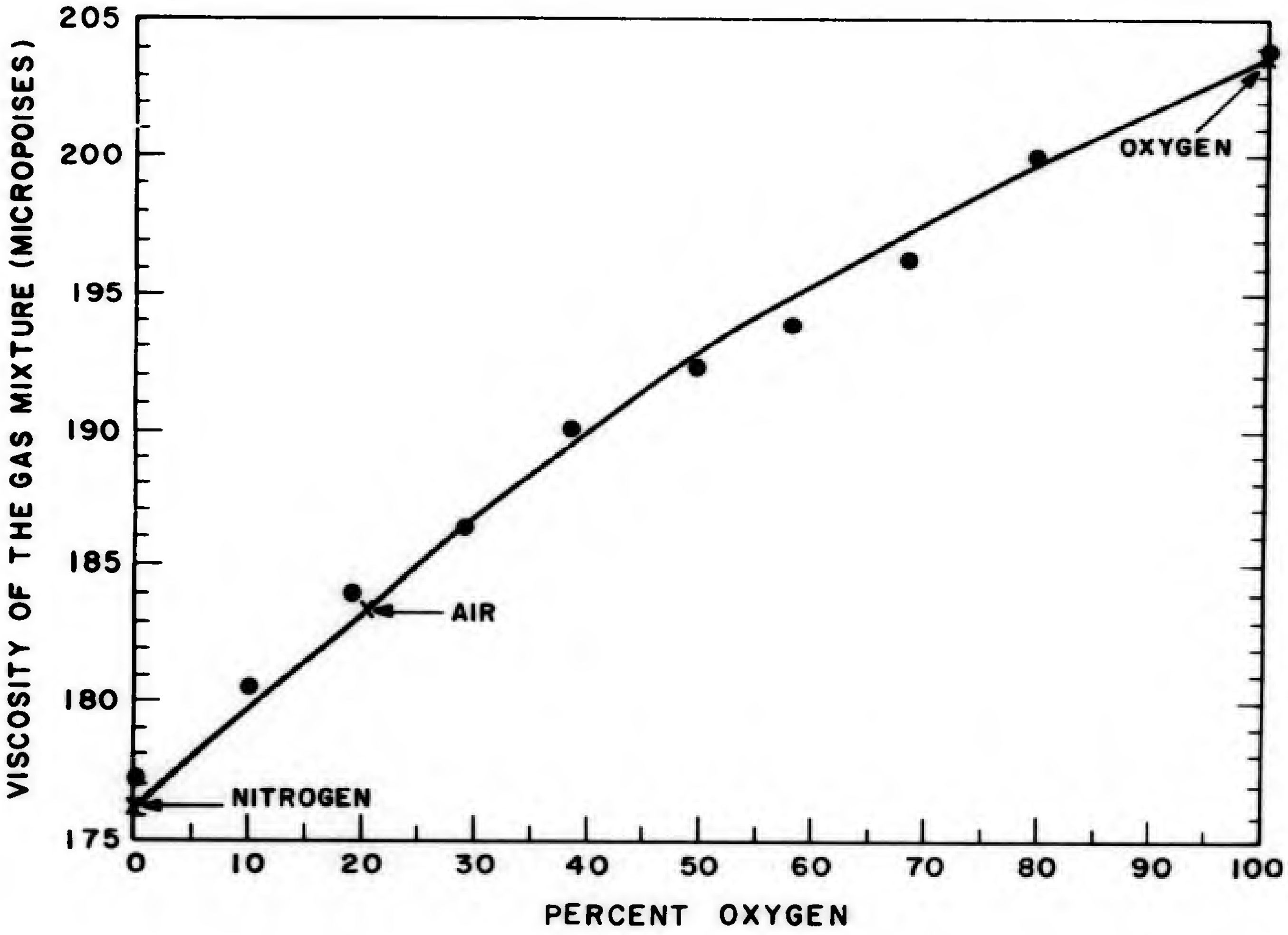


Figure D-2. Viscosity of Oxygen-Nitrogen Mixtures.

Substituting into equation (D-4) the value of the ratio of the viscosities (which remains practically constant over a wide range of temperatures) the flowmeter constants yield

$$\frac{Q_{O_2}}{Q_{N_2}} = 1.088 \frac{\Delta P_{N_2}}{\Delta P_{O_2}} . \qquad \text{(D-5)}$$

Substituting the ratio of the volumetric flows by the ratio of the gas concentrations and rearranging equation (D-5) yields

$$O_2\,\% = \frac{100}{1 + 1.088 \dfrac{\Delta P_{N_2}}{\Delta P_{O_2}}} . \qquad \text{(D-6)}$$

This equation is valid at 70°F ± 15°F.

Following a similar procedure, it is possible to obtain the carbon dioxide concentration from the indication of the manometers connected to the carbon dioxide flowmeter and oxygen-nitrogen flowmeter.

$$CO_2\,\% = \frac{100}{1 + \psi \dfrac{\Delta P_{N_2 + O_2}}{\Delta P_{CO_2}}} \qquad \text{(D-7)}$$

where $\psi$ is a parameter that depends on the oxygen concentration of the oxygen-nitrogen mixture flowing through FM4. The value of $\psi$ is given by

$$\psi = \frac{b_{CO_2}\, \mu_{CO_2}}{b_{N_2 + O_2}\, \mu_{N_2 + O_2}} . \qquad \text{(D-8)}$$

Since the ratio between the viscosity of oxygen and the viscosity of carbon dioxide and the viscosities of nitrogen and carbon dioxide, respectively, remains nearly constant over a wide range of temperature, it is reasonable to assume that the ratio of the viscosity of carbon dioxide and the viscosity of the oxygen-nitrogen mixture will also remain constant in the same range of temperature. The dashed line in figure D-3 was obtained by substituting into equation (D-8) the numerical values of the flowmeters' constants and the corresponding viscosities.

## D.5 VERIFICATION OF THE GAS MIXING APPARATUS USING A GAS ANALYZER

Part of the gas mixture made by the gas mixing apparatus was passed through a gas analyzer. Table (D-II) shows the data obtained from 20 to 100 percent oxygen. The agreement between the value measured by the gas mixing apparatus (GMA) and the gas analyzer is excellent. On the other hand, the carbon dioxide computed using the manometers' readings was about 3 percent too low with respect to the values measured with the gas analyzer. This is due to a series of approximations that may have accumulated a relatively large overall error. Also, the gas analyzer cannot measure the partial pressure of carbon dioxide to better

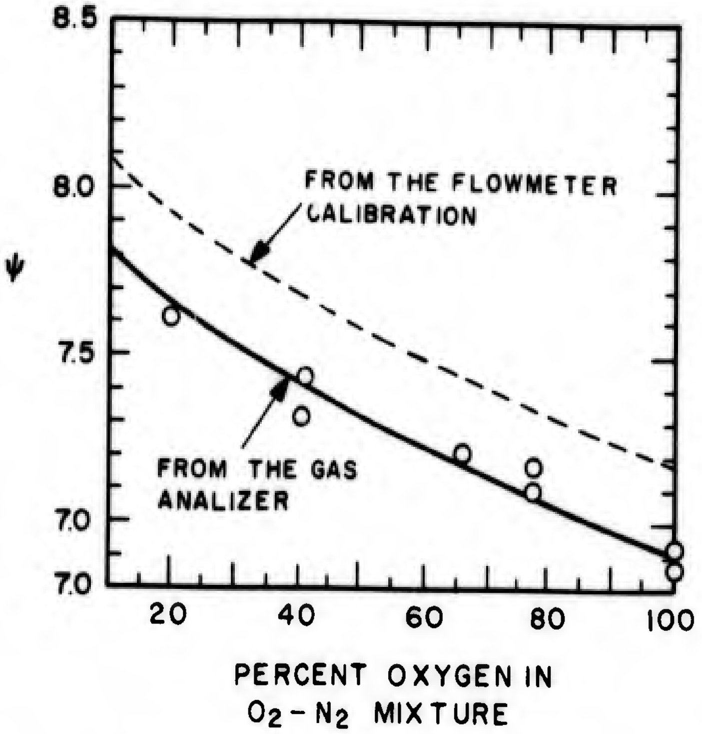


Figure D-3. Calibration Factor for Carbon Dioxide.

**Table D-II. Verification of the Predicted Oxygen Concentration.**

| $\Delta P_{N_2}$ | $\Delta P_{O_2}$ | % $O_2$ GMA | % $O_2$ Analyzer |
|---|---|---|---|
| 8.40 | 2.36 | 20.5 | 20.5 |
| 8.36 | 3.61 | 28.4 | 28.4 |
| 8.21 | 4.90 | 35.5 | 35.5 |
| 7.18 | 5.80 | 42.6 | 42.7 |
| 5.28 | 7.39 | 56.4 | 56.6 |
| 3.92 | 8.11 | 65.6 | 65.7 |
| 3.22 | 9.05 | 72.1 | 71.4 |
| 1.63 | 9.46 | 84.2 | 84.0 |
| 0 | 10.02 | 100.0 | 100.0 |

than 1 mm Hg. Nevertheless, the value of $\psi$ was computed backwards from the data obtained from the gas analyzer (fig. D-3). The resulting value of $\psi$ showed a small error in the negative direction. The curve computed using the flowmeter equation was moved about 2.5 percent, and the values of the carbon dioxide concentration computed using the manometers' readings agree now to better than 1/2 percent with the $CO_2$ concentration measured using the gas analyzer.

## Appendix E. Computerized Analysis

The theoretical performance of the monitor was determined using a digital computer. The predicted results are based on the assumption that the non-linearity of the system is only due to the flueric sensor. The computer program listing and the theoretical prediction for RQ = 0.85, 1.00, 1.10, and infinity (in the computer, $10^{20}$) are given in this appendix. A respiratory quotient of infinity represents the limiting case where no oxygen is consumed while carbon dioxide is added to the gas mixture.

Table E-I gives the carbon dioxide scale reading for different inhaled oxygen concentrations and real percentages of carbon dioxide exhaled for RQ = 0.85. The scale has been set to read exactly 7.0 for a carbon dioxide concentration of 7.0 percent when the inhaled gas is air (approximately 21 percent oxygen). The numbers in parentheses next to the oxygen percentage represent the percent oxygen in argon-free mixtures (made directly from nitrogen and oxygen). The table shows that the linearity of the scale is good in the range 0 to 10 percent carbon dioxide and that the scale indication will decrease as the concentration of oxygen inhaled increases. Table E-II gives the ratio of the scale indication when the inhaled mixture is air to that for any other oxygen concentration. Table E-II shows that this scale correction factor is quite independent of the carbon dioxide concentration.

Tables E-III through E-VIII are similar to table E-I and E-II for other respiratory quotients (1.0, 1.1, and $10^{20}$).

Tables E-IX, E-X, E-XI, and E-XII give the frequency response (beat frequency) of the sensor as a function of the inhaled oxygen concentration, carbon dioxide concentration, and RQ. The tables show that the effect of RQ decreases when the inhaled oxygen concentration increases. If the scale is set for an RQ = 1.0, the correction due to the variation of RQ in the normal physiological range will be less than four percent of the scale reading and can be ignored within the accuracy of the system.

Table E-XIII gives the oxygen scale reading and the scale correction versus oxygen concentration (in the presence of argon). Table E-XIV gives the theoretical frequency response versus the oxygen concentration in the presence of argon.

```
          ACCOM          -  EFN   SOURCE STATEMENT  -  IFN(S)  -

      COMMON CPRN,CPRO,CPRCO,CVRN,CVRO,CVRCO,RN,RO,RCO,SGR
      COMMON CPRHO,CVRHO,RHO,PHO,ZN,ZO,ZCO,ZHO
      DIMENSION PCR(10),PNR(10),PCOS(11),PNS(10,11),DF1(10,11)
      DIMENSION PCS(10,11),FR(10),FS(10,11),DF(10,11),F1(10,11)
      DIMENSION F2(10,11),DFC(10),DFC1(10),F3(10),O2(10),C(10)
      NAMELIST/DATA/CPRN,CPRO,CPRCO,CVRN,CVRO,CVRCO,RN,RO,RCO,
     1CPRHO,CVRHO,RHO,PHO,ZN,ZO,ZCO,ZHO,RG,G1,JJ,T,C2I,O2F
    2 IF(JJ.EQ.10) GO TO 777
      READ(5,DATA)
      O2(1)=21.
      PCR(1)=22.
      PNR(1)=78.
      DO 10 I=2,9
      II=10*(I+1)
      O2(I)=FLOAT(II)
      PCR(I)=0.98734*O2(I)+1.26582
   10 PNR(I)=100.-PCR(I)
      DO 20 I=1,10
   20 PCOS(I)=FLOAT(I)
      DO 30 I=1,9
      DO 40 K=1,10
      B=(100.-PCOS(K)*(1.-1./RG)./100.
      PNS(I,K)=PNR(I)*B
   40 PCS(I,K)=(PCR(I)-PCOS(K)/RG)*B
   30 CONTINUE
      DO 41 I=1,9
      X=0.
      Y=PCR(I)
      Z=PNR(I)
      CALL SRGR(X,Y,Z)
   41 FR(I)=SGR
      DO 60 I=1,9
      DO 80 K=1,10
      X=PCOS(K)
      Y=PCS(I,K)
      Z=PNS(I,K)
      CALL SRGR(X,Y,Z)
   80 FS(I,K)=SGR
   60 CONTINUE
      DO 90 I=1,9
      DO 110 K=1,10
      DF(I,K)=FR(I)-FS(I,K)
  110 DF1(I,K)=SQRT(T)*DF(I,K)/G1
   90 CONTINUE
      DO 120 I=1,9
      DO 130 K=1,10
      F1(I,K)=7.0*DF(I,K)/DF(1,7)
  130 F2(I,K)=F1(1,K)/F1(I,K)
      IF(JJ.EQ.1) GO TO 120
      DFC(I)=(FR(I)-FR(1))/(FR(9)-FR(1))
      DFC1(I)=SQRT(T)*(FR(1)-FR(I))/G1
      F3(I)=C2I+(C2F-C2I)*DFC(I)
      C(I)=O2(I)-F3(I)
  120 CONTINUE
      WRITE(6,500)
```

```
          ACCCM       -  EFN   SOURCE STATEMENT  -  IFN(S)  -
 500 FORMAT(1H1,36X33HARMY CO2/O2 CONCENTRATION MONITOR//)
     WRITE(6,510) RO
 510 FORMAT(35X27HCARBON DIOXIDE SCALE ( RO =,E10.3,1H)///)
     WRITE(6,520)
 520 FORMAT(7HPERCENT,32X22HPERCENT CARBON DIOXIDE)
     WRITE(6,530)
 530 FORMAT(1X6HOXYGEN,14X1H1,7X1H2,7X1H3,7X1H4,7X1H5,
    17X1H6,7X1H7,7X1H8,7X1H9,6X2H10//)
     DO 140 I=1,9
 140 WRITE(6,541) O2(I),PCR(I),(F1(I,K),K=1,10)
 541 FORMAT(F7.1,1X1H(,F5.1,1H),10F8.3//)
     WRITE(6,500)
     WRITE(6,550) RO
 550 FORMAT(26X46HCORRECTION FOR THE CARBON DIOXIDE SCALE ( RO =,
    1E10.3,1H)///)
     WRITE(6,520)
     WRITE(6,530)
     DO 150 I=1,9
 150 WRITE(6,541) O2(I),PCR(I),(F2(I,K),K=1,10)
     WRITE(6,500)
     WRITE(6,511) RO
 511 FORMAT(32X40HCARBON DIOXIDE FREQUENCY RESPONSE ( RO =,
    1E10.3,1H)///)
     WRITE(6,520)
     WRITE(6,530)
     DO 160 I=1,9
 160 WRITE(6,531) O2(I),PCR(I),(DF1(I,K),K=1,10)
 531 FORMAT(F7.1,1X1H(,F5.1,1H),10F8.1//)
     IF(JJ.EQ.1) GO TO 2
     WRITE(6,500)
     WRITE(6,560)
 560 FORMAT(44X12HOXYGEN SCALE///)
     WRITE(6,570)
 570 FORMAT(37X7HPERCENT,5X5HSCALE,5X5HSCALE)
     WRITE(6,580)
 580 FORMAT(38X6HOXYGEN,3X7HREADING,5X5HCORR.//)
     DO 170 I=1,9
 170 WRITE(6,590) O2(I),F3(I),C(I)
 590 FORMAT(37X,F7.1,2F10.1//)
     WRITE(6,500)
     WRITE(6,600)
 600 FORMAT(38X25HOXYGEN FREQUENCY RESPONSE///)
     WRITE(6,610)
 610 FORMAT(40X7HPERCENT,3X9HFREQUENCY)
     WRITE(6,620)
 620 FORMAT(41X6HOXYGEN,10X2HHZ//)
     DO 210 I=1,9
 210 WRITE(6,630) O2(I),DFO1(I)
 630 FORMAT(40X,F7.1,F12.1//)
     GO TO 2
 777 STOP
     END
```

```
     SRGR1       -  EFN   SOURCE STATEMENT  -  IFN(S)  -

 SUBROUTINE SRGR(PI,PJ,PK)
 COMMON CPRN,CPRO,CPRCO,CVRN,CVRO,CVRCO,RN,RO,RCO,SGR
 COMMON CPRHO,CVRHO,RHO,PHO,ZN,ZO,ZCO,ZHO
 GM1=PI*CPRCO/ZCO+PJ*CPRO/ZO+PK*CPRN/ZN+PHO*CPRHO/ZHO
 GM2=PI*CVRCO/ZCO+PJ*CVRO/ZO+PK*CVRN/ZN+PHO*CVRHO/ZHO
 GM=GM1/GM2
 RM1=PI/ZCO+PJ/ZO+PK/ZN+PHO/ZHO
 RM2=PI/RCO/ZCO+PJ/RO/ZO+PK/RN/ZN+PHO/RHO/ZHO
 RM=RM1/RM2
 SGR=SQRT(GM*RM)
 RETURN
 END
```

## Table E-I. Army $CO_2/O_2$ Concentration Monitor

### Carbon Dioxide Scale (RQ = 0.850E 00)

| PERCENT OXYGEN | PERCENT CARBON DIOXIDE 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 21.0 ( 22.0) | 1.022 | 2.036 | 3.042 | 4.042 | 5.035 | 6.021 | 7.000 | 7.973 | 8.940 | 9.900 |
| 30.0 ( 30.9) | 1.010 | 2.012 | 3.007 | 3.996 | 4.977 | 5.952 | 6.921 | 7.884 | 8.840 | 9.791 |
| 40.0 ( 40.8) | 0.997 | 1.986 | 2.969 | 3.945 | 4.915 | 5.878 | 6.836 | 7.787 | 8.732 | 9.672 |
| 50.0 ( 50.6) | 0.984 | 1.962 | 2.932 | 3.897 | 4.855 | 5.807 | 6.753 | 7.693 | 8.628 | 9.557 |
| 60.0 ( 60.5) | 0.972 | 1.937 | 2.897 | 3.849 | 4.796 | 5.737 | 6.672 | 7.601 | 8.526 | 9.444 |
| 70.0 ( 70.4) | 0.960 | 1.914 | 2.862 | 3.803 | 4.739 | 5.669 | 6.593 | 7.512 | 8.426 | 9.335 |
| 80.0 ( 80.3) | 0.949 | 1.891 | 2.828 | 3.758 | 4.683 | 5.603 | 6.517 | 7.426 | 8.330 | 9.229 |
| 90.0 ( 90.1) | 0.937 | 1.869 | 2.795 | 3.715 | 4.629 | 5.538 | 6.442 | 7.342 | 8.236 | 9.125 |
| 100.0 (100.0) | 0.927 | 1.847 | 2.762 | 3.672 | 4.576 | 5.476 | 6.370 | 7.259 | 8.144 | 9.024 |

Table E-II. Army $CO_2/O_2$ Concentration Monitor

Correction for the Carbon Dioxide Scale (RQ = 0.850E 00)

| PERCENT OXYGEN | PERCENT CARBON DIOXIDE<br>1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 21.0 ( 22.0) | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 30.0 ( 30.9) | 1.012 | 1.012 | 1.012 | 1.012 | 1.012 | 1.011 | 1.011 | 1.011 | 1.011 | 1.011 |
| 40.0 ( 40.8) | 1.025 | 1.025 | 1.025 | 1.024 | 1.024 | 1.024 | 1.024 | 1.024 | 1.024 | 1.024 |
| 50.0 ( 50.6) | 1.036 | 1.039 | 1.038 | 1.037 | 1.037 | 1.037 | 1.037 | 1.036 | 1.036 | 1.036 |
| 60.0 ( 60.5) | 1.051 | 1.051 | 1.050 | 1.050 | 1.050 | 1.049 | 1.049 | 1.049 | 1.049 | 1.048 |
| 70.0 ( 70.4) | 1.064 | 1.064 | 1.063 | 1.063 | 1.062 | 1.062 | 1.062 | 1.061 | 1.061 | 1.061 |
| 80.0 ( 80.3) | 1.077 | 1.076 | 1.076 | 1.075 | 1.075 | 1.075 | 1.074 | 1.074 | 1.073 | 1.073 |
| 90.0 ( 90.1) | 1.090 | 1.089 | 1.089 | 1.088 | 1.088 | 1.087 | 1.087 | 1.086 | 1.085 | 1.085 |
| 100.0 (100.0) | 1.103 | 1.102 | 1.101 | 1.101 | 1.100 | 1.100 | 1.099 | 1.098 | 1.098 | 1.097 |

## Table E-III. Army $CO_2/O_2$ Concentration Monitor

Carbon Dioxide Scale (RQ = 0.100E 01)

| PERCENT OXYGEN | | PERCENT CARBON DIOXIDE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 21.0 | ( 22.0) | 1.020 | 2.033 | 3.040 | 4.039 | 5.033 | 6.020 | 7.000 | 7.974 | 8.942 | 9.903 |
| 30.0 | ( 30.9) | 1.003 | 2.000 | 2.990 | 3.974 | 4.951 | 5.922 | 6.887 | 7.846 | 8.798 | 9.745 |
| 40.0 | ( 40.3) | 0.985 | 1.964 | 2.937 | 3.904 | 4.864 | 5.818 | 6.766 | 7.708 | 8.644 | 9.574 |
| 50.0 | ( 50.6) | 0.968 | 1.930 | 2.886 | 3.835 | 4.779 | 5.716 | 6.648 | 7.574 | 8.494 | 9.408 |
| 60.0 | ( 60.5) | 0.951 | 1.897 | 2.836 | 3.769 | 4.697 | 5.618 | 6.534 | 7.444 | 8.349 | 9.248 |
| 70.0 | ( 70.4) | 0.935 | 1.864 | 2.787 | 3.705 | 4.617 | 5.523 | 6.424 | 7.319 | 8.208 | 9.092 |
| 80.0 | ( 80.3) | 0.919 | 1.833 | 2.741 | 3.643 | 4.539 | 5.431 | 6.316 | 7.197 | 8.072 | 8.941 |
| 90.0 | ( 90.1) | 0.904 | 1.802 | 2.695 | 3.583 | 4.464 | 5.341 | 6.212 | 7.078 | 7.939 | 8.795 |
| 100.0 | (100.0) | 0.889 | 1.773 | 2.651 | 3.524 | 4.392 | 5.254 | 6.111 | 6.963 | 7.810 | 8.652 |

Table E-IV. Army $CO_2/O_2$ Concentration Monitor

Correction for the Carbon Dioxide Scale (RQ = 0.100E 01)

| PERCENT OXYGEN | | PERCENT CARBON DIOXIDE 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 21.0 | ( 22.0) | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 30.0 | ( 30.9) | 1.017 | 1.017 | 1.016 | 1.016 | 1.016 | 1.016 | 1.016 | 1.016 | 1.016 | 1.016 |
| 40.0 | ( 40.8) | 1.035 | 1.035 | 1.035 | 1.035 | 1.035 | 1.035 | 1.035 | 1.035 | 1.034 | 1.034 |
| 50.0 | ( 50.6) | 1.054 | 1.053 | 1.053 | 1.053 | 1.053 | 1.053 | 1.053 | 1.053 | 1.053 | 1.053 |
| 60.0 | ( 60.5) | 1.072 | 1.072 | 1.072 | 1.072 | 1.072 | 1.071 | 1.071 | 1.071 | 1.071 | 1.071 |
| 70.0 | ( 70.4) | 1.091 | 1.091 | 1.090 | 1.090 | 1.090 | 1.090 | 1.090 | 1.090 | 1.089 | 1.089 |
| 80.0 | ( 80.3) | 1.110 | 1.109 | 1.109 | 1.109 | 1.109 | 1.108 | 1.108 | 1.108 | 1.108 | 1.108 |
| 90.0 | ( 90.1) | 1.128 | 1.128 | 1.128 | 1.128 | 1.127 | 1.127 | 1.127 | 1.127 | 1.126 | 1.126 |
| 100.0 | (100.0) | 1.147 | 1.147 | 1.147 | 1.146 | 1.146 | 1.146 | 1.145 | 1.145 | 1.145 | 1.145 |

## Table E-V. Army $CO_2/O_2$ Concentration Monitor

### Carbon Dioxide Scale (RQ = 0.110E 01)

| PERCENT OXYGEN | PERCENT CARBON DIOXIDE 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 21.0 ( 22.0) | 1.019 | 2.032 | 3.039 | 4.039 | 5.032 | 6.019 | 7.000 | 7.974 | 8.942 | 9.904 |
| 30.0 ( 30.9) | 1.001 | 1.995 | 2.983 | 3.964 | 4.940 | 5.909 | 6.871 | 7.828 | 8.778 | 9.722 |
| 40.0 ( 40.3) | 0.980 | 1.954 | 2.922 | 3.884 | 4.840 | 5.789 | 6.733 | 7.670 | 8.602 | 9.527 |
| 50.0 ( 50.6) | 0.961 | 1.915 | 2.864 | 3.806 | 4.743 | 5.674 | 6.599 | 7.518 | 8.431 | 9.338 |
| 60.0 ( 60.5) | 0.942 | 1.877 | 2.807 | 3.731 | 4.650 | 5.562 | 6.469 | 7.370 | 8.265 | 9.154 |
| 70.0 ( 70.4) | 0.923 | 1.841 | 2.752 | 3.659 | 4.559 | 5.454 | 6.343 | 7.227 | 8.105 | 8.977 |
| 80.0 ( 80.3) | 0.905 | 1.805 | 2.699 | 3.588 | 4.471 | 5.349 | 6.221 | 7.098 | 7.949 | 8.805 |
| 90.0 ( 90.1) | 0.888 | 1.771 | 2.648 | 3.520 | 4.386 | 5.247 | 6.103 | 6.953 | 7.798 | 8.638 |
| 100.0 (100.0) | 0.871 | 1.737 | 2.598 | 3.453 | 4.304 | 5.149 | 5.986 | 6.823 | 7.652 | 8.476 |

## Table E-VI. Army $CO_2/O_2$ Concentration Monitor

## Correction for the Carbon Dioxide Scale (RQ = 0.110E 01)

| PERCENT OXYGEN | PERCENT CARBON DIOXIDE<br>1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 21.0 ( 22.0) | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 30.0 ( 30.9) | 1.019 | 1.019 | 1.019 | 1.019 | 1.019 | 1.019 | 1.019 | 1.019 | 1.019 | 1.019 |
| 40.0 ( 40.3) | 1.040 | 1.040 | 1.040 | 1.040 | 1.040 | 1.040 | 1.040 | 1.040 | 1.040 | 1.040 |
| 50.0 ( 50.5) | 1.061 | 1.061 | 1.061 | 1.061 | 1.061 | 1.061 | 1.061 | 1.061 | 1.061 | 1.061 |
| 60.0 ( 60.5) | 1.082 | 1.083 | 1.082 | 1.082 | 1.082 | 1.082 | 1.082 | 1.082 | 1.082 | 1.082 |
| 70.0 ( 70.4) | 1.104 | 1.104 | 1.104 | 1.104 | 1.104 | 1.104 | 1.104 | 1.103 | 1.103 | 1.103 |
| 80.0 ( 80.3) | 1.126 | 1.126 | 1.126 | 1.126 | 1.125 | 1.125 | 1.125 | 1.125 | 1.125 | 1.125 |
| 90.0 ( 90.1) | 1.148 | 1.148 | 1.148 | 1.147 | 1.147 | 1.147 | 1.147 | 1.147 | 1.147 | 1.147 |
| 100.0 (100.0) | 1.170 | 1.170 | 1.170 | 1.169 | 1.169 | 1.169 | 1.169 | 1.169 | 1.169 | 1.168 |

## Table E-VII. Army $CO_2/O_2$ Concentration Monitor

### Carbon Dioxide Scale (RQ = 0.100E 21)

| PERCENT OXYGEN | PERCENT CARBON DIOXIDE 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 21.0 ( 22.0) | 1.024 | 2.040 | 3.048 | 4.048 | 5.040 | 6.024 | 7.000 | 7.969 | 8.929 | 9.883 |
| 30.0 ( 30.9) | 0.987 | 1.966 | 2.937 | 3.901 | 4.858 | 5.807 | 6.749 | 7.683 | 8.611 | 9.532 |
| 40.0 ( 40.8) | 0.947 | 1.896 | 2.818 | 3.744 | 4.662 | 5.574 | 6.479 | 7.377 | 8.269 | 9.154 |
| 50.0 ( 50.6) | 0.906 | 1.809 | 2.704 | 3.592 | 4.474 | 5.349 | 6.218 | 7.081 | 7.938 | 8.789 |
| 60.0 ( 60.5) | 0.870 | 1.735 | 2.593 | 3.445 | 4.292 | 5.132 | 5.967 | 6.796 | 7.619 | 8.437 |
| 70.0 ( 70.4) | 0.834 | 1.663 | 2.486 | 3.304 | 4.116 | 4.922 | 5.724 | 6.520 | 7.310 | 8.096 |
| 80.0 ( 80.3) | 0.800 | 1.594 | 2.383 | 3.167 | 3.946 | 4.720 | 5.489 | 6.253 | 7.012 | 7.766 |
| 90.0 ( 90.1) | 0.766 | 1.527 | 2.283 | 3.035 | 3.782 | 4.524 | 5.262 | 5.995 | 6.723 | 7.447 |
| 100.0 (100.0) | 0.734 | 1.463 | 2.187 | 2.907 | 3.623 | 4.335 | 5.042 | 5.745 | 6.444 | 7.139 |

## Table E-VIII. Army $CO_2/O_2$ Concentration Monitor

Correction for the Carbon Dioxide Scale (RQ = 0.100E 21)

| PERCENT OXYGEN | PERCENT CARBON DIOXIDE 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 21.0 ( 22.0) | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 | 1.000 |
| 30.0 ( 30.[illegible]) | 1.038 | 1.038 | 1.038 | 1.038 | 1.037 | 1.037 | 1.037 | 1.037 | 1.037 | 1.037 |
| 40.0 ( 40.[illegible]) | 1.082 | 1.082 | 1.082 | 1.081 | 1.081 | 1.081 | 1.080 | 1.080 | 1.080 | 1.080 |
| 50.0 ( 50.5) | 1.128 | 1.128 | 1.127 | 1.127 | 1.127 | 1.126 | 1.126 | 1.125 | 1.125 | 1.124 |
| 60.0 ( 60.5) | 1.177 | 1.176 | 1.176 | 1.175 | 1.174 | 1.174 | 1.173 | 1.173 | 1.172 | 1.171 |
| 70.0 ( 70.4) | 1.228 | 1.227 | 1.226 | 1.225 | 1.224 | 1.224 | 1.223 | 1.222 | 1.221 | 1.221 |
| 80.0 ( 80.3) | 1.281 | 1.280 | 1.279 | 1.278 | 1.277 | 1.276 | 1.275 | 1.274 | 1.273 | 1.273 |
| 90.0 ( 90.1) | 1.337 | 1.336 | 1.335 | 1.334 | 1.333 | 1.331 | 1.330 | 1.329 | 1.328 | 1.327 |
| 100.0 (100.0) | 1.396 | 1.395 | 1.394 | 1.392 | 1.391 | 1.390 | 1.388 | 1.387 | 1.386 | 1.384 |

Table E-IX. Army $CO_2/O_2$ Concentration Monitor

Carbon Dioxide Frequency Response (RQ = 0.850E 00)

| PERCENT OXYGEN | PERCENT CARBON DIOXIDE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 21.0 ( 22.3) | 70.2 | 139.8 | 209.0 | 277.6 | 345.8 | 413.6 | 480.8 | 547.7 | 614.1 | 680.1 |
| 30.0 ( 30.9) | 69.4 | 138.2 | 206.6 | 274.5 | 341.9 | 408.9 | 475.4 | 541.5 | 607.2 | 672.5 |
| 40.0 ( 40.9) | 68.5 | 136.4 | 204.0 | 271.0 | 337.6 | 403.8 | 469.5 | 534.9 | 599.8 | 664.4 |
| 50.0 ( 50.6) | 67.6 | 134.7 | 201.4 | 267.7 | 333.5 | 398.9 | 463.8 | 528.4 | 592.6 | 656.4 |
| 60.0 ( 60.5) | 66.8 | 133.1 | 199.0 | 264.4 | 329.4 | 394.1 | 458.3 | 522.1 | 585.6 | 648.7 |
| 70.0 ( 70.4) | 66.0 | 131.5 | 196.6 | 261.2 | 325.5 | 389.4 | 452.9 | 516.0 | 578.8 | 641.2 |
| 80.0 ( 80.3) | 65.2 | 129.9 | 194.2 | 258.2 | 321.7 | 384.9 | 447.6 | 510.1 | 572.2 | 633.9 |
| 90.0 ( 90.1) | 64.4 | 128.4 | 192.0 | 255.2 | 318.0 | 380.4 | 442.5 | 504.3 | 565.7 | 626.8 |
| 100.0 (100.0) | 63.6 | 126.9 | 189.7 | 252.2 | 314.4 | 376.1 | 437.5 | 498.6 | 559.4 | 619.9 |

Table E-X. Army $CO_2/O_2$ Concentration Monitor

Carbon Dioxide Frequency Response (RQ = 0.100E 01)

| PERCENT OXYGEN | PERCENT CARBON DIOXIDE 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 21.0 ( 22.0) | 73.0 | 145.5 | 217.6 | 289.2 | 360.3 | 430.9 | 501.1 | 570.8 | 640.1 | 709.0 |
| 30.0 ( 30.9) | 71.8 | 143.2 | 214.1 | 284.5 | 354.5 | 424.0 | 493.0 | 561.7 | 629.9 | 697.6 |
| 40.0 ( 40.8) | 70.5 | 140.6 | 210.3 | 279.4 | 348.2 | 416.5 | 484.3 | 551.8 | 616.8 | 685.4 |
| 50.0 ( 50.6) | 69.3 | 138.2 | 206.6 | 274.6 | 342.1 | 409.2 | 475.9 | 542.2 | 608.1 | 673.5 |
| 60.0 ( 60.5) | 68.1 | 135.8 | 203.0 | 269.8 | 336.2 | 402.2 | 467.8 | 532.9 | 597.7 | 662.0 |
| 70.0 ( 70.4) | 66.9 | 133.5 | 199.5 | 265.2 | 330.5 | 395.4 | 459.8 | 523.9 | 587.6 | 650.9 |
| 80.0 ( 80.3) | 65.6 | 131.2 | 196.2 | 260.8 | 325.0 | 388.8 | 452.2 | 515.2 | 577.8 | 640.1 |
| 90.0 ( 90.1) | 64.7 | 129.0 | 192.9 | 256.5 | 319.6 | 382.3 | 444.7 | 506.7 | 568.3 | 629.6 |
| 100.0 (100.0) | 63.6 | 126.9 | 189.8 | 252.3 | 314.4 | 376.1 | 437.5 | 498.5 | 559.1 | 619.4 |

## Table E-XI. Army $CO_2/O_2$ Concentration Monitor

## Carbon Dioxide Frequency Response (RQ = 0.110E 01)

| PERCENT OXYGEN | PERCENT CARBON DIOXIDE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 21.0 ( 22.0) | 74.5 | 148.5 | 222.0 | 295.0 | 367.6 | 439.7 | 511.4 | 582.5 | 653.3 | 723.5 |
| 30.0 ( 30.9) | 73.1 | 145.7 | 217.9 | 289.6 | 360.8 | 431.6 | 502.0 | 571.8 | 641.3 | 710.2 |
| 40.0 ( 40.8) | 71.6 | 142.8 | 213.5 | 283.7 | 353.6 | 422.9 | 491.8 | 560.3 | 628.4 | 696.0 |
| 50.0 ( 50.6) | 70.2 | 139.9 | 209.2 | 278.1 | 346.5 | 414.5 | 482.0 | 549.2 | 615.9 | 682.1 |
| 60.0 ( 60.5) | 68.5 | 137.1 | 205.1 | 272.6 | 339.7 | 406.3 | 472.6 | 538.4 | 603.8 | 668.8 |
| 70.0 ( 70.4) | 67.4 | 134.5 | 201.1 | 267.3 | 333.0 | 398.4 | 463.4 | 527.9 | 592.1 | 655.8 |
| 80.0 ( 80.3) | 66.1 | 131.9 | 197.2 | 262.1 | 326.6 | 390.8 | 454.5 | 517.8 | 580.7 | 643.2 |
| 90.0 ( 90.1) | 64.9 | 129.4 | 193.4 | 257.1 | 320.4 | 383.3 | 445.8 | 508.0 | 569.7 | 631.0 |
| 100.0 (100.0) | 63.7 | 126.0 | 189.6 | 252.3 | 314.4 | 376.1 | 437.5 | 498.4 | 559.0 | 619.2 |

## Table E-XII. Army $CO_2/O_2$ Concentration Monitor

### Carbon Dioxide Frequency Response (RQ = 0.100E 21)

| PERCENT OXYGEN | PERCENT CARBON DIOXIDE<br>1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 21.0 ( 22.0) | 88.9 | 177.0 | 264.5 | 351.2 | 437.3 | 522.7 | 607.4 | 691.4 | 774.8 | 857.5 |
| 30.0 ( 30.9) | 85.6 | 170.6 | 254.9 | 338.5 | 421.5 | 503.8 | 585.6 | 666.7 | 747.2 | 827.0 |
| 40.0 ( 40.3) | 82.1 | 163.6 | 244.5 | 324.8 | 404.5 | 483.6 | 562.2 | 640.1 | 717.5 | 794.3 |
| 50.0 ( 50.6) | 78.8 | 157.0 | 234.6 | 311.7 | 388.2 | 464.1 | 539.5 | 614.4 | 688.8 | 762.6 |
| 60.0 ( 60.5) | 75.5 | 150.5 | 225.0 | 298.9 | 372.4 | 445.3 | 517.7 | 589.6 | 661.1 | 732.0 |
| 70.0 ( 70.4) | 72.4 | 144.3 | 215.7 | 286.7 | 357.1 | 427.1 | 496.6 | 565.7 | 634.3 | 702.4 |
| 80.0 ( 80.3) | 69.4 | 138.3 | 206.8 | 274.8 | 342.4 | 409.5 | 476.2 | 542.5 | 608.4 | 673.8 |
| 90.0 ( 90.1) | 66.5 | 132.5 | 198.1 | 263.3 | 328.1 | 392.5 | 456.5 | 520.1 | 583.4 | 646.2 |
| 100.0 (100.0) | 63.6 | 126.9 | 189.8 | 252.3 | 314.4 | 376.1 | 437.5 | 498.5 | 559.1 | 619.4 |

Table E-XIII. Army $CO_2/O_2$ Concentration Monitor

Oxygen Scale

| PERCENT OXYGEN | SCALE READING | SCALE CORR. |
|---|---|---|
| 21.0 | 18.0 | 3.0 |
| 30.0 | 28.1 | 1.9 |
| 40.0 | 39.2 | 0.8 |
| 50.0 | 50.0 | 0.0 |
| 60.0 | 60.6 | -0.6 |
| 70.0 | 71.0 | -1.0 |
| 80.0 | 81.2 | -1.2 |
| 90.0 | 91.2 | -1.2 |
| 100.0 | 101.0 | -1.0 |

Table E-XIV. Army $CO_2/O_2$ Concentration Monitor

Oxygen Frequency Response

| PERCENT OXYGEN | FREQUENCY HZ |
|---|---|
| 21.0 | 0.0 |
| 30.0 | 180.4 |
| 40.0 | 377.0 |
| 50.0 | 569.6 |
| 60.0 | 758.4 |
| 70.0 | 943.5 |
| 80.0 | 1125.1 |
| 90.0 | 1303.1 |
| 100.0 | 1477.8 |