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DEVELOPMENT OF A CARBON DIOXIDE PARTIAL PRESSURE SENSOR

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BIOMEDICAL LABORATORY
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FOREWORD

Work reported was performed at Isomet Corporation, Palisades Park, New Jersey, from 29 January 1962 to 15 February 1964 by Mr. Gerald Jankowitz and Mr. Edward Berlese under Contract No. AF 33(657)-8096 with the Biomedical Laboratory, Aerospace Medical Research Laboratories. The work was in support of Project No. 6373, "Equipment for Life Support in Aerospace," Task No. 637302, "Respiratory Support Equipment." 1st Lt William J. Evon, Respiratory Equipment Branch, Biotechnology Division, Biomedical Laboratory, was contract monitor.

This technical report has been reviewed and is approved.

WAYNE H. McCANDLESS
Technical Director
Biomedical Laboratory

ABSTRACT

The objective of this program was to design and develop a compact airborne CO_2 sensor unit capable of sensing and measuring the CO_2 content of manned, sealed environments. A prototype carbon dioxide sensor was designed, built, and calibrated. The sensor operates by alternately comparing the infrared absorption of the air sample at 4.26 microns, where CO_2 exhibits strong absorption and at 3.90 microns where it has little absorption. A two color rotating filter provides sampling 200 times per second. The unit weighs 10 pounds and has a power consumption of 70 watts. The instrument is capable of detecting a concentration of at least 0.30% CO_2 and has full scale capability to 5%.

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SECTION I

INTRODUCTION

The basic problems of atmosphere control are the supply of breathing oxygen and the removal of toxic and combustible gases from the atmosphere. The most abundant of these toxic gases is carbon dioxide, a product of human metabolism. In order to control the concentration of carbon dioxide in a cabin atmosphere it is first necessary to measure its concentration. A reliable analytical device that can operate in a weightless condition and can withstand the vibration and shock of launch is necessary.

The desired device should be sensitive to changes in the carbon dioxide concentration over a wide range and should be insensitive to the presence of other gases in the atmosphere.

There are several different ways of analyzing for carbon dioxide. In one method the carbon dioxide is caused to react with another reagent to form a finely divided aerosol. Passage of this aerosol through an alpha excited ionization chamber causes a change in the conductivity across the electrode system. This change can be used to measure the concentration of carbon dioxide. Such devices are large at the present time and may not be as selective as is necessary. In addition, the aerosol, as formed, might become a hazard if allowed to enter the cabin. Another approach involves measuring the thermal conductivity of the air sample. A device working on this principle would rely on the change in resistance of a hot wire caused by changes in heat loss, that would in turn,be dependent upon the thermal conductivity of the gas flowing over the hot wire. An instrument of this type would again probably lack the selectivity for carbon dioxide unless a set of absorbers could be used which would selectively remove all other impurities. Such an apparatus, in addition to requiring the proper filters and absorbers, would require a pump to pass the sample through the absorbers.

Electrochemical devices have been used in the past to measure the carbon dioxide concentration. These devices have relied on the diffusion of the carbon dioxide through a plastic membrane into a sodium bicarbonate solution, whose pH changes as the partial pressure of the carbon dioxide in the air changes. The change in pH can be measured using the glass electrode. Alternatively, the change in redox potential of the Quinhydrone system caused by change in pH can be used. As a consequence of the membrane used these devices have either long response time or a low stability over a period of time.

Finally, there is the infrared technique which depends upon the selective absorption of infrared radiation by carbon dioxide. This method appears to have the most promise and has been chosen for this investigation.

SECTION II

SYSTEM REQUIREMENTS

The carbon dioxide sensor was designed and developed with the objective of providing a compact, airborne unit capable of sensing and measuring the carbon dioxide content of manned, sealed environments. The design was based on the following six requirements:

Required Range of Operation

The unit shall sense and measure the partial pressure of carbon dioxide in the range of 0 to 40 mm Hg with an accuracy within 1% or less of the full scale reading.

Operating Characteristics

The unit must have a high electrical stability with a minimum of drift. The response time of the unit shall be extremely short, with a maximum of 2 minutes.

Operating Environment

The usual operating environment for the instrumentation unit will have a temperature range of $45^{\circ}F$ to $95^{\circ}F$ and a 20% to 80% relative humidity. Typical partial pressures of 0 to 16 mm Hg of CO_2, 150 to 200 mm Hg of O_2, and approximately 260 to 760 mm Hg total environmental pressure are anticipated. The instrumentation unit must perform accurately under all possible combinations of the extremes of these ranges.

The unit must be capable of operating under vibrations of

± 3g's at 14 to 100 cps
± 5g's at 100 to 500 cps
± 10g's at 500 to 2000 cps

The unit must be designed to function in a weightless environment and under accelerations as high as 20g's along any axis.

The unit shall be capable of operating under shock of 15 g's for 11-milliseconds duration in any direction and of withstanding 100 g's for a 7-millisecond duration in any direction.

Maintenance

The operating life of the unit must be at least 1 month or longer with minimal service. The shelf life shall be 1 year without service.

Design

The unit shall be compact, with all measurement indicated on a panel so that they can be clearly and easily seen. The scale indicating partial pressure of CO_2 shall be graduated in millimeters of Hg.

Weight and Power

The unit shall be of minimal weight and consume minimal power from a 28-volt d-c source.

SECTION III

INFRARED DESIGNS CONSIDERED

Double Pass Instrument

The first sensor to be considered would compare the CO_2 absorption in a standard sample cell to that in the atmosphere. A single radiant source produces two collimated beams of energy, one of which passes through the standard sample and the second through the atmosphere in question. The beams are reflected through 90° in opposing directions on a common optical axis. Between the two reflecting mirrors on this axis is a continuously rotating mirror. This mirror chops the light into pulses and combines the two optical paths into a common axis allowing both to fall on the detector. This pulsed light signal passes through a suitable optical band pass filter to a lens which images the energy onto the detector. The output of the detector is amplified and demodulated.

There were two major problems in this system. First the electrical bandwidths required to pass the narrow pulse type information generated by the scanning technique resulted in a degradation of the sensitivity of the system. The second problem was the sensitivity of the device to changes in atmospheric temperature and pressure. These two problems caused this detection technique to be discarded.

Rocking Interference Filter Sensor

This design provides both the reference and measurement functions in a single optical path. A rocking interference filter is used to scan both the absorption line of CO_2 and a nonabsorbing nearby spectral region. The absorption line is at 4.26 microns and the desired comparison window at 4 microns. This system was fabricated in a breadboard form and when used as a photometer, with the filter stationary, worked quite satisfactorily. When attempts were made to measure the spectral shift resulting from rocking the interference filter, the central pass band of the filter did not shift by a large enough amount. When spectrometer transmission measurements were made, multiple transmission bands appeared in the inclined position. We concluded that the high index materials used to fabricate the multilayer interference filter in the inclined position were causing an optical mismatch. The resulting total internal reflection within the interference filter prevented a significant shift of the transmission band of the filter. The rocking filter system also showed mechanical weakness. Systems that convert rotary motion to linear motion, when subjected to a high adverse mechanical environment, are difficult to engineer. Stiffening the crank arm without jeopardizing the desired precise motion turned out to be fairly cumbersome. This concept was therefore abandoned.

Two Spectral Region Alternate Comparison Technique

The final concept to be evaluated was the one that was used in the final system. It compares the transmission in the air sample at 4.26 microns and at 3.90 microns, where CO_2 has a strong absorption and very little absorption, respectively. One light source is used and comparison of the two spectral regions is made by means of a rotating multifilter disc.

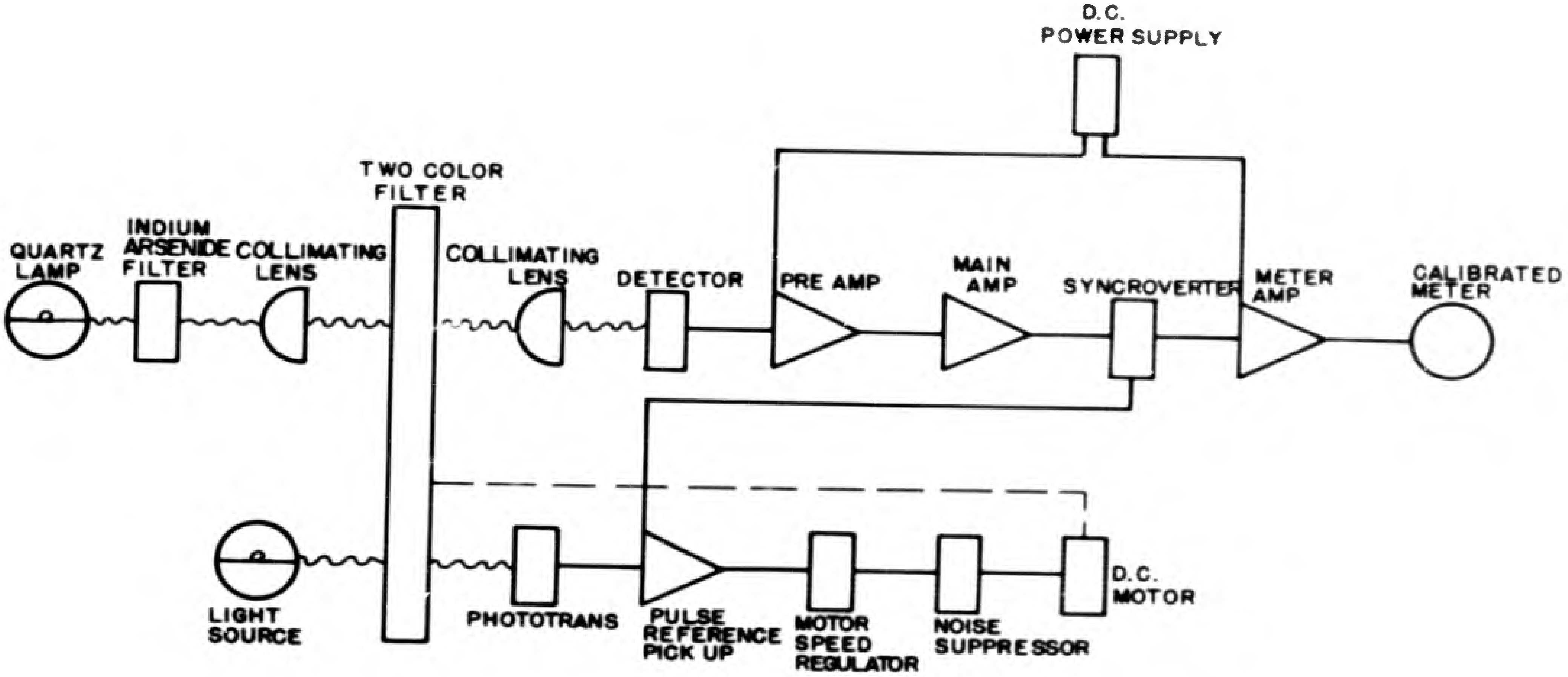


FIGURE I SYSTEM BLOCK DIAGRAM

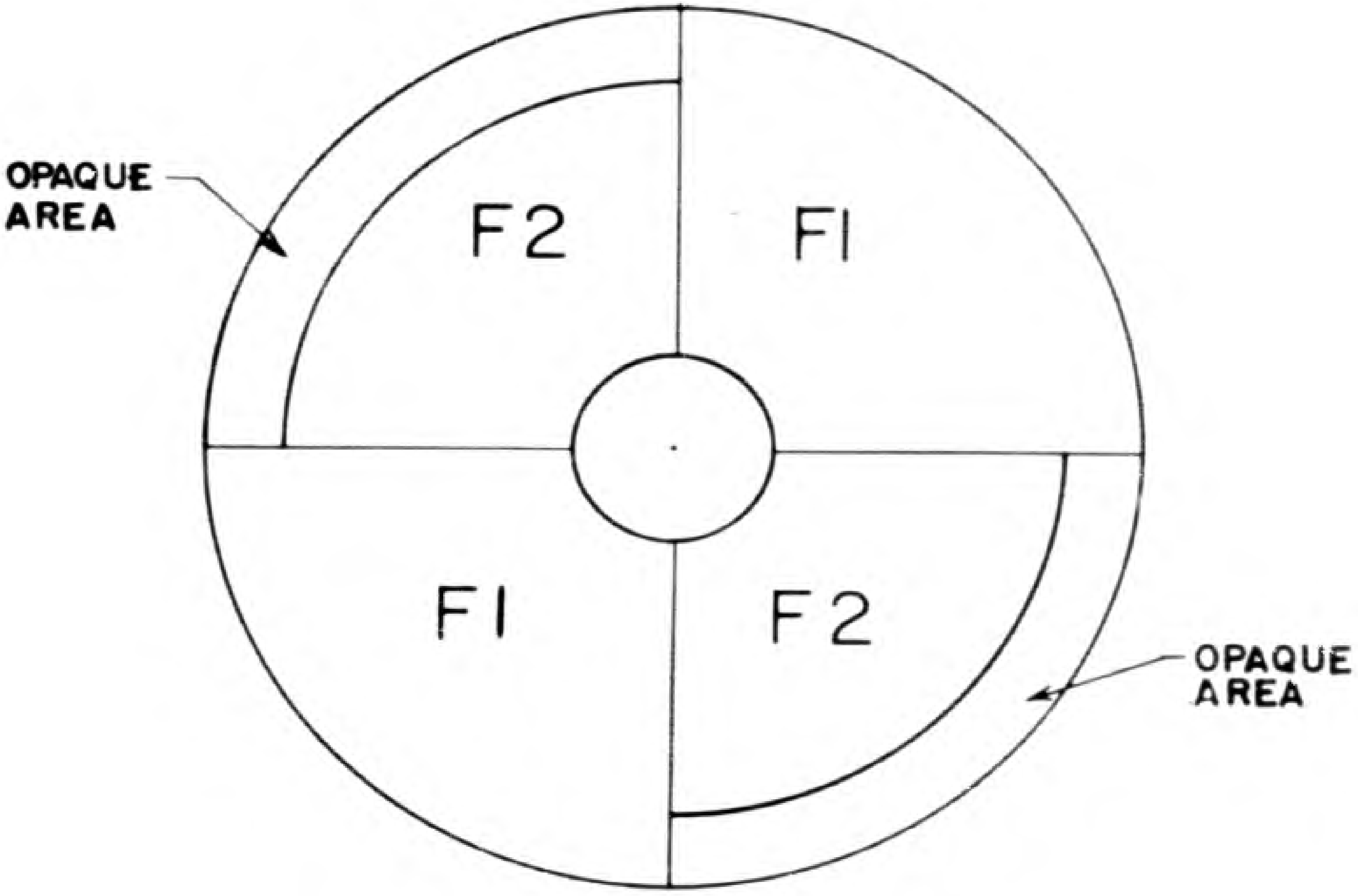
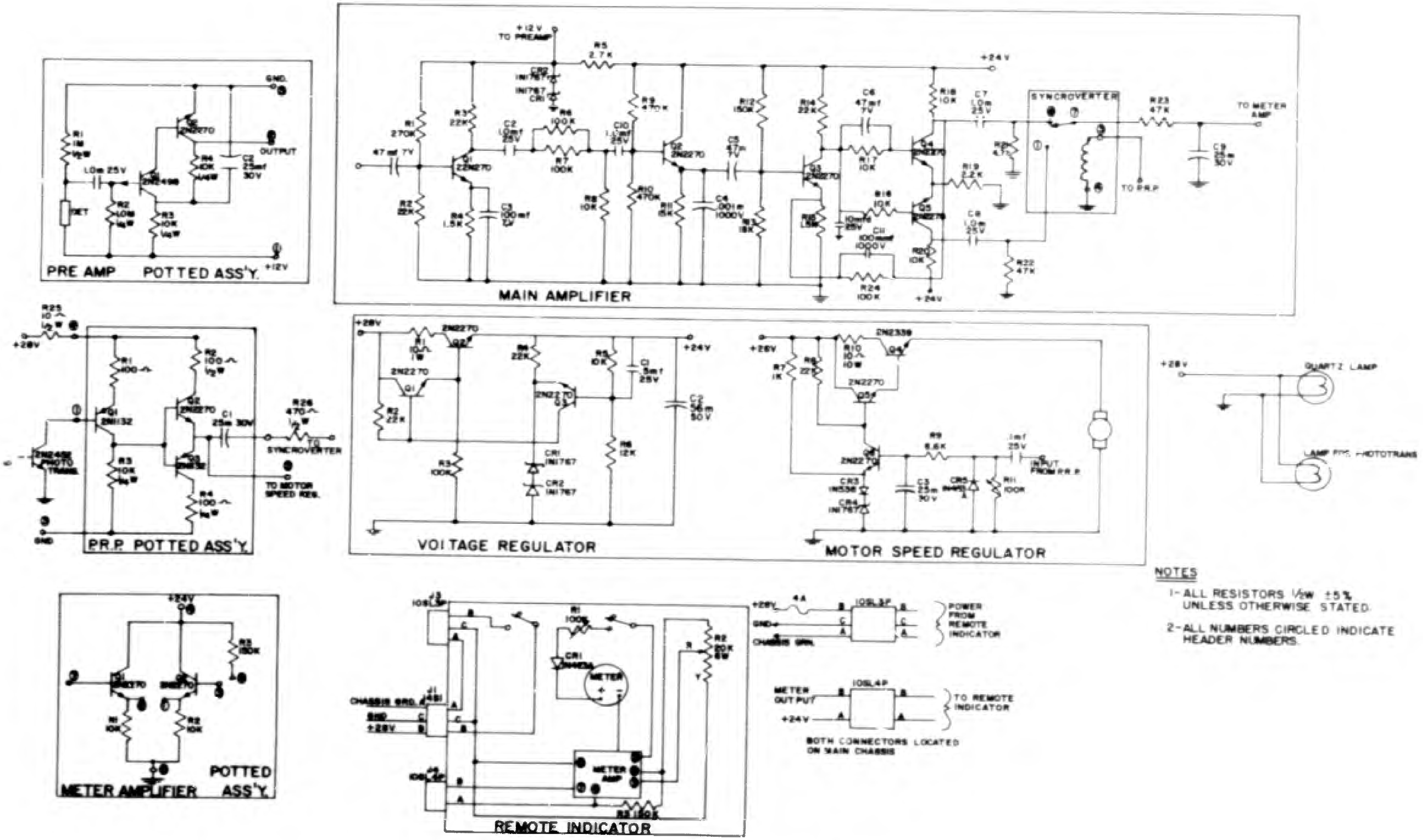


FIGURE 2 TWO COLOR FILTER DISC



NOTES

1- ALL RESISTORS 1/2W ±5% UNLESS OTHERWISE STATED.

2- ALL NUMBERS CIRCLED INDICATE HEADER NUMBERS.

FIGURE 3 ELECTRONIC SCHEMATIC

SECTION IV

SYSTEM DESCRIPTION

The block diagram of the system is shown in figure 1. Light from the tungsten lamp is filtered by an indium arsenide filter which transmits infrared radiation only between 3.8 and 7 microns. The lamp light transmitted through the indium arsenide is collimated with a calcium fluoride (CaF_2) lens, transmitted through the plane of the two color filter disc, and imaged onto the lead selenide (PbSe) detector by a second CaF_2 lens.

Rotating the filter disc shown in figure 2 interposes two filters (F_1 and F_2) in the path of the IR beam. One filter transmits a narrow band spectrum centered at 3.90 microns, the other a band centered on the CO_2 absorption line at 4.26 microns. The transmission of the optical system, from lamp to detector, only varies with the amount of CO_2 in the atmosphere if the 4.26 micron filter is in the beam but not if it is replaced by the 3.90 micron filter. The latter is used to generate a CO_2 insensitive reference optical path for the system. If the atmosphere is free of CO_2, the two filters transmit identically and spinning the filter disc causes no modulation of the output of the detector. As CO_2 is introduced, the transmission at the 4.26 micron absorption line decreases. Spinning the disc now generates an a-c signal, the level of which is a function of the concentration. The a-c detector output is fed into the preamplifier mounted on the detector housing. The output of the preamplifier is amplified in the main amplifier and then full wave synchronously rectified by the synchroverter switch. The rectified signal is fed into the R-C filter (R23, C9 in figure 3) and then into the meter amplifier. The output is displayed on a 0-50 microampere meter movement.

Calibration is achieved by adjusting two resistors (R_1 and R_2 shown in figure 3) in the meter indicator. The synchroverter synchronously rectifies the signal without causing any reduction in signal voltage. This type of synchronous detection scheme provides maximum signal to noise ratio. The reference signal, properly phased, is supplied to the synchroverter by a reference signal generating system. A small lamp and a phototransistor and one annular section (shown in figure 2) of the filter disc combine to generate the reference signal. This annular section, which is not the main beam path, has four alternating opaque and transparent sectors, one sector for each color filter sector. The sectors are oriented on the disc so that as the color filter switches the color in the main optical path, the light to the phototransistor is also switched. The phototransistor output is therefore a square wave, synchronous with the main signal. The pulse reference pickup amplifies the phototransistor output and drives both the synchroverter and the motor speed regulator. The regulated speed determines the system operating frequency, normally about 200 cycles per second, and can be adjusted by R11 (figure 3). The motor speed regulator provides a reserve of power so that compensation is available if the friction in the motor bearings is changed by extreme temperature or other environmental strains.

The sensor contains its own regulated 24-v,d-c power supply which delivers power to the main amplifier and meter amplifier. The output of the motor speed regulator is fed into a noise suppressor to reduce brush noise on the input to the d-c motor.

Figures 4 and 5 show the details of the assembly of the sensor, while figure 6 is an illustration of the finished sensor delivered to Aerospace Medical Research Laboratories.

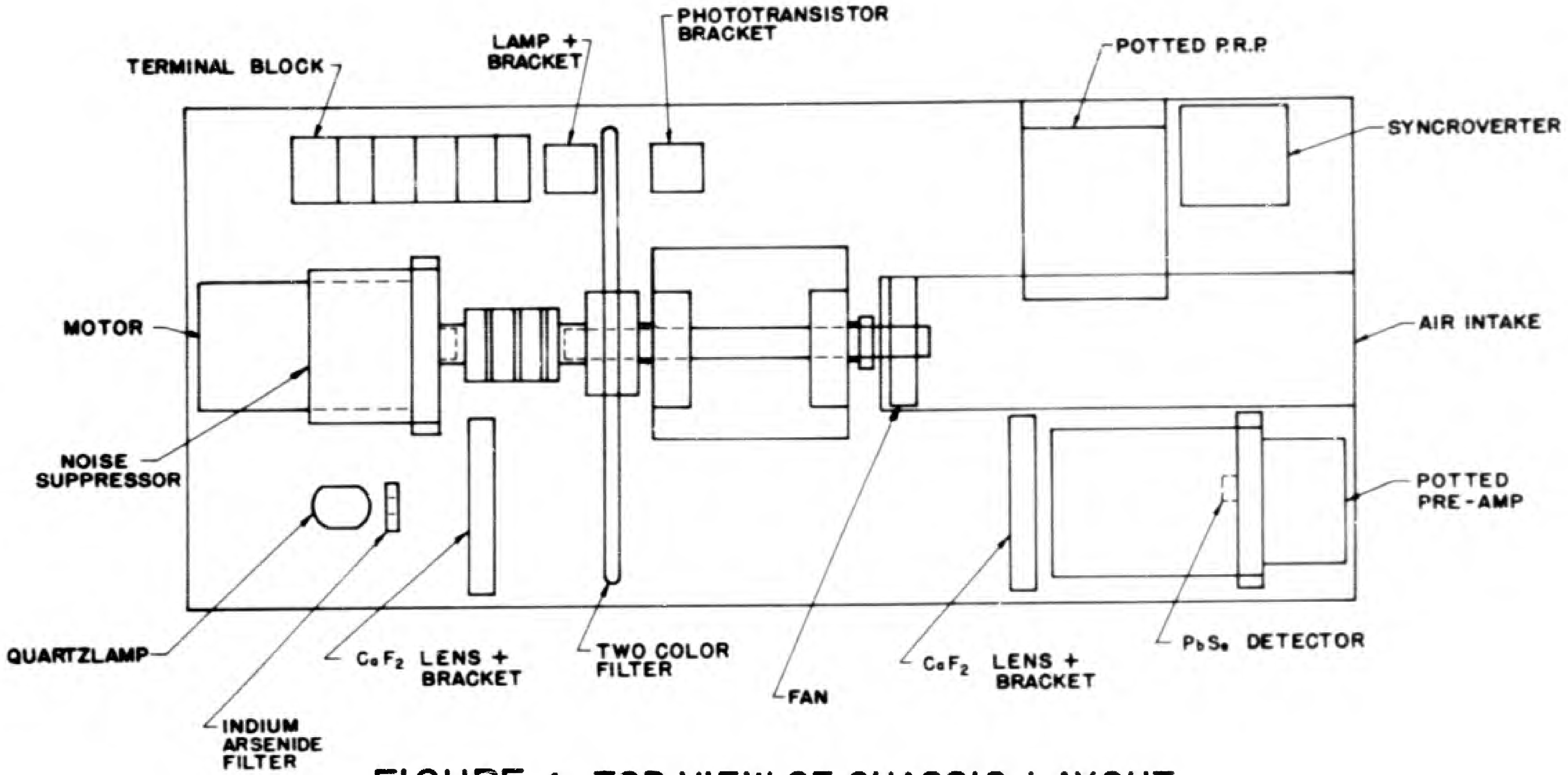


FIGURE 4 TOP VIEW OF CHASSIS LAYOUT

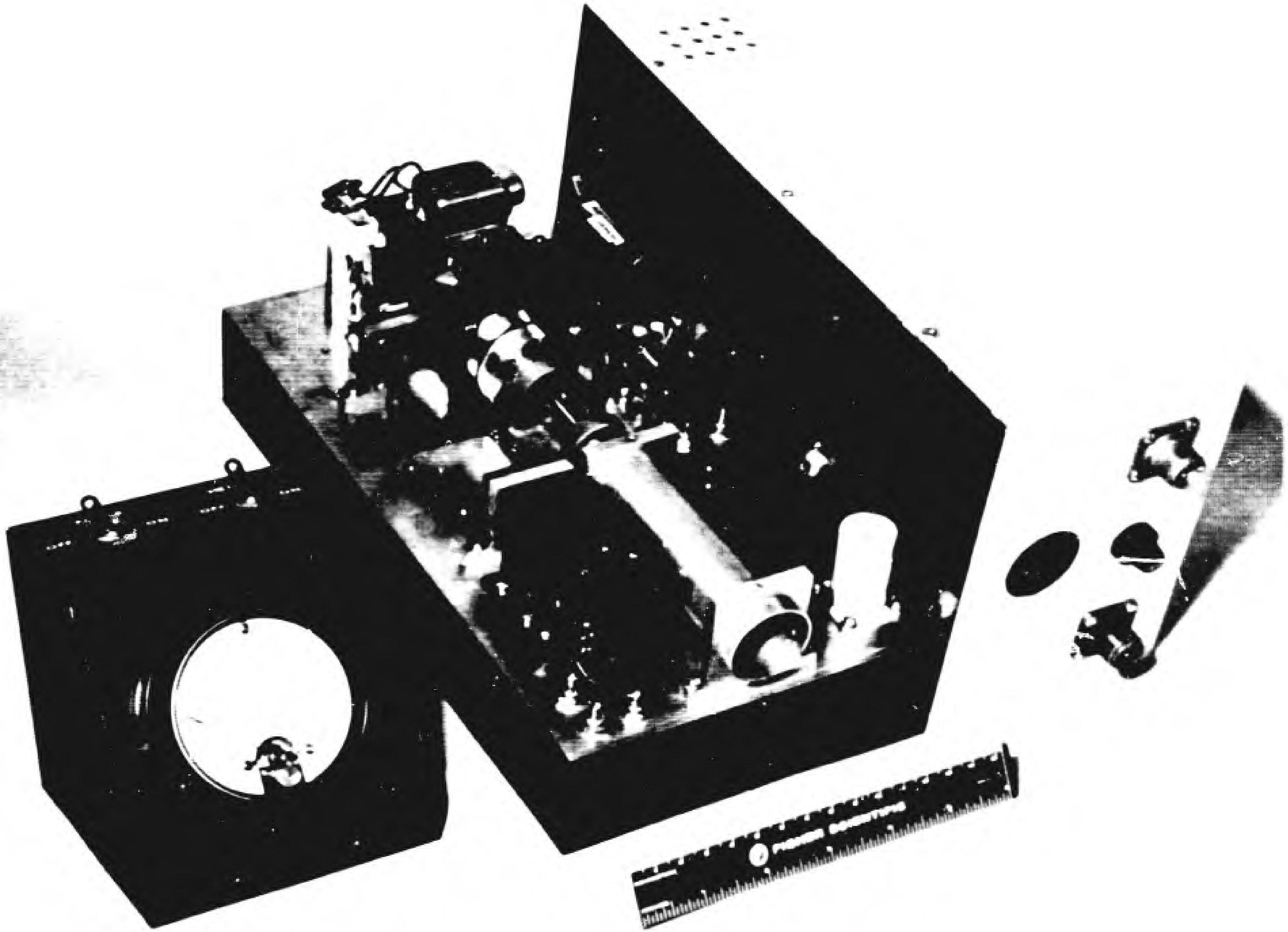


FIGURE 7 - Picture of Carbon Dioxide Sensor with Cover Removed

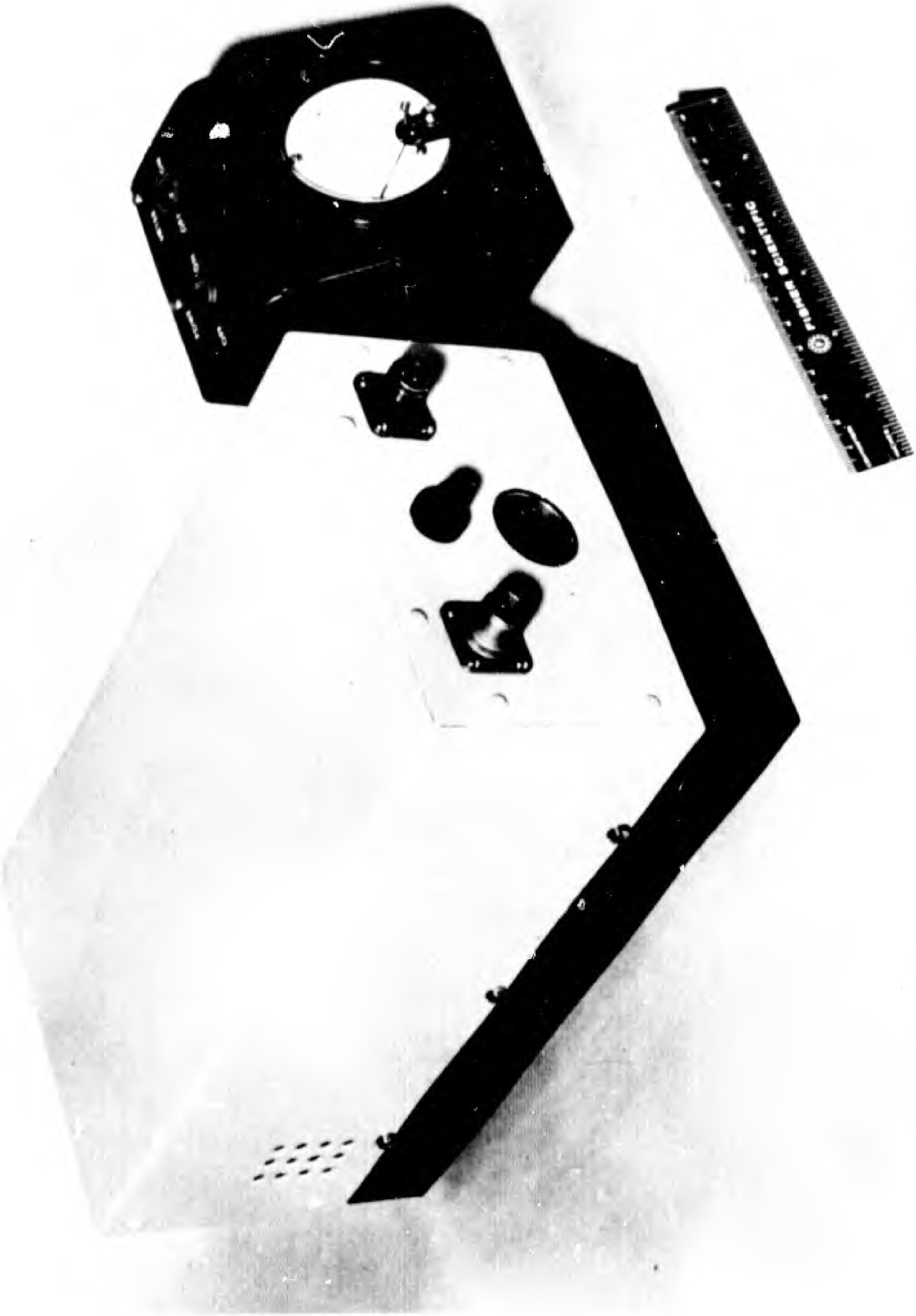


FIGURE 6 - Picture of Finished Carbon Dioxide Sensor Delivered to AMRL

SECTION V

DESIGN CONSIDERATIONS

Infrared Source

The need for a rugged light source was solved by the choice of the Type FAL General Electric iodine quartz lamp. For all practical purposes this lamp does not blacken or dim, and maintains approximately the same intensity from the beginning to the end of its life. It has stable color, is double focussed, and has double buffer springs to cradle the filaments, which are enclosed in a quartz envelope. Since the lamp will be used at only one-third of its rated voltage, its life expectancy will be greatly extended.

Lenses and Filters

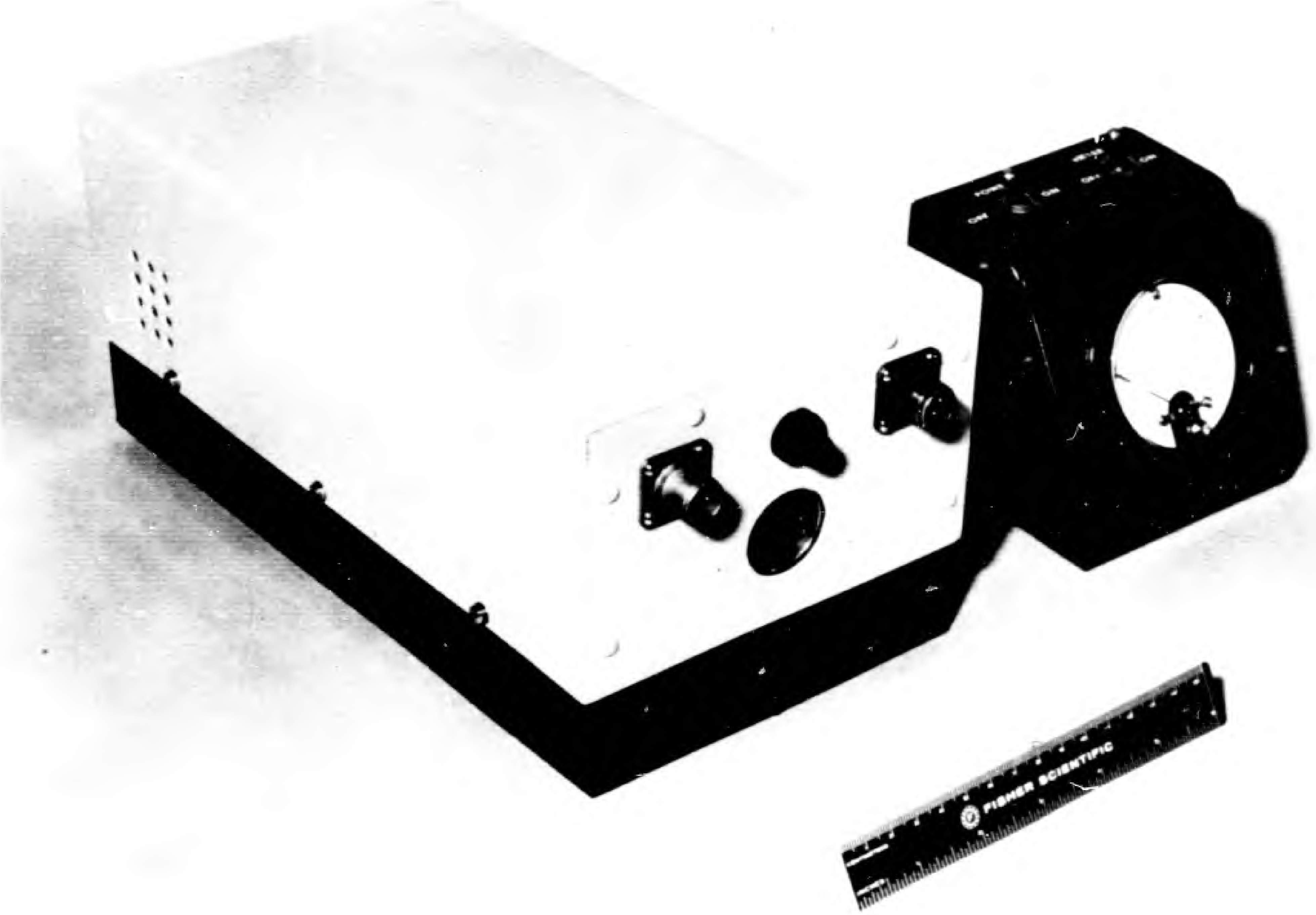
The two collimating lenses consist of high quality plano-convex CaF_2 lenses one inch in diameter and 1/4 inch thick and manufactured at Isomet Corporation. An indium arsenide filter was used to cut off all radiation from the source except the radiation in the 3.8 to 7 micron region.

Design of the Rotating Disc Filter

The rotating filter as shown in figure 2 consists of two main sections, F_1 and F_2, transmitting 4.26 and 3.90 micron radiation, respectively. The opaque annular sections at the perimeter of the disc are used to generate the reference signals for the synchroverter. The filter is 4 5/8 inches in diameter and 1/16 inch in thickness and is composed of silver chloride.

The filter system selected was of the ADI (all dielectric interference) or Fabry-Perot type. Since the mechanical properties of silver chloride are highly compatible with the properties imposed on the filter by the system requirements, it was chosen as the filter substrate. Germanium and chiolite ($5\ NaF\text{-}3AlF_3$) were chosen as the thin film materials because of their transparency and large difference in refractive indices.

The transmittance, T, of a Fabry-Perot system, assuming normal incidence and negligible absorption, is given by the well known Airy Formula[1] :



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$$T = \frac{t^2}{(1-R)^2} \left[\frac{1}{1+F\sin 2\emptyset}\right] \qquad \text{(Eq. 1)}$$

Where t is the transmittance through the reflector, R is its reflectance, $\emptyset$ is the optical thickness of the spacer layer and F is Fabry's coefficient of finesse,

$$F = \frac{4R}{(1-R)^2}$$

The half-width of a Fabry-Perot system, the full peak width at one half the peak intensity, may be derived from equation 1. Making a small angle approximation and neglecting dispersion in the reflectors, the half width, $\lambda_{1/2}$, becomes[2]

$$\lambda_{1/2} = \frac{\lambda(1-R)}{m\pi\sqrt{R}} \qquad \text{(Eq. 2)}$$

Where m is the order of interference and λ is the peak wavelength of the transmission band.

This well known expression was extremely important in the design of the CO_2 sensor filter system. Since the sensor depends upon comparing the transmission through a filter centered at the CO_2 absorption band at 4.26 microns to the transmission through a similar filter centered at approximately 3.9 microns, the sensitivity of the system obviously depends, at least in part, upon how well the energy transmitted by the two filters is matched in the absence of CO_2.

The initial design chosen for the filters was a simple 11 layer ADI represented by,

S [HLHLHLLHLHLH]A

where H represents a layer of high index material (Ge) whose optical thickness is one quarter wave at the peak wavelength, L represents a layer of low index material (chiolite) of the same optical thickness, S represents the substrate (AgCl), and A represents air, the external medium.

Since the half-width (equation 2) exhibits considerable dependence on the reflectance of media on either side of the spacer layer (LL), let us examine the properties of the reflectors. In this case, the reflectors may be viewed as simple five layer stacks,

S [HLHLH]

The reflectance of a single dielectric layer on a "semi-infinite" dielectric is given[3] by

$$\bar{r} = \frac{r_1 + r_2 e^{-2i\emptyset}}{1 + r_1 r_2 e^{-2i\emptyset}} \qquad \text{(Eq. 3)}$$

where r_1 and r_2 are the Fresnel reflectance coefficients at the first and second interfaces, and $\emptyset$ is the optical thickness of the dielectric layer.

The effects of interference are maximized when the optical thickness of the layer is one quarter wavelength[4] in which case,

$$\bar{r} = \frac{r_1 - r_2}{1 - r_1 r_2} \qquad \text{(Eq. 4)}$$

To analyze the effects of a five layer coating, one first uses equation 4 to determine the reflectance due to the first layer. Then, since all layers are of the same optical thickness, replace the first layer substrate combination with an "effective substrate" having the same properties. Thus, by a process of reiteration, one calculates through the combination, layer by layer, until the last interface has been taken into account. For normal incidence, when only two filming materials are used alternately and an odd number of films are used beginning with a high index layer, this process yields[4] for 5 films an intensity reflection, R,

$$R = \bar{r}\,\bar{r}^{*} = \left[\frac{N_H{}^6 - N_L{}^4 S}{N_H{}^6 + N_L{}^4 S}\right]^2 \qquad \text{(Eq. 5)}$$

where N_H is the index of refraction of the high index layers
N_L is the index of refraction of the low index layers
S is the index of refraction of the substrates

From this expression, we see that the reflectance of the stack is extremely dependent upon the indices of refraction of the filming materials and on the difference in index between the two materials. Although chiolite exhibits negligible dispersion in the range of 3.5 to 4.5 microns, the index of germanium changes appreciably. Therefore, while we may assume that the refractive index of chiolite (N_L) is the same at 3.9 and 4.3 microns, we must give germanium (N_H) a slightly higher index at 3.9 microns than at 4.3. Since the reflectance, R, depends upon the 6th power of N_H, there will be a significant increase in reflection at 3.9 microns over the value at 4.3 microns. Furthermore, since the half width given in equation 2 depends upon R, the transmission band at 3.9 microns obviously will be narrower than the one at 4.3 microns.

However, if we consider the reflectance of the stacks to be due to a single interface, we can use equation 3 to investigate the transmission through the complete Fabry-Perot system. In this case, since the dielectric is a half-wave layer, equation 3 reduces to

$$\bar{r} = \frac{r_1 + r_2}{1 + r_1 r_2} \qquad \text{(Eq. 6)}$$

However, r_1 and r_2 represent the amplitude reflectance of the stacks, with a sign difference. Hence, since $r_1 = -r_2$ in the conventional Fabry-Perot interferometer, the reflectance becomes zero when the spacer is a half-wave thick. Thus, in the absence of absorption, the Fabry-Perot system has a theoretical 100% transmission at the peak. But, if the reflectances of stacks are not equal, some reflectance will be present even at the peak. The decrease in transmitted energy at 3.9 microns, due to the decreased half-width, can be partially compensated for by mismatching the reflecting stacks in the 4.3 micron filter. This technique was used to improve the "energy match" in the four quadrants of the filter.

The filter was made at Isomet in an 18 inch diameter coating chamber at an average pressure of approximately 5×10^{-5} mm Hg and an average distance of about 20 inches from the filaments. The germanium was evaporated from a tungsten basket and the chiolite from a stainless steel howitzer which was heated by a tungsten filament.

Since the silver chloride substrate had a tendency to warp when heated, no substrate heating was employed. The resulting filter could not withstand washing in warm water. A chiolite-water combination might produce enough sodium hydroxide to cause deterioration in the germanium layers. For this reason, the final filter was sprayed with a protective layer of transparent lacquer (Krylon). This lacquer is quite transparent in the 3.9 to 4.3 micron range and did not significantly effect the optical properties of the filter. It did, however, greatly improve the moisture resistance of the filter element.

Electronics

Detector

A low noise, high sensitivity detector, which would work efficiently in the infrared region, was required. A PbSe detector, Santa Barbara Model 5675-10, was chosen. This detector was 2 mm x 2 mm in size and had an output impedance about 1.5

megohms with a noise equivalent power at 4.26 microns of 5 x 10^{-9} watts.

Preamplifier

The preamplifier characteristics were made to match the detector. The requirements for the preamplifier are a high input impedance, low noise level, temperature stability and minimum drift. These were achieved by employing the circuit shown in figure 7. This circuit uses two transistors: a Texas Instrument 2N2498 field effect transistor and an RCA 2N2270 NPN-silicon transistor. The former has a high input impedance and serves as an impedance converter. The latter serves to provide a stage of gain. This preamplifier has an input impedance of about 600K ohms, a voltage gain of about 20, and a minimum detectable signal of 50 microvolts. Temperature tests were made on the preamplifier and the results are shown in table I. These data show that the preamplifier temperature characteristics well exceed the specifications. Table II gives the frequency response of the preamplifier. The output is down 3db at 15 CPS and 10 KC. This also well exceeds the system requirements. In order to minimize noise pick-up it was found necessary to mount the detector as close to the preamplifier as possible. The preamplifier was placed in a metal can, potted in General Electric LTV-602, and then solder sealed. The potting compound was resilient enough to reduce the effects of shock and the metal can served as a necessary electro-static shield.

Main Amplifier

The main amplifier is a high-gain, low-drift, temperature stable unit. This design was accomplished by the circuit shown in figure 7. It employs five 2N2270 silicon transistors and two 1N1767, 6.8-volt Zener diodes. The diodes provide an isolated power supply both for the first stage of the main amplifier and for the pre-amplifier. The circuit employs d-c feedback for temperature stability. For best performance the output transistor pair, Q4 and Q5, should have their beta's matched to within 5% of each other. The output of the main amplifier is that of a phase splitter with the output of Q3 fed into the base of Q4 and emitter coupled into Q5. The net result is two signals of the same amplitude 180° out of phase. This system provided a signal that when rectified, needed but a small amount of filtering. This in turn reduced the size of R23 and C9, which are determining factors in the overall system time constant. The approximate time constant of the main amplifier is 1.2 seconds. The closed loop voltage gain of the

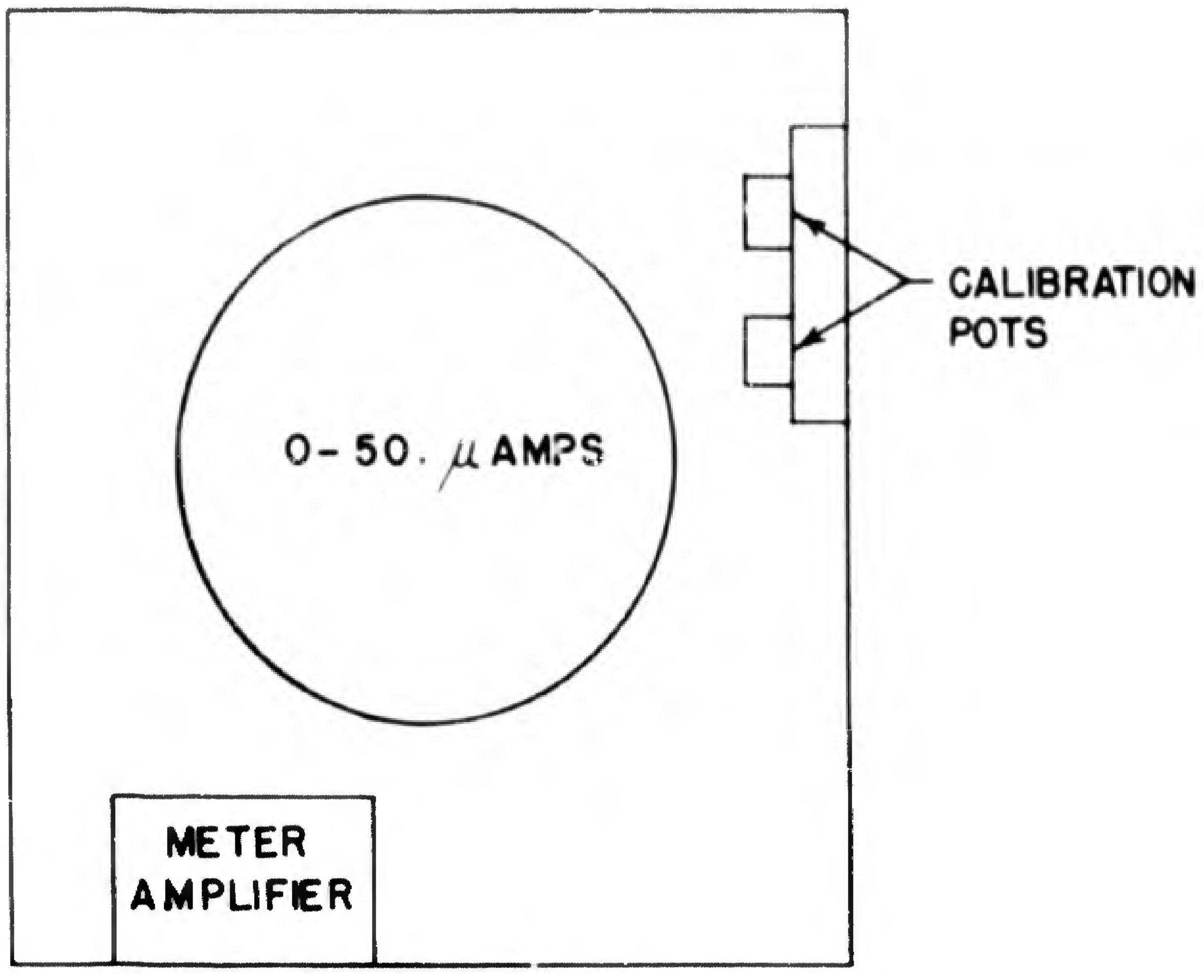

FIGURE 7 REMOTE INDICATOR CUT-AWAY VIEW

TABLE I

Preamplifier Temperature Characteristics

Temp, °C	V_{out}, Rms
19	0.15
31	0.15
42	0.15
51	0.15
62	0.15
72	0.15

TABLE II

Preamplifier Frequency Response

Frequency cps	V_{out} Rms
10,000	0.280
5,000	0.400
200	0.400
60	0.400
20	0.300
15	0.280

main amplifier is approximately 750. The main amplifier temperature stability and frequency response characteristics well exceed the specifications as can be seen in tables III and IV.

The main amplifier is mounted on an epoxy glass board on the bottom of the main chassis as shown in figures 8 and 9.

Voltage Regulator

The CO_2 sensor required its own regulated power supply. A series voltage regulator employing three 2N2270 transistors was designed. Its input is +28-V,d-c and its output is +24-V,d-c. As can be seen in table 5, its stability and temperature characteristics are well within the specifications.

Motor Speed Regulator

For best system performance it was found necessary to design a motor speed regulator. The final circuit appears in figure 3. It employs two 2N2270 transistors and one 2N2339 power transistor. Any change in motor speed changes the frequency of the input signal, and in turn allows greater or less current flow through Q4, the series regulating transistor. This in turn allows more or less voltage to the motor. As can be seen from the data in table 6 the motor speed was constant with temperature.

Photo Pickup and Pulse Reference Pickup

A device was needed to provide synchronous information correlating the position of the synchroverter switch to the color of the filter sector in the main optical path. A system of this type has the advantage of not requiring highly regulated motor speed. The circuit design is shown in figure 3. The output of the phototransistor drives the pulse reference pickup and the synchroverter. The unit employs a 2N2245 silicon phototransistor, two 2N1132 and one 2N2270 silicon transistors. The circuit, with the exception of the phototransistor, is potted with LTV-602 in a metal can for shielding. The temperature and stability characteristics are well within the specifications.

Meter Amplifier

The meter amplifier included in figure 3 was designed as a means for isolating the output of the amplifier from the meter. It employs two 2N2270 silicon transistors. It is a difference amplifier providing high input impedance and extra current gain for greater sensitivity. It has an additional

TABLE III

Main Amplifier Temperature Characteristics

Temp. °C	V_{out}, Rms
20	3.0
50	3.0
62	3.0
68	3.0

TABLE IV

Main Amplifier Frequency Response

Frequency cps	V_{out}, Rms
20	2.1
1000	3.0
2000	3.0
10000	3.0
20000	2.1

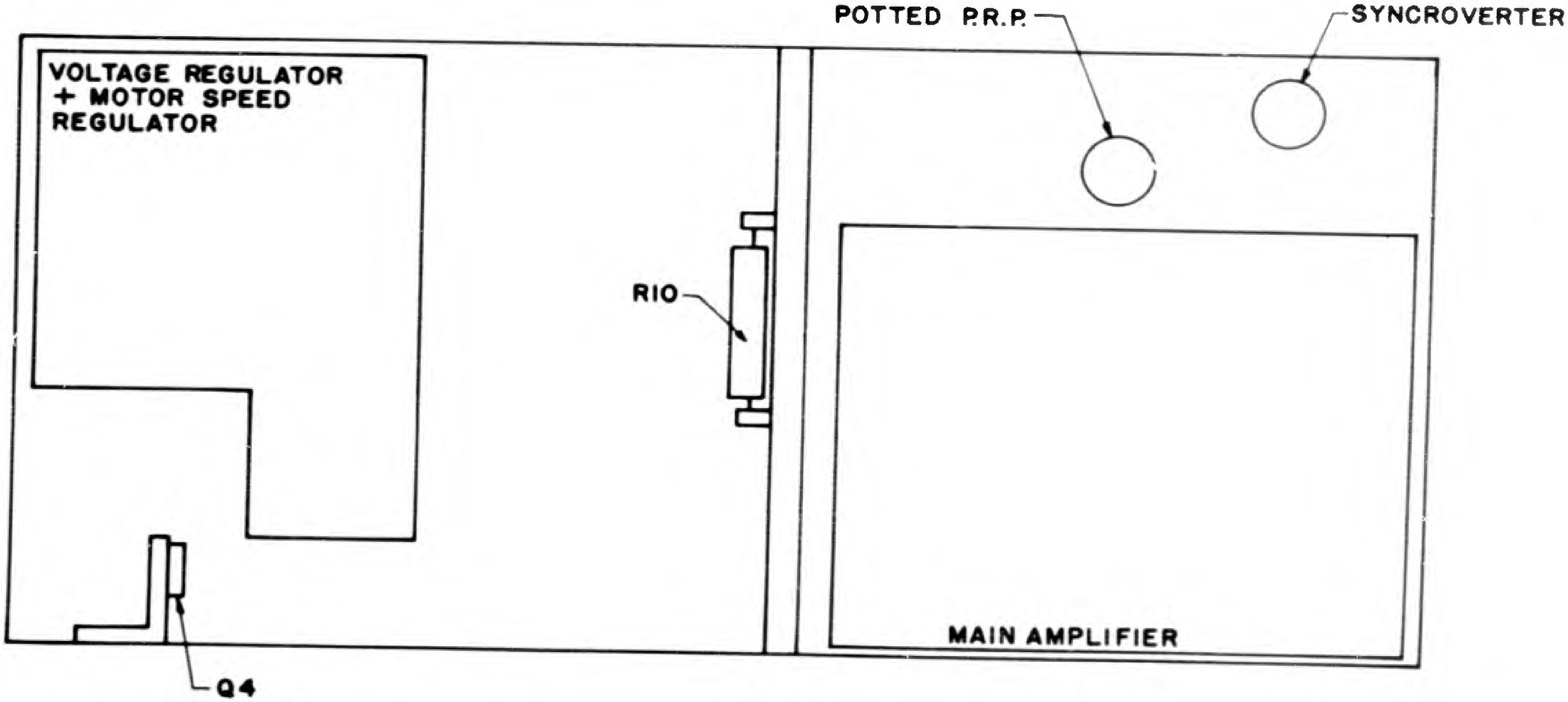

FIGURE 8 BOTTOM VIEW CHASSIS LAYOUT

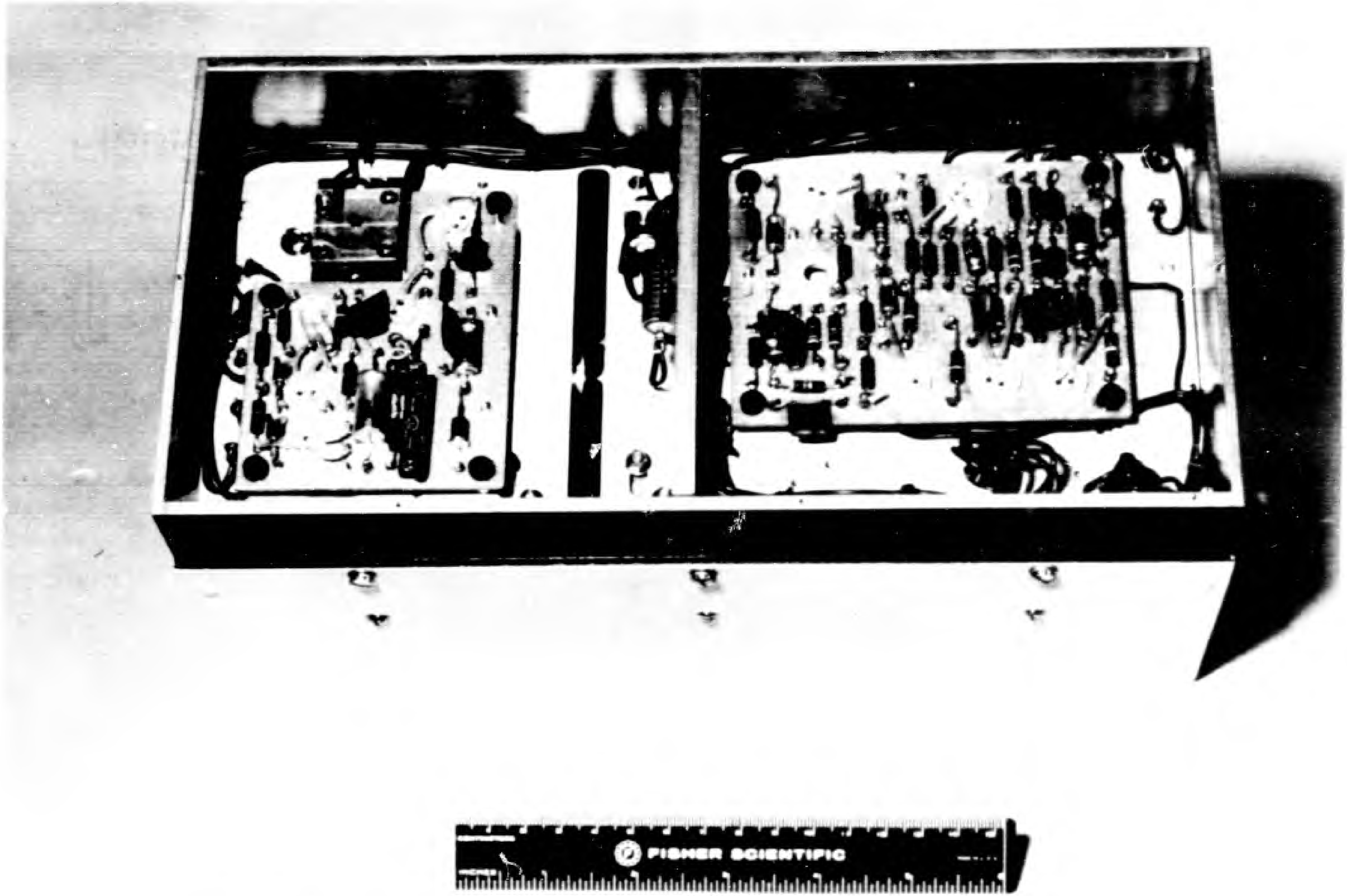

FIGURE 9 - Picture of Carbon Dioxide Sensor with Bottom Removed

TABLE V

Voltage Regulator Temperature Characteristics

Temp. °C	d-c Voltage from Regulator
20	24.0
40	24.0
69	24.0

TABLE VI

Motor Regulator Temperature Characteristics

Temp. °C	Motor Speed as a Function of Amplifier Output Frequency
20	200
40	200
60	200

function in that it is made to be adjustable thereby permitting calibration of the instrument.

Meter

Weston's ruggedized microammeter was chosen for its reliability and ability to meet the shock requirement.

Motor and Noise Suppressor

A Barber-Coleman noise suppressor, Model CYZR246-2, was used to keep down system noise due to the motor. The motor chosen was a Barber-Coleman direct current permanent magnet motor, Type FYLM 43400-51. This is a continuous duty 0.75 amp motor that operates from 27-volts d-c and has a maximum speed of 10,500 rpm.

Air Flow

The air in the sensor should always be the same as that external to the sensor in the environment being measured. Fresh outside air is blown into the unit continuously in order to minimize the system response time. This is accomplished by ducting the outside air through a tube and pushing it out over the lamp by means of a fan blade attached to the main motor shaft. This action simultaneously provides cooling for the lamp.

Weight, Size and Power

The weight, size and power consumption were to be minimal. This imposed a packaging and electronic design problem. By using all solid state components, the power consumption was kept low, and packaging the electronics in hermetically sealed modules, minimum volume was obtained. The power consumption is about 70 watts, 50 watts of which is consumed by the quartz lamp. The final weight of the sensor was 10 pounds.

SECTION VI

CALIBRATION AND TESTS

Calibration Procedure

Allow the CO_2 sensor to warm up for approximately 15 minutes. With a cathode ray oscilloscope, check to see if the output of the pulse reference pickup pin 2, figure 3, is a 200 cps square wave. This is the optimum system operating frequency. If the frequency is not at 200 cps ± 20 cps, adjust pot R11 in motor speed regulator until the proper frequency is attained. Adjust pot R1 of the remote indicator to 0 ohms. The CO_2 sensor is then placed in a dry box. The remote indicator (Figure 9) remains external to the dry box. The dry box and the CO_2 sensor are then flushed with dry nitrogen. Flush the nitrogen directly into the air intake of the sensor to insure that the sensor is completely flushed. The remote readout indicates the residual output of the sensor. This is compensated by adjusting pot R2 of the remote indicator unitl the meter reads 0 microamperes. The dry box is then flushed with gas whose partial pressure of carbon dioxide is 40 mm Hg. If this is not convenient, weighed pellets of dry ice may be introduced into the dry box. The weight of dry ice needed depends on the volume of the dry box. A box 2 feet x 2 feet x 2 feet requires 2.2 grams dry ice for concentration of 40 mm Hg. With a 40 mm Hg concentration of CO_2 in the dry box, the meter will probably read off scale because of the high sensitivity. This is compensated for by means of the attenuating pot R1 of the remote indicator. R1 is adjusted so that the meter reads 50 microamperes. After this adjustment both the dry box and the sensor are flushed with dry nitrogen. Known quantities of CO_2 corresponding to partial pressure from 0 to 40 mm Hg are then flushed into the dry box and the meter current in microamperes is noted. The calibration curve is obtained by plotting the output current for various values of the CO_2 pressure. Figure 10 gives the calibration of the sensor prior to shipment.

Reproducibility

It is important that the sensor maintain its stability once a calibration has been established. Tables VII, VIII, IX give the performance data for three separate tests made to determine reproducibility. The data indicate a high degree of stability.

The tests were performed by allowing weighed pellets of solid carbon dioxide to evaporate in a dry box containing the

TABLE VII

First Test Run

Grams of Dry Ice	Meter Reading Microamperes
0	0
0.5	21.5
1.0	32.5
1.5	40
2.0	46.5
2.2	49
0	0

TABLE VIII

Second Test Run

Grams of Dry Ice	Meter Reading Microamperes
0	0
0.5	21.0
1.0	32
1.5	39
2.0	45
2.2	48
0	0

TABLE IX

Third Test Run

Grams of Dry Ice	Meter Reading Microamperes
0	0
0.5	22
1.0	32
1.5	39.5
2.0	47
2.2	49.5
0	0

sensor. After each pellet of dry ice evaporated, a period of 15 minutes was allowed for equilibration of the atmosphere in the dry box before a sensor reading was made. After each reading the dry box was flushed with dry nitrogen.

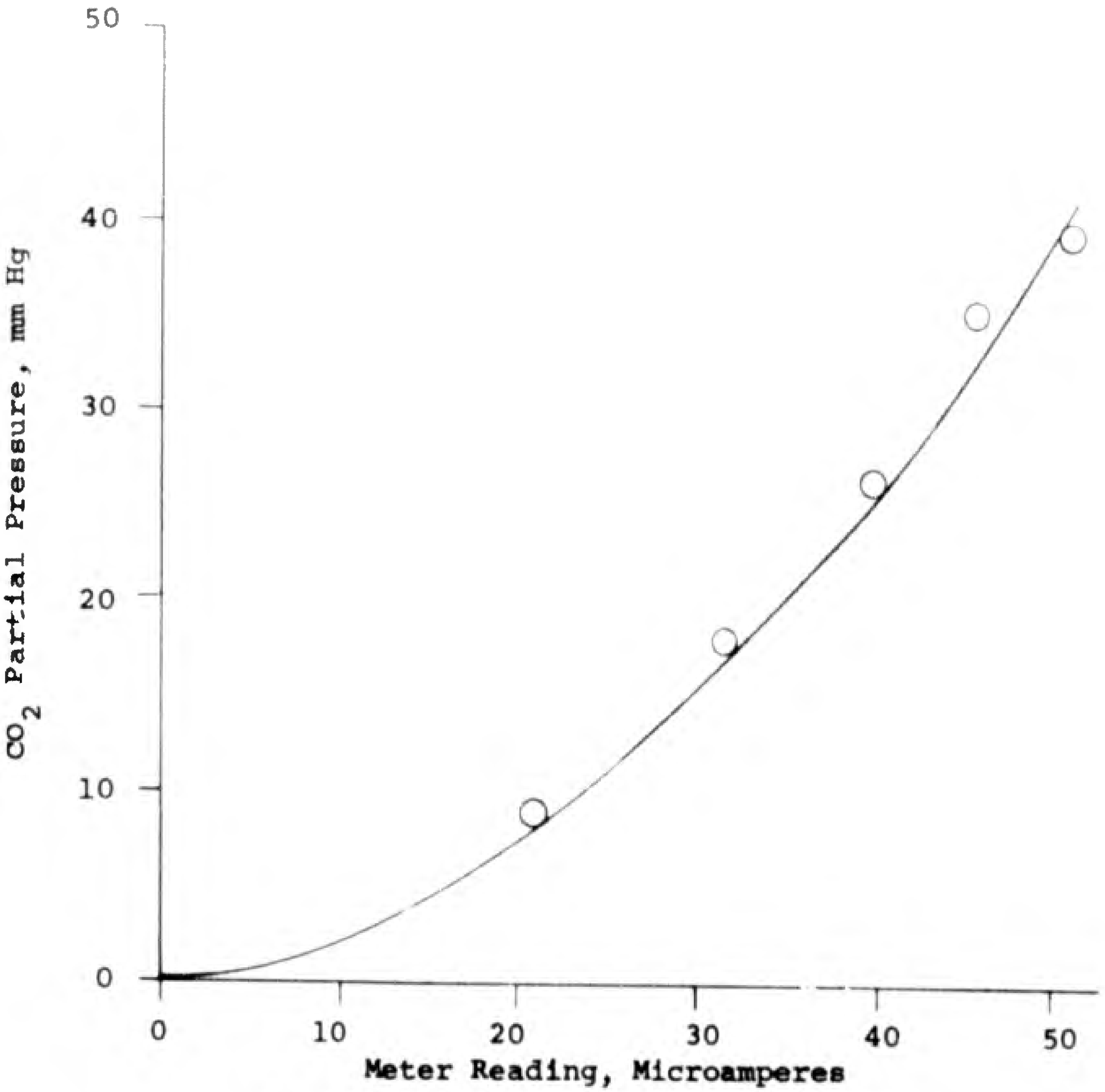

FIGURE 10 - SENSOR CALIBRATION CURVE

SECTION VII

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13. ABSTRACT

The objective of this program was to design and develop a compact airborne CO_2 sensor unit capable of sensing and measuring the CO_2 content of manned, sealed environments. A prototype carbon dioxide sensor was designed, built, and calibrated. The sensor operates by alternately comparing the infrared absorption of the air sample at 4.26 microns, where CO_2 exhibits strong absorption and at 3.90 microns where it has little absorption. A two color rotating filter provides sampling 200 times per second. The unit weighs 10 pounds and has a power consumption of 70 watts. The instrument is capable of detecting a concentration of at least 0.30% CO_2 and has full scale capability to 5%.

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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Infrared						
Instrumentation						
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