New Advances in Non-Dispersive IR Technology for CO_2 Detection

John W. Small and Wayne L. Odegard

Astro International Corporation

ABSTRACT

This paper discusses new technology developments in carbon dioxide (CO_2) detection using Non-Dispersive Infrared (NDIR) techniques. The method described has successfully been used in various applications and environments. It has exhibited extremely reliable long-term stability without the need of routine calibration. The analysis employs a dual wavelength, differential detection approach with compensating circuitry for component aging and dirt accumulation on optical surfaces. The instrument fails "safe" and provides the operator with a "fault" alarm in the event of a system failure. The NDIR analyzer described has been adapted to NASA Space Station requirements and a breadboard furnished under NASA contract NAS8-17612.

THE MEASUREMENT OF CARBON DIOXIDE (CO_2) GAS by Non-Dispersive Infrared (NDIR) detection has been the analytical method of choice for over four (4) decades. While innovative techniques to minimize limitations of traditional NDIR approaches have significantly improved CO_2 analyzer performance, problems still remain related to cost and applications using standard techniques. The purpose of this paper is to briefly relate some alternate NDIR CO_2 detection approaches and describe a unique technique adapted to certain industrial processes, safety monitoring and NASA's Space Station program. It is a "fail-safe", open path, dual wavelength, dual slope integration method, which has successfully been used in such diverse environments as the Sahara desert, North Sea and various petrochemical plants worldwide.

REVIEW OF CURRENT CO_2 NDIR ANALYZER APPROACHES

The phenomenon of infrared energy absorption by certain gases at specific wavelengths has been applied to the analysis of many gases of interest. CO_2 has a strong absorption band at 4.3 microns (Figure 1), which is generally used in all NDIR techniques. The infrared source is directed down a path of known length and the infrared absorption by the gas molecules is detected as a measure of concentration.

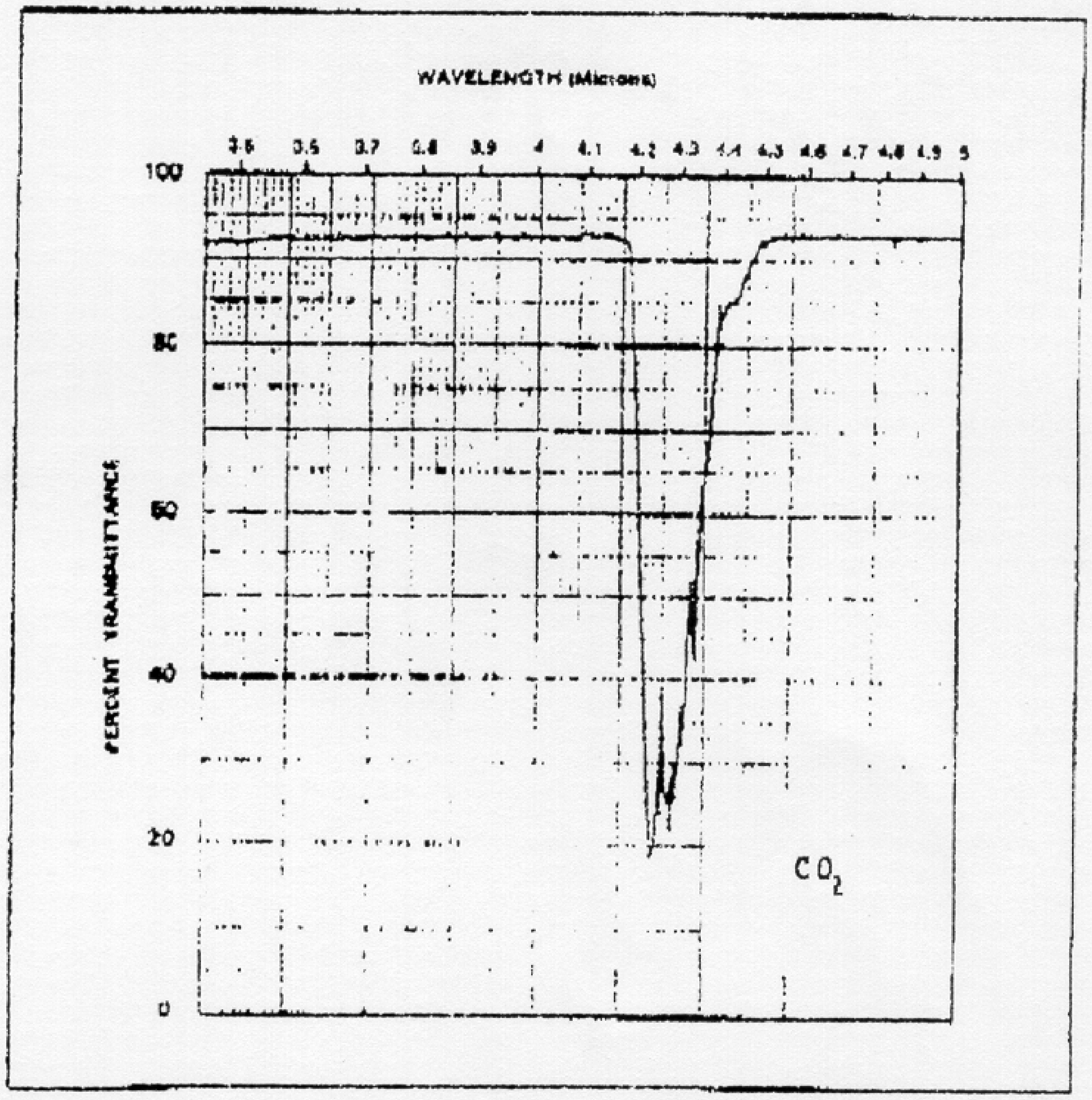


FIGURE 1. CO_2 SPECTRUM

CLOSED SAMPLE AND REFERENCE CELL TECHNIQUE

Figure 2 depicts a popular method of CO_2 detection used for many years.[1] It consists of a reference cell and a sample cell, each with individual infrared (IR) sources. The figure illustrates a capacitive diaphram detector, which becomes distended as the partial pressure of the sample cell changes related to the reference cell, due to the absorption of IR energy by the gas molecules in the sample cell. The differential measurement is quantified and directly related to gas concentration. While some significant improvement was gained in substituting solid state IR detectors for capacitive detectors, problems related to aging rate differences in multiple IR sources and detectors still caused sensor drift.

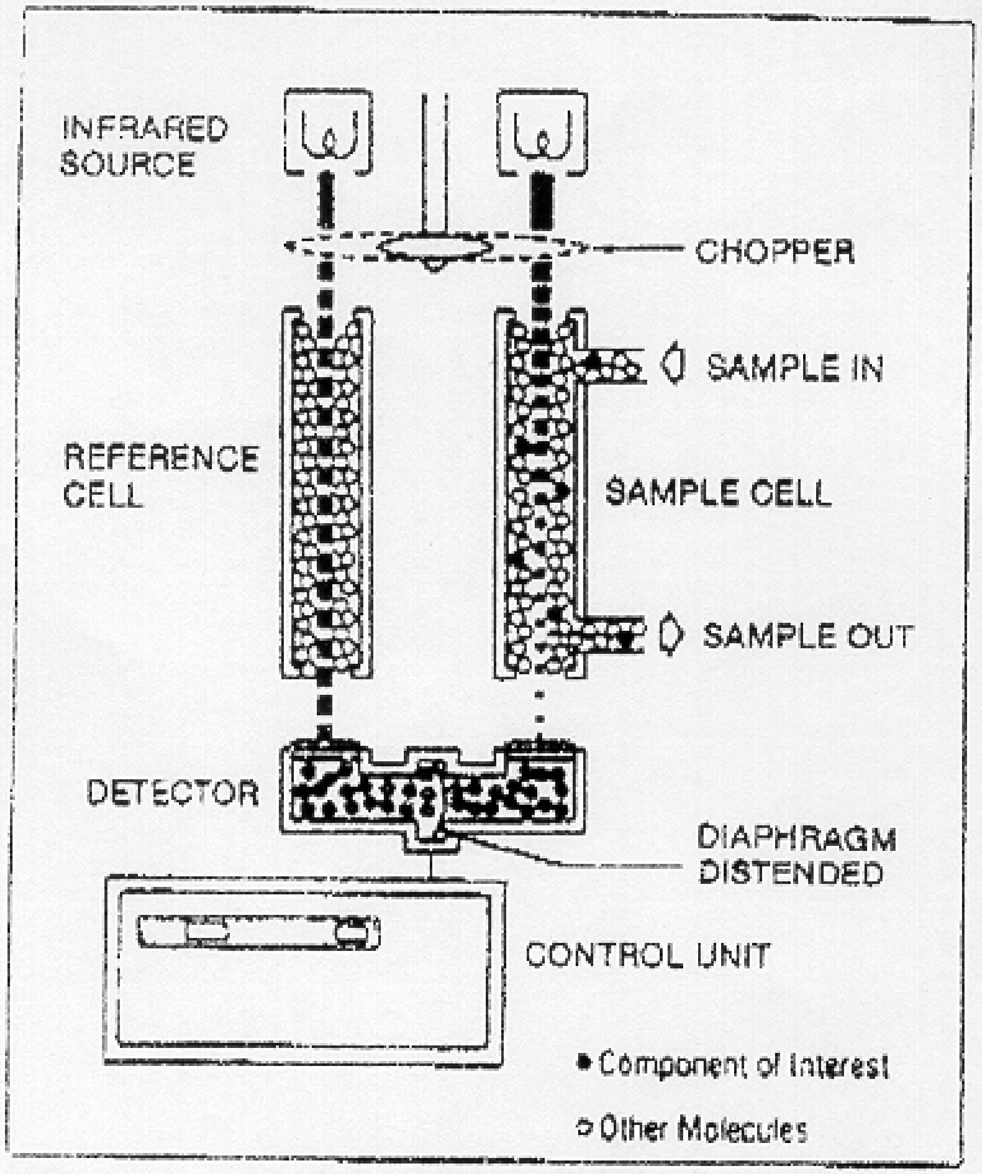


FIGURE 2. LUFT DETECTION PRINCIPLE NON—DISPERSIVE INFRARED ANALYZER

Figure 3 shows another approach to NDIR.[3] It uses dual IR sources and dual detectors to eliminate all moving parts, such as a beam chopper. The system incorporates an optical reference path for system gain calibration. The reference filter is chosen to provide an absolute "zero", with no response to any gas or water vapor present. The measurement path contains an optical filter selected for the gas to be analyzed. Thus, when the sample gas enters the measuring cell, a differential measurement for the "measuring" path and the "reference" path is made, resulting in a gas concentration analysis. The normal drift of the IR sources and detectors associated with aging and associated varying drift rates is corrected in calibration with standard gases at regular intervals.

A summary of the problems of using a reference cell and multiple detectors and/or sources follows:

1. The reference cell, which is normally filled with a "reference" gas can leak, resulting in sensor drift. This is a particularly annoying problem if a slow leak or a changing leak rate develops.

2. The use of either a dual IR source and/or dual IR detector has the obvious shortcoming of producing varying drift rates associated with aging.

3. In dual path systems (separate reference and sample paths), differences in IR absorption caused by uneven coating of optical surfaces results in erroneous measurements. This effect is directly proportional to the "cleanliness" of the gas sample and consequent deposits on the sample cell optical surfaces.

4. Most closed sample cell NDIR analyzers use a highly-reflective surface (normally gold) to collimate the IR beam, which directly corresponds to overall system gain. Many field reports relate peeling or corrosion of gold-lined substrates, resulting in drift.

5. A closed sample cell requires the use of a pump or aspirator to draw the sample, creating an external failure mode (eg. a pump failure or a ruptured line), undetected by the analyzer, except for additional flow monitors, which do not normally detect downstream leaks (eg. in the sample cell).

In summary, the above described systems using separate references and sample cells, multiple sources and/or detectors have some inherent shortcomings because changes occurring in one IR path related to the other are, for the most part, undetectable. One may ask: which is drifting, the reference or the sample path? Frequent calibration is used to minimize these problems but the systems do not fail "safe" or alert the operator when a major fault occurs.

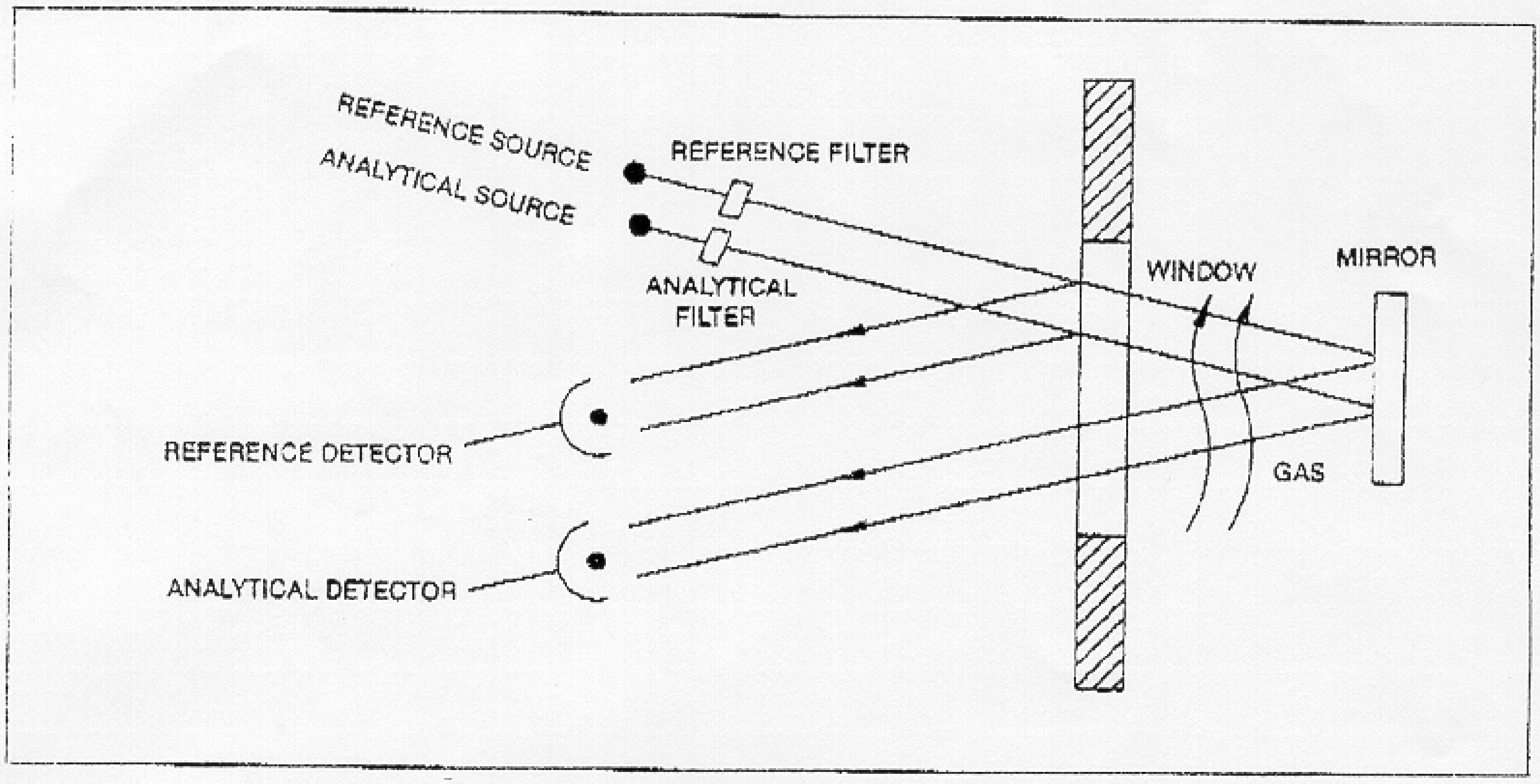


FIGURE 3. DUAL BEAM NDIR WITH DUAL IR SOURCES & DETECTORS

"FAIL-SAFE"*, OPEN PATH, DUAL WAVELENGTH NDIR

REQUIREMENTS FOR FAIL-SAFE MONITORING - Design requirements of a system to reliably and safely monitor gases are as follows:

1) The system should be "active", i.e. it should continuously monitor the environment by performing an operation which results in the direct sensing and quantitative measurement of the CO_2 gas present, rather than await a secondary effect for detection. The absence of the active operation must result in a "fault" warning indicating a sensor malfunction. In other words, it must fail "safe".

2) The device should be self-checking, automatically calibrate zero, eliminate span drift, not require periodic field maintenance to verify its operation and provide a "fault" alarm in the event of a malfunction.

3)The sensor should not be "blinded" in any gas concentration (even 100%) and operate in any atmosphere.

4) The sensor should not be poisoned by any chemical agent or environment.

5) The sensor should be immune to interferences from other gases and water vapor to eliminate erroneous results.

6) The sensor must be stable in any application. Its sensitivity must not be degraded with time or gas exposure.

7) Detection must be reliable, fast and therefore cannot rely on external sample systems.

SYSTEM DESCRIPTION — IR GAS DETECTOR - A non-Dispersive-Infrared (NDIR) Detector sensitive to CO_2 was developed to meet all of the above-mentioned design requirements (reference figure 4). It is powered by 24 volts DC and provides a 4-20 mA analog signal output. A system "Fault" is indicated by "O" mA output.

The IR Transmitter uses a single beam dual wavelength system with an open sample cell arrangement. Two discrete, narrow-band optical interference filters are used to a) detect the CO_2 gases and to b) provide a true "Zero" for an absolute reference

The IR transmitter has automatic compensating circuitry for IR source and detector aging, dirt accumulation on the window and system gain changes. Automatic Gain Control is employed in the detection process. An alarm signal is transmitted if the infrared signal strength falls below allowable compensation limits or if an instrument malfunction occurs. Fail-Safe operation and system status are automatic.

OPERATION - The IR Gas Detector's unique wavelength ratioing and differential integration technique virtually eliminates zero drift or sensor deterioration.

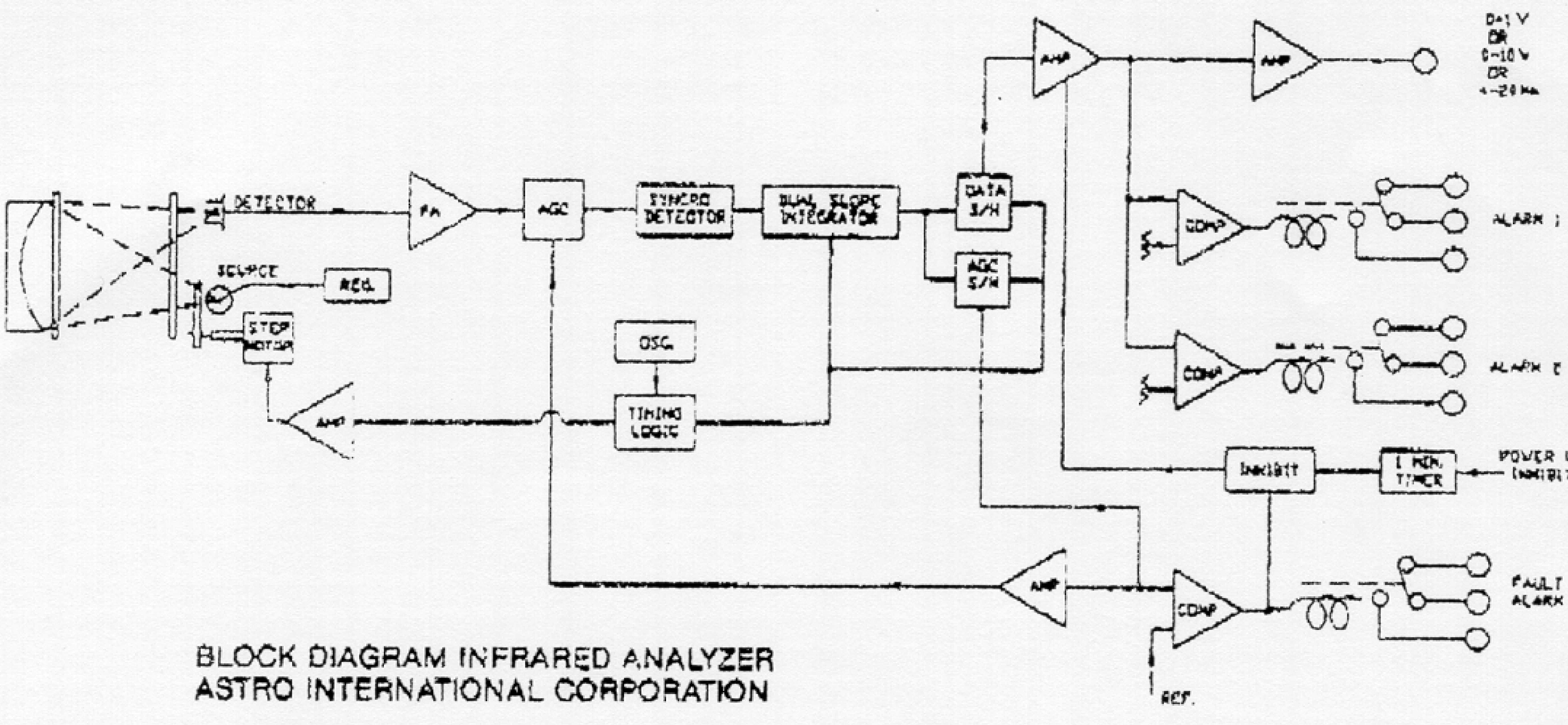
A) Infrared energy from the IR source passes through two narrow band interference filters, a sapphire protective window and open cell and is reflected and focused by the spherical mirror back through the window onto the solid-state detector.

B) The sample filter wavelength is selected for the specific line spectra absorbed by the gas to be analyzed.

C) The "Zero" or reference filter is chosen for non-absorbance characteristics of moisture and all other gases present. True "Zero" is checked and reset 3 times/second.

D) Synchronous detection, dual wavelength ratioing and processing of reference and sample signals are then performed to eliminate the drift associated with alternate IR detectors.

SENSOR RESPONSE - Measurement of CO_2 gas of up to 100% concentration in any environment is easily obtainable with this design. Typical CO_2 responses are illustrated in figure 5. Since there are no sample system delays with the open cell configuration, system response time is on the order of 3 seconds or less.



BLOCK DIAGRAM INFRARED ANALYZER
ASTRO INTERNATIONAL CORPORATION

FIGURE 4. BLOCK DIAGRAM INFRARED ANALYZER ASTRO INTERNATIONAL CORPORATION

*"FAIL-SAFE" is defined as the inherent characteristic of the instrument to indicate faulty operation in any failure mode.

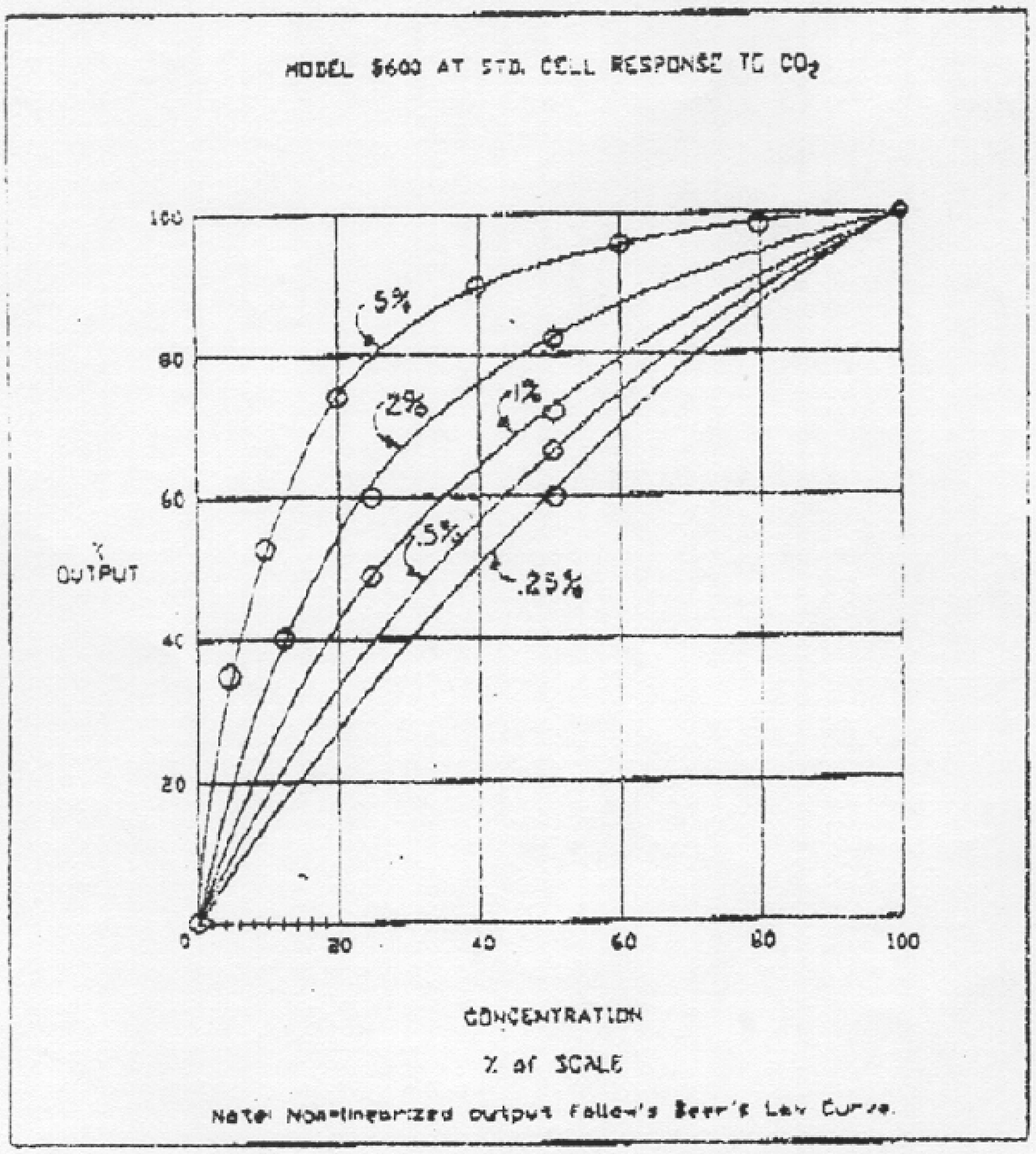


FIGURE 5. MODEL 5600 AT STD. CELL RESPONSE TO CO_2

MAINTENANCE - The IR Gas Detector described requires no periodic field adjustment or calibration. "Maintenance-On-Demand" is indicated by the "Fault" alarm. The "Fault" alarm signal is transmitted when either the infrared energy is decreased beyond the automatic electronic compensation capability or if a component malfunctions. When the "Fault" alarm signal activates due to insufficient energy reaching the detector beyond the electronic compensation, the probable cause is a dirty optical window. Ease of window cleaning (usually only required in the absence of a "dust cover" in a dirty environment) is a major feature of the IR Transmitter. No tools are required. The protective window need only be wiped clean. The IR transmitter does not have to be turned off, requires no realignment, recalibration, nor even opening of the enclosure, enabling rapid return to service.

FIELD RESULTS - The SIRA Institute in the United Kingdom has tested the IR detection technique used in the Astro NDIR Detector. Evaluation Report E 1563.82 is available to members of the Institute.

SENTER FOR INDUSTRIFORSKNING (SI) in Oslo, Norway has evaluated the Astro NDIR Gas Detection method in connection with its approval for use as a combustible gas detector in Norway, including North Sea operations. The evaluation involved a six (6) month long-term test.

OTHER APPLICATIONS - Use of the IR Transmitter for ambient monitoring of combustible levels of carbon monoxide (CO) and combustible gases (C-H) has successfully been accomplished. Process monitoring for either C-H, CO or CO_2 use a closed process cell configuration. Figure 6 shows the configuration used as the CO_2 detector incorporated into a Total Organic Carbon analyzer for the Space Station.

SUMMARY AND CONCLUSION - The new infrared technology applied to the monitoring of carbon dioxide has afforded the user an economical, fail-safe method of detection which has eliminated the major failure modes of alternate sensors. Field reports from industrial and governmental users have expressed significant enhancement in detection, reliability and lower maintenance costs of its operation.

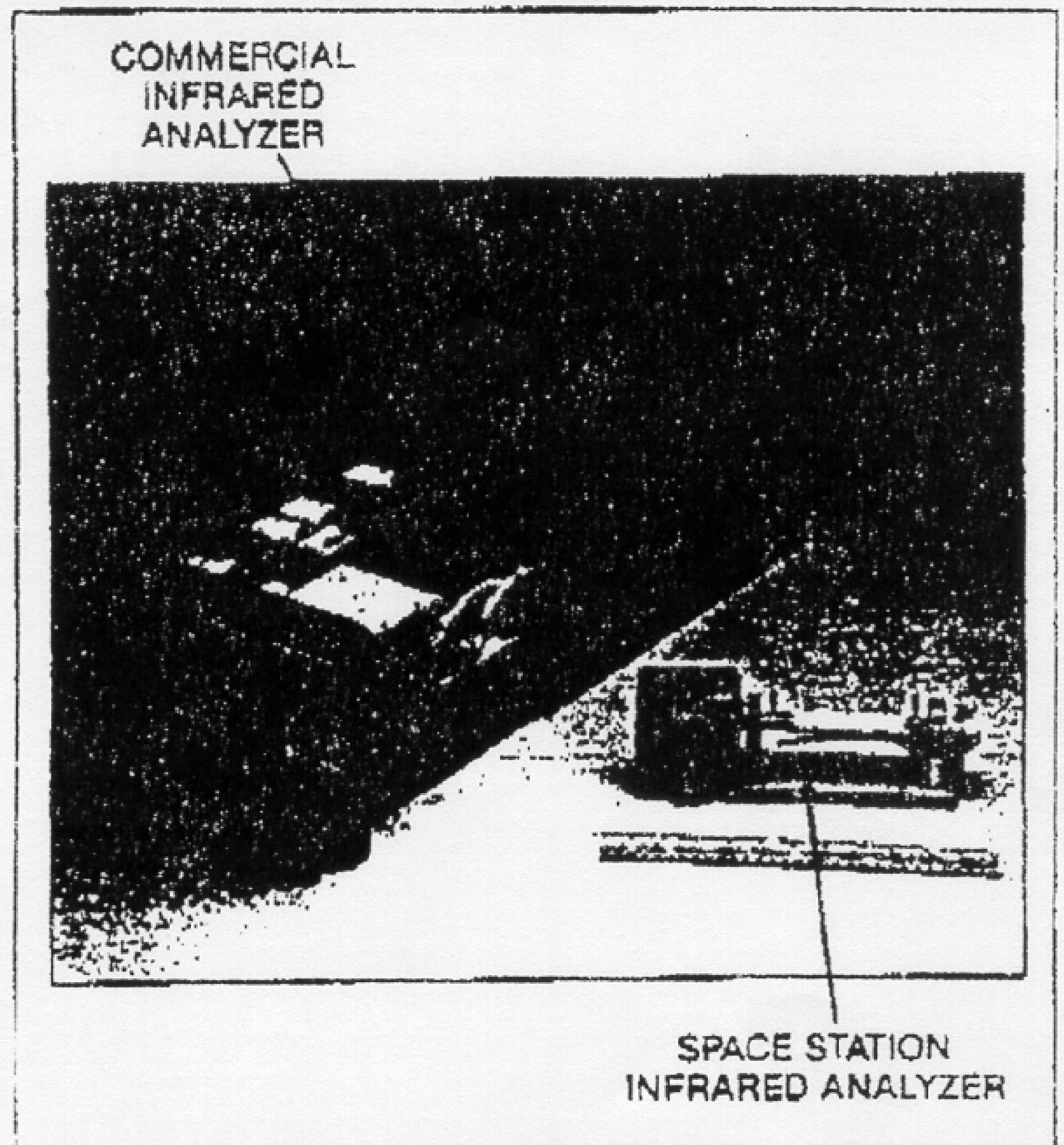


FIGURE 6. SPACE STATION/COMMERCIAL NON—DISPERSIVE INFRARED ANALYZER

REFERENCES

(1) Beckman Industrial Division, Rosemont Analytical, Non-Dispersive Infrared Analyzer, December, 1987.
(2) Simrad Optronics, Infrared Gas Detector for Offshore Platforms and Petro-Chemical Plants, February, 1986.
(3) NASA Contract No. NAS9-17612, Final Report.
(4) NASA Contract No. NAS9-16846, Final Report.
(5) NASA Contract No. NAS9-17282, Final Report.
(6) EPA Standard Method 415.1.
(7) Safranko, J.W., Schuler, J.D., and Small, J.W., American Laboratory 15 (8), 56-65 (1983).