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Volume IV- Appendix G
Task 7 Report
Advanced Instrumentation: Technology Database Enhancement

Technical Report

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ADVANCED LIFE SUPPORT ANALYSES (Contract No.: NAS8-38781)

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Task 7 - Advanced Instrumentation/Sensors Database Modification

The purpose of this task was to add to MDSSC Sensors Database, including providing additional information on the instruments and sensors described in the database and adding information about other instruments and sensors applicable to P/C ECLSS or CELSS which were not previously included. The Sensors Database was reviewed in order to determine the types of data required, define the data categories, and develop an understanding of the data record structure. An assessment of the MDSSC Sensors Database identified limitations and problems in the database. Guidelines and solutions were developed to address these limitations and problems in order that the requirements of the task could be fulfilled. Following the guidelines set forth, the MDSSC Sensors Database was broken into smaller relational databases based on sensor types shown in Exhibit 1, data fields not applicable to a given sensor type were deleted, some additional fields were added, and new report forms were made for each sensor database to present the only relevant information in report form. The sensor data was verified, additional sensor data information was added, sensor operational specification data in each description category was converted to one standard unit, new references were added, and new sensor technologies were added to some of the sensor type databases. In addition to these changes, Appendices B through H documentation was created in order to replace the Appendices B through H (Sensor Database) in McDonnell Douglas Space Systems Company report entitled "ECLSS Integration Analysis - Advanced ECLSS Subsystem and Instrumentation Technology Study for the Space Exploration Initiative". As shown in Exhibit 1, each appendix is representative of a given sensor type database. These appendices include the information printed out on the new report form, sensor figures on new figure report forms, sensor and figure listing, an additional reference summary, and MCDSSC's original brief sensor type description.

SENSOR TYPE	Appendix	Number of Sensor Technologies	
		MDSSC Database	New Database
Microbial	B	17	17
Chemical	C	32	32
Conductivity	D	3	3
Flow Measurement	E	11	11
Moisture/Humidity	F	9	11
Pressure	G	10	12
Temperature	H	7	9

Exhibit 1. Sensor Types Included in MDSSC Sensors Database

An assessment of the MDSSC Sensors Database identified limitations in the database record structure. It was determined that the record definitions, in general, were usable but misleading or incomplete. The database was designed as a general instrumentation and sensors database in which all 90 sensor technologies entries were given the same descriptive data fields. Many of the data fields were not applicable to a given sensor type and many of the fields that required numeric inputs were defined as a character fields in order to allow for proper unit notation for a given sensor type. This database design provide some search and sort capability, but substantially limited detailed search and sort capabilities that are common for most computerized databases due to the inability of databases to search for a given numeric range in a character field. The information for each instrumentation or sensor from this database was presented in a general report form. This required presenting data information that was not applicable for a given sensor type and was represented as "---" in the data fields of the report form. Many data fields could only be a value for a particular sensor design. It was determined that some general philosophies for building databases were not used, such as 1) enter data at lowest level, and 2) several small relational databases are better than one large conglomerate database.

In order to provide a more useful database, SRS recommended working within the existing Sensors Database structure and developing guidelines for entering data. After further consideration, guidelines for modification of the database structure were developed. The guidelines are 1) retention of all existing data, 2) creation of separate, but relational, databases per sensor type, 3) creation of unique record structures per sensor type including the deletion and/or addition of data fields, and 4) creation of unique report forms, input forms, indexes, etc. per database. These guidelines were implemented in order that the modifications could be made allowing for easier and or meaningful data entry and database operations.

In addition to changing the record structure, the data in each sensor database was verified and modified, if required. Additional references were used in order to verify the sensor operational data entered and to provide additional sensor information. The additional information included a more detail description of operational parameters, such as ranges, and important operational concerns (performance, environment,etc.). The variables used in the previous performance equations were defined and additional technology performance equations, with their variable descriptions, were added. The operational class description was changed for some sensor technologies to make them consistent with the operational class described in the MDSSC Sensor Database manual. Some of the data fields were deleted and some were modified in order to develop an independent but relational database. The non-applicable fields were deleted so that unrelated data fields for the temperature sensor types would not be shown in the input data forms. Some of the character fields were modified by increasing or decreasing in size to allow for

additional information and changed to numeric fields to allow for more detailed database search and sort capabilities. In order to present only the information related to a specific temperature sensor technology, a new report form was developed. These report forms are similar to the report form used for MDSSC Sensors Database, due to customer's information requirement needs, but with the exceptions of increased description and reference fields size, the omission of non-applicable sensor data fields and information, and addition of relative data fields.

Each sensor database originally included a number of sensor technology rating categories (Automation, Reliability, Development Potential, and Score) for which rating or scaling schemes were not describe in the MDSSC sensor database documentation. These categories can provide a very useful means for comparison of the various related sensor technologies for a given ECLSS subsystem technology. Therefore, the rating schemes for each category should be defined and the ratings information entered into each sensor databases. The sensor information report forms can then be easily modified in order to include ratings information.

The appendices (B through H), included in the main appendix of this document, are to be used as a replacement for the sensor database appendices (B through H) in McDonnell Douglas Space Systems Company (MDSSC) report entitled "ECLSS Integration Analysis - Advanced ECLSS Subsystem and Instrumentation Technology Study for the Space Exploration Initiative". All format and page numbering schemes used by MDSSC were used in the new sensor and instrumentation database appendices. The changes to the appendices include: new report forms print outs for each sensor type (or sensor database) with only relevant sensor type data included; updated and modified sensor data and information; additional sensor and instrumentation figures; new figure report forms; and a reference summary, located at the beginning of each appendix, for each sensor type. The new appendices were copied in a double sided format so that the sensor or instrumentation information and description report forms are always shown on the left hand side of the document and corresponding sensor figure, if available, is shown on the right hand sided of the document. This will allow easy replacement or modification of sensor information and figures.

As noted on the new forms, some of the sensor data categories (Power, Weight, Volume, Operational Temperature Range, and Operational Pressure Range) are design specific data and should be entered into the database when it is made available. The information, that has already been entered into the database for these categories, includes some design specific data selected for a specified sensor. This information can be misleading, in many cases, and should verified when each specific design case.

Appendix

The following appendices (B through H) are to be used as a replacement for the sensor database appendices (B through H) in McDonnell Douglas Space Systems Company (MDSSC) report entitled "ECLSS Integration Analysis - Advanced ECLSS Subsystem and Instrumentation Technology Study for the Space Exploration Initiative". All format and page numbering schemes used by MDSSC were used in the new sensor and instrumentation database appendices.

Appendix B

Microbial Sensors

Microbial Sensors

List of Figures

Microbial Sensors Reference Summary

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14. The Vitek Immuno Diagnostic Assay System (VIDAS)	5, 11
15. The Vitek System	5, 12
16. Two Dimensional Fluorescence Spectroscopy	1
17. Volatile Product Detection	7

References

1. Chou-pong Pau, Isiah M. Warner, and Thomas M. Rossi, "Two Dimensional Fluorescence Spectroscopy Analytical Chemistry", Vol. 7, No. 2, 1988.
2. Dean Monroe, "Enzyme Immunoassy", Analytical Chemistry, Vol. 56, No. 8, July 1984.
3. E.B. Rogers, D.B. Seale, M.E. Boraas, and C.V. Sommer, "Ecology of Micro-organisms in a Small Closed System: Potential Benefits and Problems for Space Station", SAE 891941, 1989.
4. I. J. Higgins, G. Hall, and A. Swain, "Analytical Strategies in Biotechnology", Trend in Analytical Chenstry, Vol. 8, No. 1, 1989.
5. Kent Schien, Sean D. Crosby, J. Wayne Lanham, Ph. D., and James C. Serati, "Microbial Monitoring for Human Exploration Initiative", Report, 1990.
6. Leonard Baskin, "Biosensors Offer Real-Time Diagnostic Capability but Broad Application Awaits Cheaper Couple Designs.", The Medical Business Jounal,September 15,1989.
7. M. V. Kilgote, Jr., R. J. Zahorchak, S. S. Wood ward, D. L. Pierson, and W. F. Arendale, "Definition of a Near Real Time Microbiological Monitor for Application in Space Vehicles", SAE 891541, 1989.
8. Oliver J. Murphry, Tom D. Roger, and Roger Lorenzo, "Technology fo the Rapid Enumeration of Bacteria. A Portable Biosensor for Inflight Monitoring of Spacecraft Water", Proposal to NASA RD-89-198, Oct. 1989.
9. "Microbial Load Monitor (MLM) Final Report, MDC E1879, 30 June 1979, McDonnell Douglas Astronautics Company - St. Louis, McDonnell Douglas Corporation.
10. BACTOMETER Brochure, BACI 1188-10K, Vitek Systems Inc., Industial Division
11. VIDAS Brochure, VTK 101088-15K, Vitek Systems Inc., Industrial Div.
12. 1990 Clinical Catalog and Price List, VTKC1289, Vitek Systems Inc.

Microbial Sensors

A microbial sensor is composed of two parts: a biological molecule or cell which detects the analyte, and a transducer, which converts the detector event into an electrical signal. The biological components fall into two categories:

1) Biocatalysts: enzymes microbes, plants and animal cells

2) Bioreceptors: antibodies, lectins, cell membranes receptors, etc. These are non catalytic and usually irreversible.

SENSOR NAME : **Adenosine Triphosphate Measurement (ATP)**

SENSOR INFORMATION

SUBSYSTEM: WRM

TECHNOLOGY: All in WRM

SENSOR TYPE: BIO

OPERATION: Biology + HPLC or Fluorescence

ACCURACY: ± --- %

RESOLUTION: 1.0E -7 G

NO. OF DETECTABLE MICROBES: 8

DETECTABEL SPECIES: Living Cells

SELECTIVITY RATING: 2.0

Operational Environment

TEMP. RANGE: ---

PRESS. RANGE: ---

POWER: --- W*

WEIGHT: --- LB*

VOLUME: --- FT^3*

CYCLE TIME: --- MIN.

LIFETIME: --- YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

Adenosine Triphosphate (ATP) is a molecule associated with energy transport in biological systems and occurs only in living cells. It is easily detectable photometrically or by HPLC. An increasing background signal would indicate bacterial growth and suggest a more specific measurement. Measurement of ATP is a good method for providing early warning of microbial growth.

REFERENCE:

E. B. Rogers, D. B. Seale, M. E. Boraas, and C. V. Sommer, "Ecology of Micro-organisms in a Small Closed System: Potential Benefits and Problems for Space Station", SAE 891941, 1989.

Sensor Figure Not Included

SENSOR NAME : **Bactometer**

SENSOR INFORMATION

SUBSYSTEM: WRM	TECHNOLOGY: All in WRM	
SENSOR TYPE: BIO	OPERATION: Bioelectrical	
ACCURACY: ± 1.00 %	<u>Operational Environment</u>	POWER: 1200 W*
RESOLUTION: 1.0E -9 G	TEMP. RANGE: ---	WEIGHT: 110 LB*
NO. OF DETECTABLE MICROBES: 8	PRESS. RANGE: ---	VOLUME: 3.7 FT^3*
DETECTABEL SPECIES: All Microbes		CYCLE TIME: 27.00 MIN.
SELECTIVITY RATING: 3.0		LIFETIME: --- YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

The Bactometer is a fully automated single module instrument that can detect bacteria in virtually any type of sample by detecting changes in electrical current caused by microbial growth. The operator can choose the detection method, which can be based on either changes in conductance, capacitance, or impedance. 128 individual samples can be handled simultaneously. The identity and progressive status of each sample is automatically indicated on the display screen.

REFERENCE:

Kent Schien, Sean D. Crosby, J. Wayne Lanham, Ph. D., and James C. Serati, "Microbial Monitoring for Human Exploration Initiatives", Report, 1990.

BACTOMETER Brochure, BACI 1188-10K, not dated, Vitek Systems Inc., Industrial Division.

Sensor Figure Not Included

SENSOR NAME : **Biosensor**

SENSOR INFORMATION

SUBSYSTEM: WRM	TECHNOLOGY: All in WRM	
SENSOR TYPE: BIO	OPERATION: Biochemical	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER: --- W*
RESOLUTION: 1.0E -9 G	TEMP. RANGE: ---	WEIGHT: --- LB*
NO. OF DETECTABLE MICROBES: 8	PRESS. RANGE: ---	VOLUME: --- FT^3*
DETECTABEL SPECIES: Microbes, Chemical Compound		CYCLE TIME: --- MIN.
SELECTIVITY RATING: 8.0		LIFETIME: 10.0 YEARS

* Design specific information, to be determined.

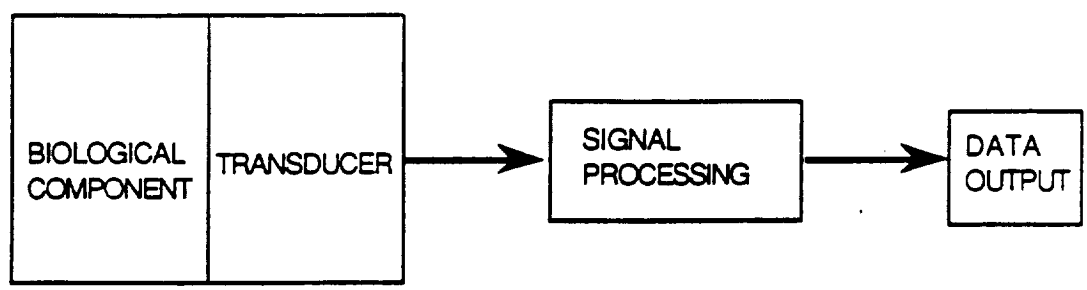
SENSOR DESCRIPTION:

Biosensors, as the name indicates, sense biological activity and produce a measureable signal. The sensing mechanism can be electrochemical, optical, or sensitive to changes in mass. These devices may ultimately provide the most adaptable system for continuous monitoring of spacecraft/habitat air and water. Biosensors will be prepared as kits containing biological receptors designed to react with specific microbial contaminants. The electrical signals generated by these reactions indicate the presence of a given contaminant. Sensor sophistication will probably be refined to permit more than bacteria detection, identification, and enumeration. Sensor sophistication will probably be refined to permit detection, identification, and enumeration. As more is understood about how biochemical and structural characteristics are related to levels of antimicrobial sensitivity, it is possible that biosensors will also be able to perform this function.

REFERENCE:

Kent Schien, Sean D. Crosby, J. Wayne Lanham, Ph. D., James C. Serati, "Microbial Monitoring for Human Exploration Initiatives", Report, 1990.

Leonard Baskin, "Biosensors Offer Real-time Diagnostic Capability but Broad Application Awaits Cheaper Couple Designs.", The Medical Business Journal, Sept. 15, 1989.



B.1 Biosensor Components and Mode of Operation

SENSOR NAME : **DNA Probes**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: All in WRM	
SENSOR TYPE: BIO		OPERATION: Molecule Techniques	
ACCURACY: ± 1.50 %	Operational Environment	POWER:	--- W*
RESOLUTION: 1.0E -9 G	TEMP. RANGE: ---	WEIGHT:	--- LB*
NO. OF DETECTABLE MICROBES: 5	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: Bacteria		CYCLE TIME:	120.00 MIN.
SELECTIVITY RATING: 8.0		LIFETIME:	--- YEARS

* Design specific information, to be determined.

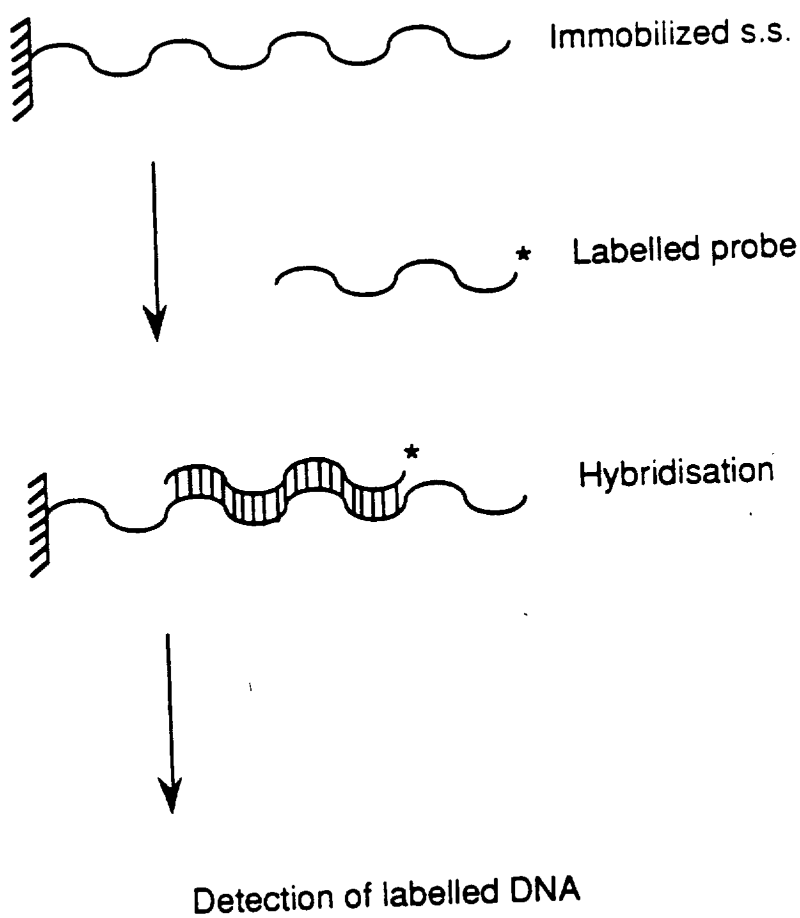
SENSOR DESCRIPTION:

The most specific method for identifyfing a microbe is the DNA probe which is based on nucleic acid hybridization reactions. The normally double stranded DNA molecule can be denatured into a single stranded form and, if a short length of single stranded "probe" DNA is then added, it will only bind to DNA with a complementary sequence. The presence of bound probe DNA reveals the existence of the marker sequence being search for in the sample. Many nuisance microbes which cannot be cultured, and therefore not easily identified by traditional methods, are detectable by this method. Since probes do not require a pure culture of organisms to produce accurate results, a working sample can be easily obtained. Commercially available kits now identify organisms in under two hours. The major problem is that some false negatives can occur. Another problem is that the correct probe must be used to detect specific organisms or an array of probes must be constructed.

REFERENCE:

I. J. Higgins, G. Hall, and A. Swain, "Analytical Strategies in Biotechnology", Trend in Analytical Chemistry, Vol. 8, No. 1, 1989.

E. B. Rodgers, D. B. Seale, M. E. Boraas, and C. V. Sommer, "Ecology of Micro-organisms in a Small Closed System: Potential Benefits and Problems for Space Station", SAE 891491, 1989.



B.2 DNA Hybridiaztion - The Principle of DNA Probe Technology

SENSOR NAME : **Electron Particle Detection (EPD)**

SENSOR INFORMATION

SUBSYSTEM: WRM	TECHNOLOGY: All in WRM	
SENSOR TYPE: BIO	OPERATION: Particle Counting	
ACCURACY: ± --- %	Operational Environment	POWER: --- W*
RESOLUTION: 1.0E -10 G	TEMP. RANGE: ---	WEIGHT: --- LB*
NO. OF DETECTABLE MICROBES: 8	PRESS. RANGE: ---	VOLUME: --- FT^3*
DETECTABEL SPECIES: Bacteria		CYCLE TIME: --- MIN.
SELECTIVITY RATING: 2.0		LIFETIME: --- YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

By far the oldest of candidate methodologies, Electron Particle Detection involves the detection and counting of microbiological particles as they temporarily alter the electric field through which they pass. Like laser scattering, EPD can detrmine size and number of particles but cannot distinguish between living cell and inanimate particles. Major redesign is required for micrgravity. This method is applicable to real time, total volume monitoring.

REFERENCE:

M. V. Kilgore, Jr., R. J. Zahorchak, S. S. Woodward, D. L. Pierson, and W. F. Arendale, "Definition of a Near Real Time Microbiological Monitor for Application in Space Vehicles", SAE 891541, 1989.

Sensor Figure Not Included

SENSOR NAME : **Enzyme Immunosensors**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: All in WRM	
SENSOR TYPE: BIO		OPERATION: Immunochemical	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER:	--- W*
RESOLUTION: 1.0E -9 G	TEMP. RANGE: ---	WEIGHT:	--- LB*
NO. OF DETECTABLE MICROBES: 5	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: Antibody, Antigen		CYCLE TIME:360.00 MIN.	
SELECTIVITY RATING: 8.0		LIFETIME:	--- YEARS

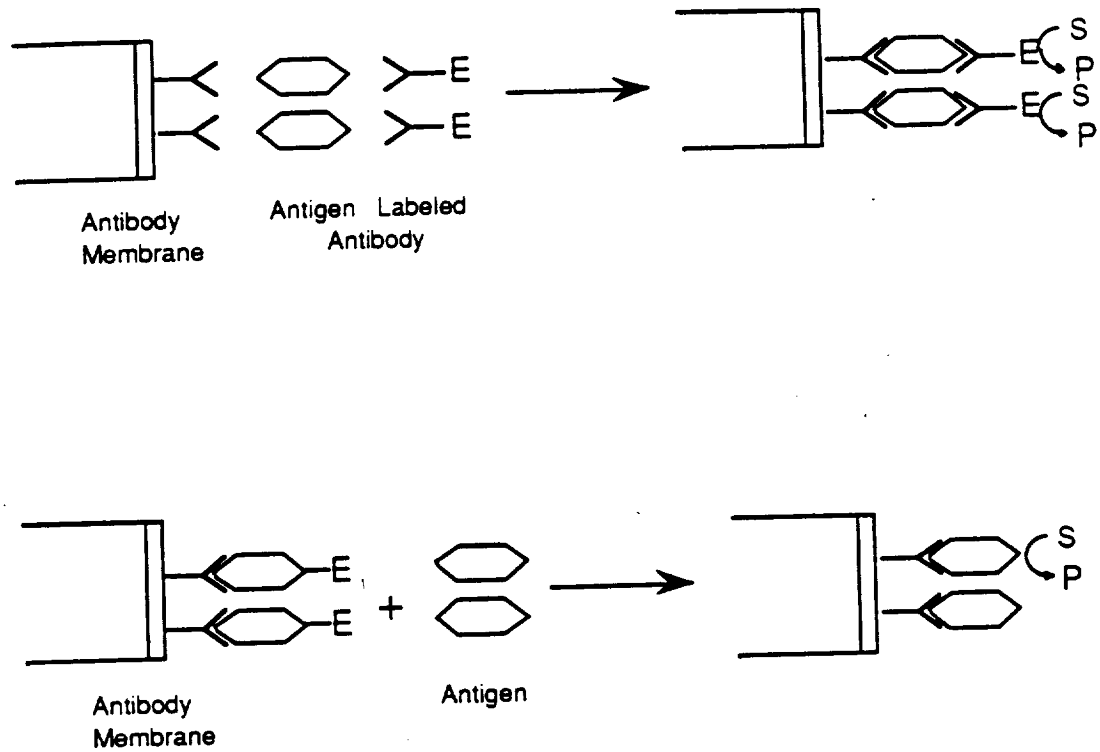
* Design specific information, to be determined.

SENSOR DESCRIPTION:

Antibodies are proteins called immunoglobins produced in the body to neutralize and destroy invading foreign substances known as antigens (virus, bacteria, drugs. . .) . Immunosensors rely on the immune complex bond formation which allows an antigen and antibody to fit together. Either a sandwhich assay or competitive binding assay can be used. In both cases an antibody for the analyte of interest is attached to a membrane which is placed on the surface of an electrochemical sensor. In the sandwich assay the antibdy binds the analyte antigen which then binds an enzyme labeled second antibody. The membrane is washed thoroughly to remove any non-specifically absorbed label. The sensor is placed into a solution containing the substrate for the enzyme. The rate of product formation is electrochemically measured and is directly proportional to the amount of analyte antigen in the in the solution. In the competitive bind mode the sample antigen competes with the enzyme label antigen for antibody binding sites on the membrane. The membrane is washed and the sensor is placed in a solution containing the substrate for the enzyme. The rate of reaction is measured electrochemically, and in this case, is inversely proportional to the concentration of sample antigen.

REFERENCE:

Dean Monroe, "Enzyme Immunoassy', Analytical Chemistry, Vol. 56, No. 8, July 1984.



B.3 Priciple of Operation of Enzyme Immunosensors

SENSOR NAME : **Epifluorescence Microscopy (EPM)**

SENSOR INFORMATION

SUBSYSTEM: WRM

TECHNOLOGY: All in WRM

SENSOR TYPE: BIO

OPERATION: Epifluorescence

ACCURACY: ± --- %

RESOLUTION: 1.0E -10 G

NO. OF DETECTABLE MICROBES: 8

DETECTABEL SPECIES: Bacteria

SELECTIVITY RATING: 2.0

Operational Environment

TEMP. RANGE: ---

PRESS. RANGE: ---

POWER: 100 W*

WEIGHT: 75 LB*

VOLUME: 2.3 FT^3*

CYCLE TIME: 0.25 MIN.

LIFETIME: 2.0 YEARS

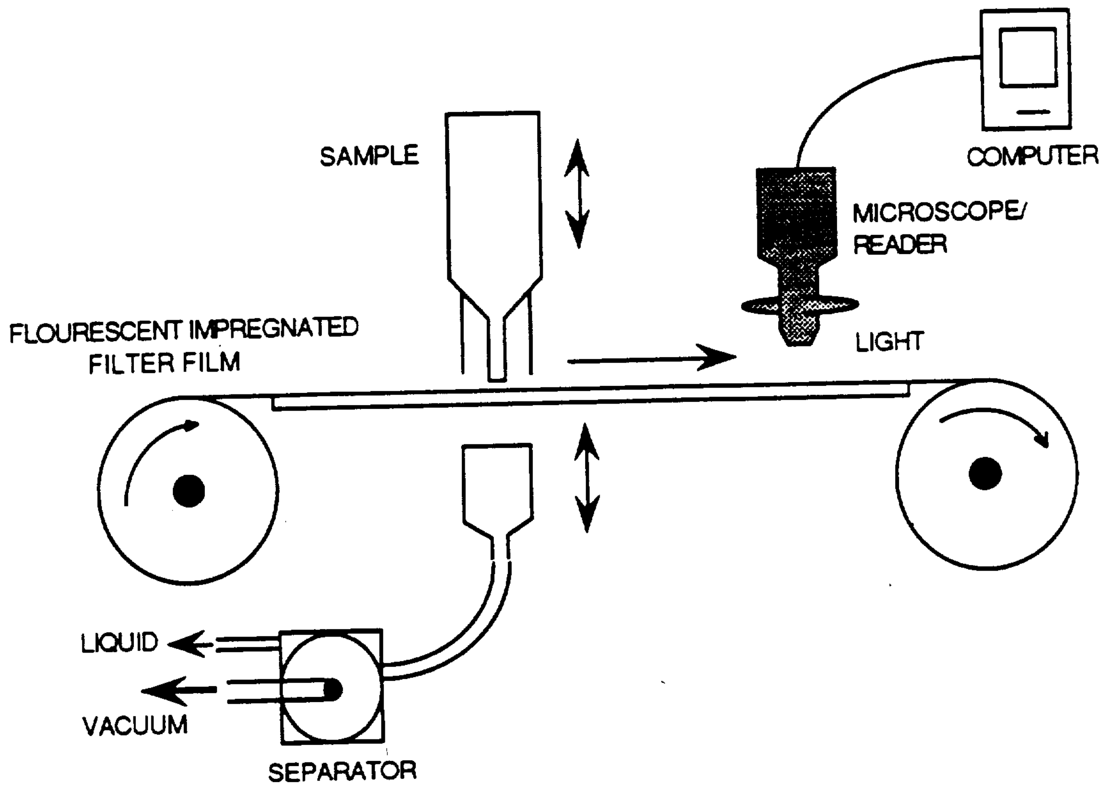
* Design specific information, to be determined.

SENSOR DESCRIPTION:

Epifluorescence is conducted by passing the air, water, or surface sample through a submicro-size filter to trap and concentrate the microorganisms. This method utilizes a filter impregnated with a fluorescent stain which highlights bacteria as a liquid sample is passed through. When illuminated with ultraviolet light, the individual bacteria become visible and subsequently can be counted under a microscope. EPM will detect and enumerate bacteria, fungi, and viruses, although the technology to this point has focused on bacteria. EPM can not perform antimicrobial susceptibility testing.

REFERENCE:

Kent Schien, Sean D. Crosby, J. Wayne Lanham, Ph. D, James C. Serati, "Microbial Monitoring for Human Exploration Initiatives", Report, 1990.



B.4 Automatic Epiflourescence Microscopy

SENSOR NAME : **Laser Light Scattering**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: All in WRM	
SENSOR TYPE: BIO		OPERATION: Optics	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER:	--- W*
RESOLUTION: 1.0E -10 G	TEMP. RANGE: ---	WEIGHT:	--- LB*
NO. OF DETECTABLE MICROBES: 8	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: All BIO		CYCLE TIME:	--- MIN.
SELECTIVITY RATING: 2.0		LIFETIME:	--- YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

Laser light scattering is currently used for the detection and charaterization of particulate contamination. Applicable to liquids and gases, different lasers can be selected to meet different wavelengths required for analysis. Rapid response time permits repetitive measurements to improve accuracy. Using this method in real time, total volume measurements are possible. This system has limited a capacity discriminate between inanimate particles and living bacterial cells. It can, however, discern particles in the size range of bacteria as a primary warning system.

REFERENCE:

M. V. Kilgore, Jr., R. J. Zahorchak, Samuel S. Woodward, Duane L. Pierson, and W. F. Arendale , "Definition of a Near Real Time Microbiological Monitor for Application in Space Vehicles", SAE 891541, 1989.

Sensor Figure Not Included

SENSOR NAME : **Microbial Fuel Cell**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: All in WRM	
SENSOR TYPE: BIO		OPERATION: Bioelectrical	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER:	--- W*
RESOLUTION: 1.0E -7 G	TEMP. RANGE: ---	WEIGHT:	10 LB*
NO. OF DETECTABLE MICROBES: 8	PRESS. RANGE: ---	VOLUME:	0.3 FT^3*
DETECTABEL SPECIES: Viable Microorganism, Gram Positive, Gram Negative		CYCLE TIME:	0.40 MIN.
SELECTIVITY RATING: 3.0		LIFETIME:	1.0 YEARS

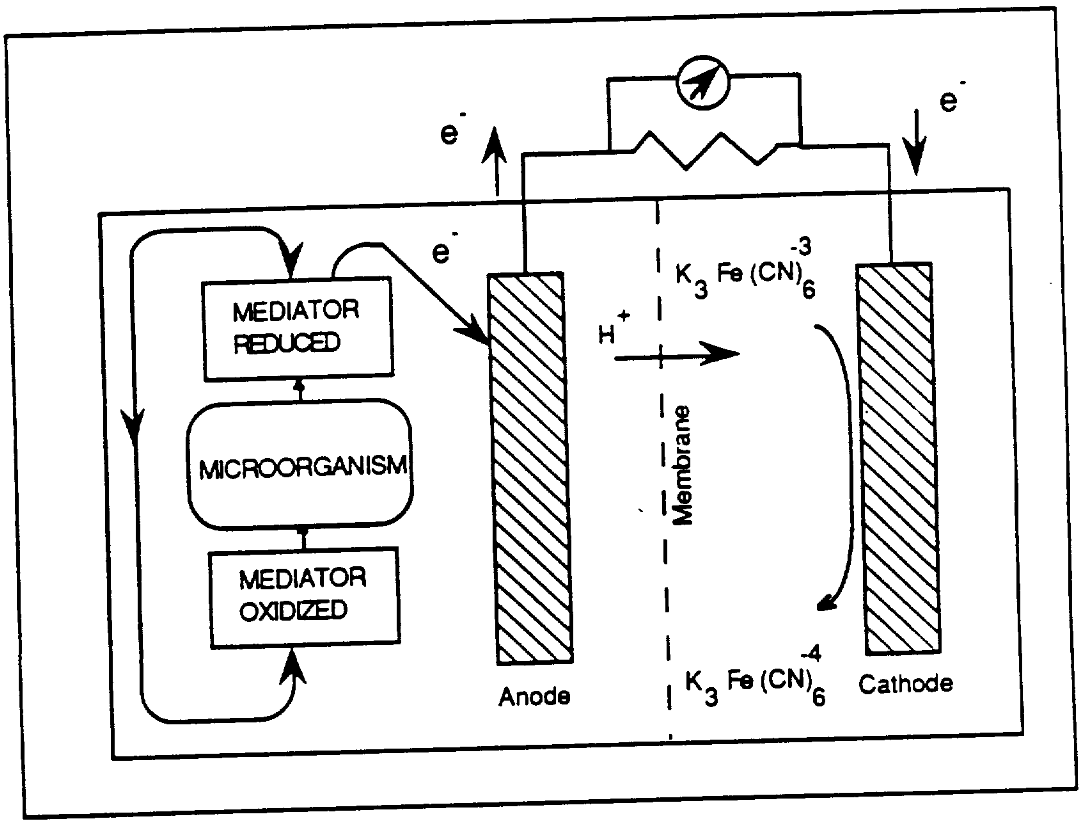
* Design specific information, to be determined.

SENSOR DESCRIPTION:

Viable bacteria generate metabolic intermediates that are electron rich. Electron flow can be established by using redox dyes on mediators. A reduced mediator diffuses through a cell membrane, contacts an electrode, and produces electrical current. The intensity of the current is proportional to bacteria/unit volume. This technique has potential for high sensitivity, portability, and automation Microbial Fuel Cells detect only visible organisms.

REFERENCE:

Oliver J. Murphy, Tom D. Roger, and Roger Lorenzo, "Technology for the Rapid Enumeration of Bacteria. A Portable Biosensor for Inflight Monitoring of Spacecraft Water", Proposal to NASA RD-89-198, Oct. 1988.



B.5 Microbial Fuel Cell

SENSOR NAME : **Microbial Load Monitoring (MLM)**

SENSOR INFORMATION

SUBSYSTEM: WRM

TECHNOLOGY: All in WRM

SENSOR TYPE: BIO

OPERATION: Culture Method + Computer Anal

ACCURACY: ± --- %

RESOLUTION: 1.0E -7 G

NO. OF DETECTABLE MICROBES: 8

DETECTABEL SPECIES: Microbes

SELECTIVITY RATING: 7.0

Operational Environment

TEMP. RANGE: ---

PRESS. RANGE: ---

POWER: 159 W*

WEIGHT: --- LB*

VOLUME: --- FT^3*

CYCLE TIME: 6.00 MIN.

LIFETIME: --- YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

Microbial Load Monitoring (MLM) was designed to give fairly accurate identification and antimicrobial susceptibility for nine species of clinically significant urinary-tract organisms if they were present at a concentration of 10E5/ml or greater. It had three modules; (1) Filling, (2) Reader/Incubator, and (3) Computer. Light Emitting Diodes (LEDs) are used to detect the level of microbial growth or susceptibility.

REFERENCE:

Kent Schien, Sean D. Crosby, J. Wayne Lanham, Ph. D., and James C. Serati, "Microbial Monitoring for Human Exploration Initiatives", Report, 1990.

"Microbial Load Monitor (MLM) Final Report, MDC E1879, 30 June 1979, McDonnell Douglas Astronautics Company-St. Louis, McDonnell Douglas Corporation.

Sensor Figure Not Included

SENSOR NAME : **Primary Fluorescence**

SENSOR INFORMATION

SUBSYSTEM: WRM	TECHNOLOGY: All in WRM		
SENSOR TYPE: BIO	OPERATION: Spectroscory		
ACCURACY: ± --- %	Operational Environment	POWER:	--- W*
RESOLUTION: 1.0E -9 G	TEMP. RANGE: ---	WEIGHT:	--- LB*
NO. OF DETECTABLE MICROBES: 8	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: Bacteria with Fluorescence		CYCLE TIME:	--- MIN.
SELECTIVITY RATING: 2.0		LIFETIME:	--- YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

In some molecules the absorption of light radiation produces emission at a longer wavelength, due to the vibrational energy lost in collision with other molecules. A large number of molecules present in cells have fluorescent properties and can serve as detection markers. Bacterial characterization is possible using known fluorescence decay times. Real-time, total-volume analysis is feasible using this method. Related bacteria are difficult to differentiate, and not all bacteria fluoresce.

REFERENCE:

M. V. Kilgore, Jr., R. J. Zahorchak, Samuel S. Woodward, D. L. Pierson, and W. F. Arendale, "Definition of a Near Real Time Microbiological Monitor for Application in Space Vehicles", SAE 891541, 1989.

Sensor Figure Not Included

SENSOR NAME : **Pyrogen Detection**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: All in WRM	
SENSOR TYPE: BIO		OPERATION: Pyrogen Detection by Colorimet	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER:	--- W*
RESOLUTION: 1.0E -7 G	TEMP. RANGE: ---	WEIGHT:	--- LB*
NO. OF DETECTABLE MICROBES: 6	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: Gram negative		CYCLE TIME:	--- MIN.
SELECTIVITY RATING: 3.0		LIFETIME:	--- YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

Pyrogens are products of gram-negative bacterial growth that can serve as indicators of bacterial contamination. Measured colorimetrically, pyrogens provide fairly accurate data on the presence of microorganisms. However, since many gram-negatives produce endotoxins, little information is gained on the identification of the contaminating organism. Also, since each species produces different amounts, no substantial information can be gained on enumeration of the contaminating bacteria. The advantage of Pyrogen Detection is that it requires no more than a few (6-8) manipulations and no more than 15-20 minutes of astronaut time per sample.

REFERENCE:

Kent Schien, Sean D. Crosby, J. Wayne Lanham, Ph. D., and James C. Serati, "Microbial Monitoring for Human Exploration Initiatives", Report, 1990.

Sensor Figure Not Included

SENSOR NAME : **Secondary Fluorescence**

SENSOR INFORMATION

SUBSYSTEM: WRM	TECHNOLOGY: All in WRM	
SENSOR TYPE: BIO	OPERATION: Spectroscopy	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER: --- W*
RESOLUTION: 1.0E -9 G	TEMP. RANGE: ---	WEIGHT: --- LB*
NO. OF DETECTABLE MICROBES: 8	PRESS. RANGE: ---	VOLUME: --- FT^3*
DETECTABEL SPECIES: Bacteria		CYCLE TIME: 30.00 MIN.
SELECTIVITY RATING: 2.0		LIFETIME: --- YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

Secondary fluorescence involves the addition of a fluorophore agent to detect and characterize bacteria which does not exhibit natural fluorescence. It is based on flow cytometry where a sample of bacteria is strained with a fluorophore, and a fluorometer is used for detection. Reaction cocktails can be modified to analyze specific physiological groups of interest, providing a direct count of specific microorganisms. Collection/analysis time is about thirty minutes.

REFERENCE:

M. V. Kilgore, Jr., R. J. Zahorchak, S. S. Wooward, Duane L. Pierson, and W. F. Arendale, "Definition of a Near Real Time Microbiological Monitor for Application in Space Vehicles", SAE 891541, 1989.

Sensor Figure Not Included

SENSOR NAME : **The Vitek Immuno Diagnostic Assay System (VIDAS)**

SENSOR INFORMATION

SUBSYSTEM: WRM	TECHNOLOGY: All in WRM	
SENSOR TYPE: BIO	OPERATION: Immunology	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER: 500 W*
RESOLUTION: 1.0E -9 G	TEMP. RANGE: ---	WEIGHT: 117 LB*
NO. OF DETECTABLE MICROBES: 8	PRESS. RANGE: ---	VOLUME: 5.7 FT^3*
DETECTABEL SPECIES: Bacteria, Fungi, Virus, Metabolic Product		CYCLE TIME: 8.00 MIN.
SELECTIVITY RATING: 8.0		LIFETIME: 2.0 YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

VIDAS is an immunology method which utilizes the specificity of an antigen - antibody reaction. VIDAS provides a full spectrum of capabilities for detection, identification, and enumeration of bacteria, fungi, viruses and metabolic products such as toxins and pyrogens. Its only shortcoming is that it does not, at present, determine antimicrobial susceptibilities. To start processing, samples are introduced into pre-dispensed disposable reagent strips and combined with matching Solid Phase Receptacles (SPR's). Interaction between the strips and SPR's provide extremely sensitive enzyme-linked fluourescence immunoassays. Six kinds of assay kits are available.

REFERENCE:

Kent Schien, Sean D. Crosby, J. Wayne Lanham, Ph. D., and James C. Serati, "Microbial Monitoring for Human Exploration Initiatives", Report, 1990.

VIDAS Brochure, VTK 101088-15K, not dated, Vitek Systems Inc., Industrial Division.

Sensor Figure Not Included

SENSOR NAME : **The Vitek System**

SENSOR INFORMATION

SUBSYSTEM: WRM	TECHNOLOGY: All in WRM	
SENSOR TYPE: BIO	OPERATION: Culture Method + Computer Anal	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER: 380 W*
RESOLUTION: 1.0E -12 G	TEMP. RANGE: ---	WEIGHT: 110 LB*
NO. OF DETECTABLE MICROBES: 8	PRESS. RANGE: ---	VOLUME: 7.8 FT^3*
DETECTABEL SPECIES: Bacteria, Fungi		CYCLE TIME: 11.00 MIN.
SELECTIVITY RATING: 7.0		LIFETIME: 2.0 YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

The Vitek system used to be known as the Automicrobic System (AMS). This instrument is based on technology developed for Microbial Load Monitoring. The main difference between MLM and the Vitek system is the card (circuit board) used. An advantage of Vitek is its accuracy and dependability in providing the best possible information relative to identification and susceptiblities. From a labor standpoint, a disadvantage is that Vitek must be used with pure culture isolates, which can require considerable time to culture. Experienced judgement is also required to select the right isolation for examination.

REFERENCE:

Kent Schien, Sean D. Crosby, J. Wayne Lanham, Ph. D., and James C. Serati, "Microbial Monitoring for Human Exploration Initiatives", Report, 1990.

1990 Clinical Catalog and Price List, VTKC1289, not dated, Vitek Systems, Inc.

Sensor Figure Not Included

SENSOR NAME : **Two Dimensional Fluorescence Spectroscopy**

SENSOR INFORMATION

SUBSYSTEM: WRM	TECHNOLOGY: All in WRM		
SENSOR TYPE: BIO	OPERATION: Spectroscopy		
ACCURACY: ± --- %	Operational Environment	POWER:	--- W*
RESOLUTION: 1.0E -10 G	TEMP. RANGE: ---	WEIGHT:	--- LB*
NO. OF DETECTABLE MICROBES: 8	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: Microbes		CYCLE TIME:	--- MIN.
SELECTIVITY RATING: 8.0		LIFETIME:	--- YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

TDFS is a technique whereby the fluorescent intensity is recorded as a function of the excitation and emission wavelength. By scanning the excitation wavelength and recording the emission wavelength, a two dimensional plot can be generated which is unique to the microorganism. Computer methods can then be used to identify the spectra. TDFS is a powerful analytical technique due to high sensitivity and multiparameter capabilities.

REFERENCE:

Chou-pong Pau, Isiah M. Warner, and Thomas M. Rossi, "Two Dimensional Fluorescence Spectroscopy Analytical Chemistry", Vol. 7., No. 2, 1988.

Sensor Figure Not Included

SENSOR NAME : **Volatile Product Detection**

SENSOR INFORMATION

SUBSYSTEM: WRM	TECHNOLOGY: All in WRM		
SENSOR TYPE: BIO	OPERATION: Membrane + MS		
ACCURACY: ± --- %	Operational Environment	POWER:	--- W*
RESOLUTION: 1.0E -10 G	TEMP. RANGE: ---	WEIGHT:	--- LB*
NO. OF DETECTABLE MICROBES: 6	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: Microbes		CYCLE TIME:	--- MIN.
SELECTIVITY RATING: 6.0		LIFETIME:	--- YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

Volatile Product Detection is accomplished using a hyphenated mass-spectroscopy technique. Sample volume is concentrated using a membrane filter and incubated as required for detection of physiological groups of interest. Over time, volatile products are analyzed from the head space. This method is directly applicable to liquids, gases, and solids.

REFERENCE:

M. V. Kilgore, Jr., R. J. Zahorchak, S. S. Woodward, D. L. Pierson, and W. F. Arendale, "Definition of a Near Real Time Microbiological Monitor for Application in Space Vehicles", SAE 891541, 1989.

Sensor Figure Not Included

Chemical Sensors

Many of the chemical analysis techniques can be stacked: GC is usually followed MS. The first instrument usually separates the sample into groups and the second identifies individual compounds. It is becoming routine to utilize as many as three independent instruments in sequence to identify large numbers of compounds for real time analysis. No attempt was made in this report to evaluate number of combinations utilized by analytical chemists. A simple explanation of the operation, selectivity, and advantages/disadvantages is presented.

SENSOR NAME : **Amperometric**

SENSOR INFORMATION

SUBSYSTEM: CO_2 REDUCTION, CO_2 REMOVAL, O_2 GENERATION.

TECHNOLOGY: All in these Subsystems.

SENSOR TYPE: CH

OPERATION: Electrochemical

ACCURACY: ± 1.00 %

RESOLUTION: 1.0E -9 G

NO. OF DETECTABLE MICROBES: 6.0

DETECTABEL SPECIES: CO_2, O_2, H_2O, CO , NO_2, NCHO, Organics

SELECTIVITY RATING: 5.0

Operational Environment

TEMP. RANGE: -30°F to 120°F

PRESS. RANGE: ---

POWER: --- W*

WEIGHT: --- LB*

VOLUME: 0.1 FT^3*

CYCLE TIME: 0.50 MIN.

LIFETIME: 2.0 YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

Amperomertic sensors rely on oxidation or reduction at the surface of an electrode in an electrochemical cell at a controlled potential. Current is generated and can be directly related to analyte concentration. In practice, multigas sensing is accomplished by scanning the voltage. As the cell reaches the redox potential of each species, current is generated and measured. An array of amperometric sensors can measure O_2, CO_2, H_2O, CO, NO_2, and HCHO.

REFERENCE:

Hank Wohltjen, "Chemical Microsensors and Microinstrumentation" Analytical Chemistry, Vol. 56, No. 1, Jan. 1984.

H. V. Venkatasetty, "Electrochemical Multigas Sensors for Air Monitoring Assembly", SAE 881082, 1988.

Chemical Sensors Reference Summary

Sensor	Reference No.
1. Amperometric	2, 3
2. Atomic Absorption Spectrophotometer (AAS)	1, 4
3. Atomic Emission Spectrometer (AES)	1, 4
4. CHEMFET/ISFET (Ion Sensing Field Effect Transistor)	2, 5
5. Catalytic Dector (Pellistor)	1, 6
6. Electron Capture Detector (ECD)	1, 4
7. Flame Ionization Detector (FID)	1, 4
8. Flame Photometric Detector (FPD)	1
9. Fluorescence Detector	4, 7
10. Fourier Transform Infrared (FTIR)	8
11. Fuel Cell Oxygen-measuring Instrument	1
12. High Performance Liquid Chromatography (HPLC)	1, 4, 7
13. High Temperature Ceramic Sensor Oxygen Probes	1, 6
14. Inductively Coupled Plasma Emission (ICPE)	1, 7
15. Infrared Spectroscopy (IR)	1, 4
16. Metal Oxide	5, 9, 10
17. Non-Dispersive Infrared Spectroscopy (NDIR)	1, 11
18. Nuclear Magnetic Resonance (NMR)	1, 12
19. Paramagnetic Oxygen Analyzers	1
20. Photo-Ionization Detector (UV) or (PID)	1, 4
21. Polarographic Process Oxygen Analyzer	1
22. Potentiometric	2, 3
23. Semiconductor Detector	1, 6
24. Surface Acoustic Wave (SAW)	2, 9, 13
25. Thermal Conductivity Detectors (TCD)	1, 4
26. Thin Layer Chromatography (TLC)	1, 4
27. Ultrasonic Detector	1
28. Enzymes	14, 15
29. Gas Chromatograph/Mass Spectroscopy (GC/MS)	4
30. Gas Chromatography (GC)	1, 4, 8
31. Mass Spectroscopy (MS)	1, 4
32. Tandem Mass Spectrometry (MS/MS)	8, 16

References

1. B. E. Noltingk, "Jones' Instrument Technology, 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.
2. Hank Wohltjen, "Chemical Microsensors and Microinstrumentation", Analytical Chemistry, Vol. 56, No. 1, Jan. 1984.
3. H. V. Venkatasetty, "Electrchemical Multigas Sensors for Air Monitoring Assembly", SAE 881082, 1988.
4. Lawrence Berkeley Laboratory Environmental Instrumentation Survey, "Instrumentation for Environmental Monitoring", Vol.2, Water, John Wiley & Sons, Inc.,1986.
5. Bernard Hulley, "Chemical Sensors - An Overview", Measurement & Control, Vol. 21, Mar. 1988.

6. D. E. Williams and P. T. Moseley, "Progress in the Developmentof Solid State Gas Sensors", Measurement & Control, Vol. 21, Mar. 1988.
7. Lenore S. Clesceri, Arnold E. Greenberg, and R. Rhodes Trussell, "Standard Methods for the Examination of Water and Wastewater", Ammerican Public Health Ass., 17th Edition, 1989.
8. Scott J. Selover, "Evaluation of Approaches to Space Based Environmental Monitoring", Material and Process Laboratories Lockheed Missiles and Space Co., Inc., Oct. 1988.
9. T. A. Jones, "Trends in the Development of Gas Sensors", Measurement & Control, Vol. 22, July/Aug. 1989.
10. C. Hierold and R. Muller, "Quantitative Analysis of Gas Mixtures with Non-Selective Gas Sensors", Sensors and Actuators, 17 (1989) P587-592.
11. John W. Small, " Monitoring of Combustible Gases", Measurement & Control, June 1988.
12. R. H. Perry, D. W. Green, and J. O. Maloney, "Perry's Chemical Engineers' Handbook", McGraw-Hill Book Co., 6th Edition, 1984.
13. A. Damico and E. Verona, "SAW Sensors", Sensors and Actuators, 17 (1989) P55-66.
14. Steven L. Brooks and Anthony P. F. Turner, "Biosensors for Measurement and Control", Measurement & Control, Vol. 20, May1987.
15. R. K. Kobos, "Enzyme-Based Electrochemical Biosensors", Trends in Analytical Chemistry, Vol. 6, No. 1, 1987.
16. F. W. McLafferty, "Tandem Mass Spectrometry", John Wiley & Sons, Inc., 1983.

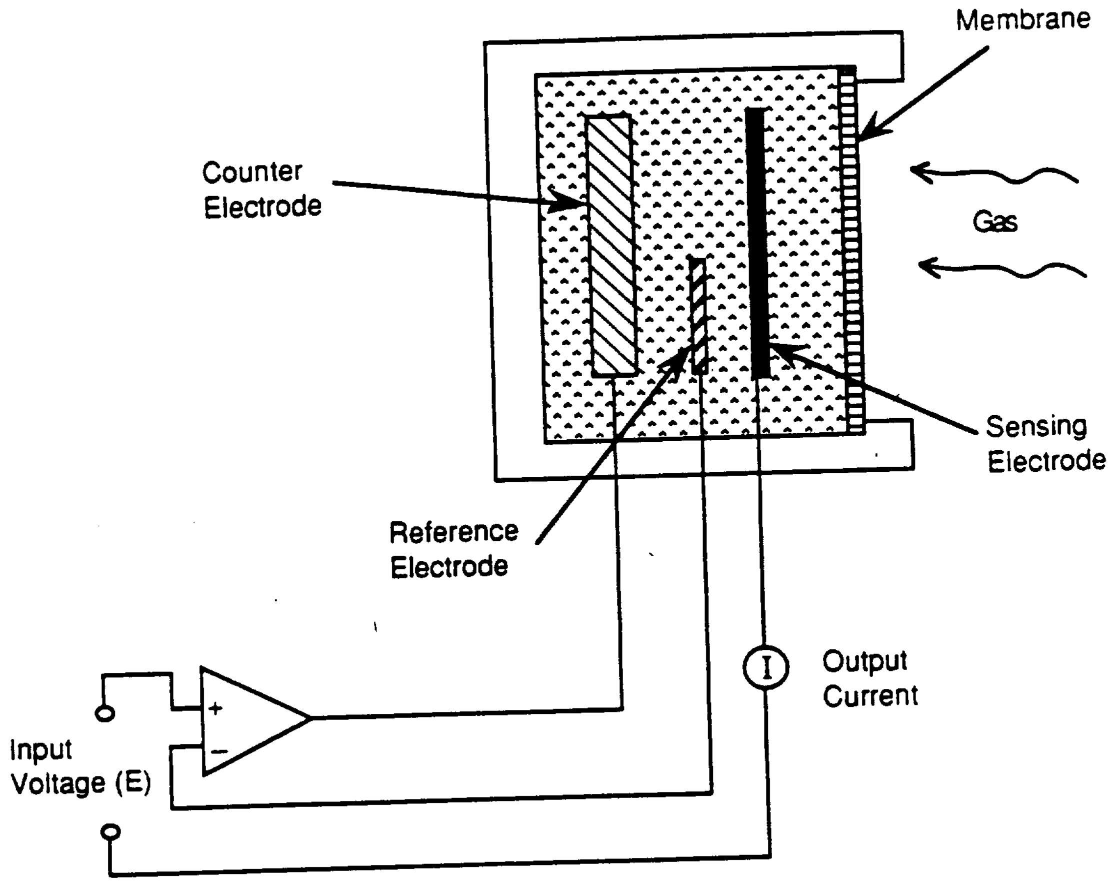
Chemical Sensors

Sensor	Page No.

List of Figures

Appendix C

Chemical Sensors



C.1 Amperometric Chemical Sensor

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SENSOR NAME : **Atomic Absorption Spectrophotometer (AAS)**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: All WRM	
SENSOR TYPE: CH		OPERATION: Atomic Absorption	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER:	--- W*
RESOLUTION: 1.0E -6 G	TEMP. RANGE: ---	WEIGHT:	--- LB*
NO. OF DETECTABLE MICROBES: 7.0	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: Salinty, Dissolved solid, Major ions, Metals		CYCLE TIME:	--- MIN.
SELECTIVITY RATING: 9.0		LIFETIME:	--- YEARS

* Design specific information, to be determined.

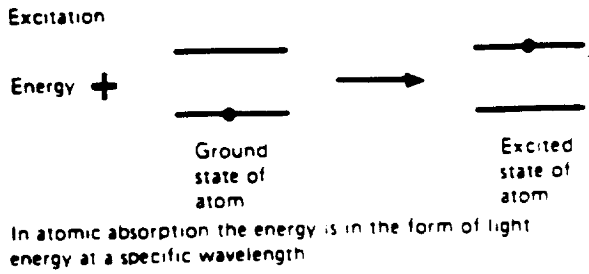
SENSOR DESCRIPTION:

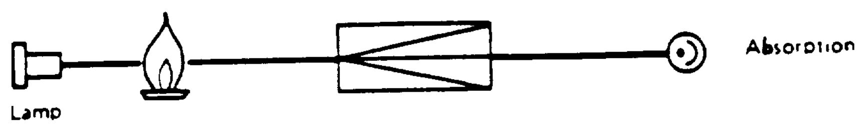
An Atomic Absorption Spectrophotometer (AAS) measures the light of a specific wavelength transmitted through a metal vapor. If the wavelength (frequency) of light incident upon the vapor corresponds to the difference in the energy levels in the metal atom, then the light is absorbed. Because the energy of light absorbed corresponds to a specific and well known wavelength for a given metal, AAS can be used for qualitative or, more frequently, quantitative analysis.

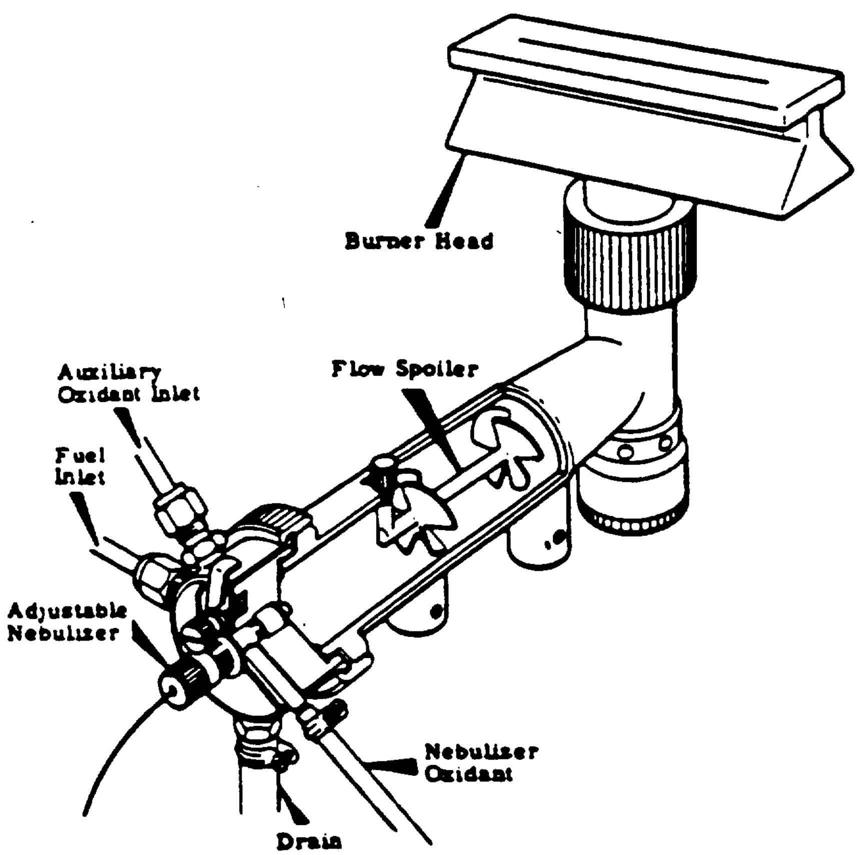
REFERENCE:

Lawrence Berkeley Laboratory Environmental Instrumentation Survey, "Instrumentation Environmental Monitoring", Vol. 2, Water, John & Wiley Sons Inc., 1986.

Ben E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.







C.2 Atomic Absorption Burner System

SENSOR NAME : **Atomic Emission Spectrometer (AES)**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: All WRM
SENSOR TYPE: CH		OPERATION: Atomic Emission
ACCURACY: ± --- %	Operational Environment	POWER: --- W*
RESOLUTION: 1.0E -8 G	TEMP. RANGE: ---	WEIGHT: --- LB*
NO. OF DETECTABLE MICROBES: 7.0	PRESS. RANGE: ---	VOLUME: --- FT^3*
DETECTABEL SPECIES: Metals		CYCLE TIME: 10.00 MIN.
SELECTIVITY RATING: 9.0		LIFETIME: --- YEARS

* Design specific information, to be determined.

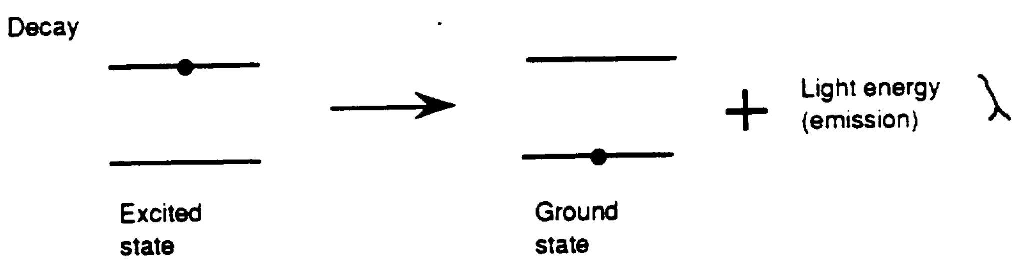
SENSOR DESCRIPTION:

An Atomic Emission Spectrometer measures the wavelengths and intensity of light emitted from a metal vapor that has been raised to an excited electronic state. The wavelength of the light emitted is characteristic of a given metal. All atoms (and sometimes ions) in the vapor will emit their characteristic radiation, if properly excited with an intensity proportional to their concentration.

REFERENCE:

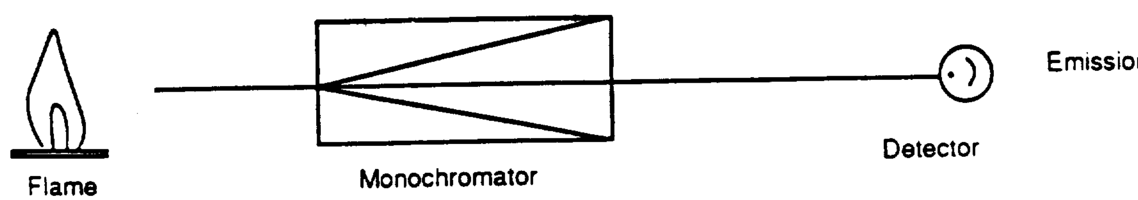
Lawrence Berkely Laboratory Environmental Instrumentation Survey, "Instrumentation Environmental Monitoring", Vol. 2, Water, John Wiley & Sons Inc., 1986.

Ben E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.



The energy source may be a flame, electrical arc or a plasma.

The above processes are utilized in three forms of atomic spectroscopy.



C.3 Atomic Emission

SENSOR NAME : **CHEMFET/ISFET(Ion Sensing Field Effect Transistor)**

SENSOR INFORMATION

SUBSYSTEM: ALL	TECHNOLOGY: All	
SENSOR TYPE: CH	OPERATION: Electrochemical and Semiconductor	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER: --- W*
RESOLUTION: 1.0E -9 G	TEMP. RANGE: ---	WEIGHT: --- LB*
NO. OF DETECTABLE MICROBES: 5.0	PRESS. RANGE: ---	VOLUME: --- FT^3*
DETECTABEL SPECIES: H_2, H_2S, NH_3, CO		CYCLE TIME: --- MIN.
SELECTIVITY RATING: 5.0		LIFETIME: --- YEARS

* Design specific information, to be determined.

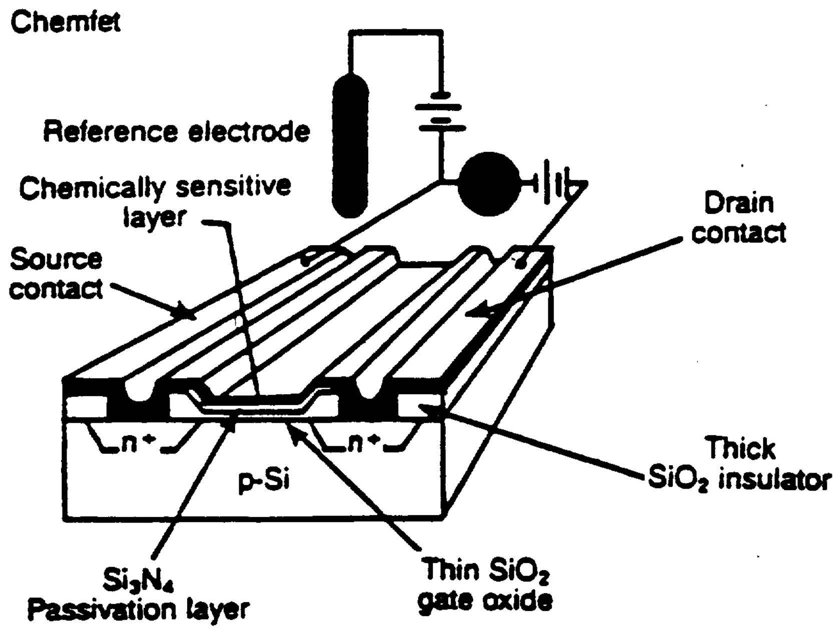
SENSOR DESCRIPTION:

A CHEMFET is an insulated-gate field effect transistor with its metallic gate contact replaced by a chemically sensitive coating and reference electrode. It senses chemical species whose presence modulates the transport electronic charge in the device. In normal operation a current is made to flow by the application of a voltage across the source and drain contacts. Variation of the E-field in the gate region, between the source and drain, produces corresponding variations in drain current. CHEMFET's are very small - good for a multiple ion sensing array. Ion-selective coating are being used to overcome difficulties with moisture and contaminates that induce instabilities. CHEMFET is good H_2 detector below 1ppm.

REFERENCE:

Bernard Hulley, "Chemical Sensors - An Overview", Measurement + Control, Vol. 21, March 1988.

Hank Wohltjen, "Chemical Microsensors and Microinstrumentation", Analytical Chemistry, Vol. 56, No. 1, Jan. 1984.



C.4 CHEMFET Sensor

SENSOR NAME : **Catalytic Dector (pellistor)**

SENSOR INFORMATION

SUBSYSTEM: CO2 REDUCTION		TECHNOLOGY: ACRS, BOSCH, SABATIER	
SENSOR TYPE: CH		OPERATION: Measuring Heat Output from Catalytic Oxidation	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER:	10 W*
RESOLUTION: --- G	TEMP. RANGE: ---	WEIGHT:	--- LB*
NO. OF DETECTABLE MICROBES: 6.0	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: Combustible gases		CYCLE TIME:	0.05 MIN.
SELECTIVITY RATING: 6.0		LIFETIME:	--- YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

Catalytic gas detectors operate by measuring the heat output resulting from the catalytic oxidation of flammable gas molecules to carbon dioxide and water vapor at a solid surface. By use of a catalyst, the temperature at which the oxidation takes place is much lower compared with gas phase oxidation. A stream of sample gas is fed over the sensor, and flammable gases in the sample are continuously oxidized, releasing heat and raising the temperature of the sensor. Temperature variations in the sensor are monitored to give a continuous record of the flammable gas concentration in the sample. The choice of catalyst, and treatment of the outside of the bead influences the overall sensitivity of the sensor, and the sensitivity to different gases. The sensitivity and selectivity are also influenced by the choice of catalyst and by the temperature at which the sensor is operated.

REFERENCE:

D. E. Williams and P. T. Moseley, "Progress in the Development of Solid State Gas Sensors", Measurement + Control, Volume 21, March 1988.

B. E. Noltingk, "Jones' Instrument Technology 2) Measurement Temperature and Chemical Composition", Buttterworths, 1985.

Sensor Figure Not Included

SENSOR NAME : **Electron Capture Detector (ECD)**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: All WRM	
SENSOR TYPE: CH		OPERATION: Electrons Capture	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER:	--- W*
RESOLUTION: 1.0E -12 G	TEMP. RANGE: ---	WEIGHT:	--- LB*
NO. OF DETECTABLE MICROBES: 6.0	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: Halogenated oxygenated		CYCLE TIME:	--- MIN.
SELECTIVITY RATING: 5.0		LIFETIME:	--- YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

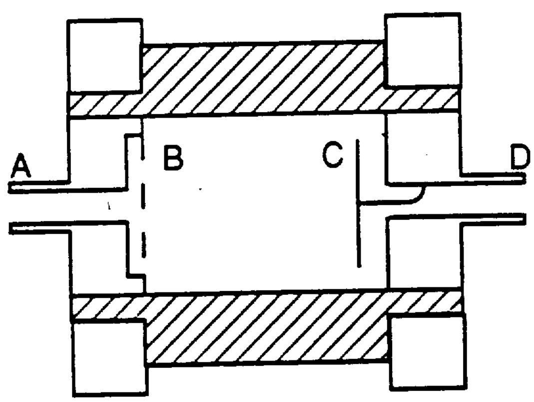
The electron capture detector consists of a cell containing a beta-emitting radioactive source purged with an inert gas. Electrons emitted by the radioactive source are slowed to thermal velocities by collision with the gas molecules and are eventually collected by a suitable electrode giving rise to a standing current in the cell. If a gas with greater electron affinity is introduced to the cell, some of the electrons are captured, forming negative ions, and the current, which can be related to the composition of the sample, is reduced.

REFERENCE:

Lawrence Berkeley Laboratory Environmental Instrumentation Survey, "Instrumentation Environmetal Monitoring", Vol. 2, Water, John & Wiley & Sons Inc., 1986.

Ben E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.

A - Inlet for carrier gas and anode
B - Diffuser - made of 100 mesh brass gauze
C - Source of ionizing radiation
D - Gas outlet and cathode



C.5 Electron Capture Detector (ECD)

SENSOR NAME : **Flame Ionization Detector (FID)**

SENSOR INFORMATION

SUBSYSTEM: WRM	TECHNOLOGY: All WRM	
SENSOR TYPE: CH	OPERATION: Flame ionization	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER: --- W*
RESOLUTION: 1.0E -11 G	TEMP. RANGE: ---	WEIGHT: --- LB*
NO. OF DETECTABLE MICROBES: 6.0	PRESS. RANGE: ---	VOLUME: --- FT^3*
DETECTABEL SPECIES: Organics		CYCLE TIME: --- MIN.
SELECTIVITY RATING: 2.0		LIFETIME: --- YEARS

* Design specific information, to be determined.

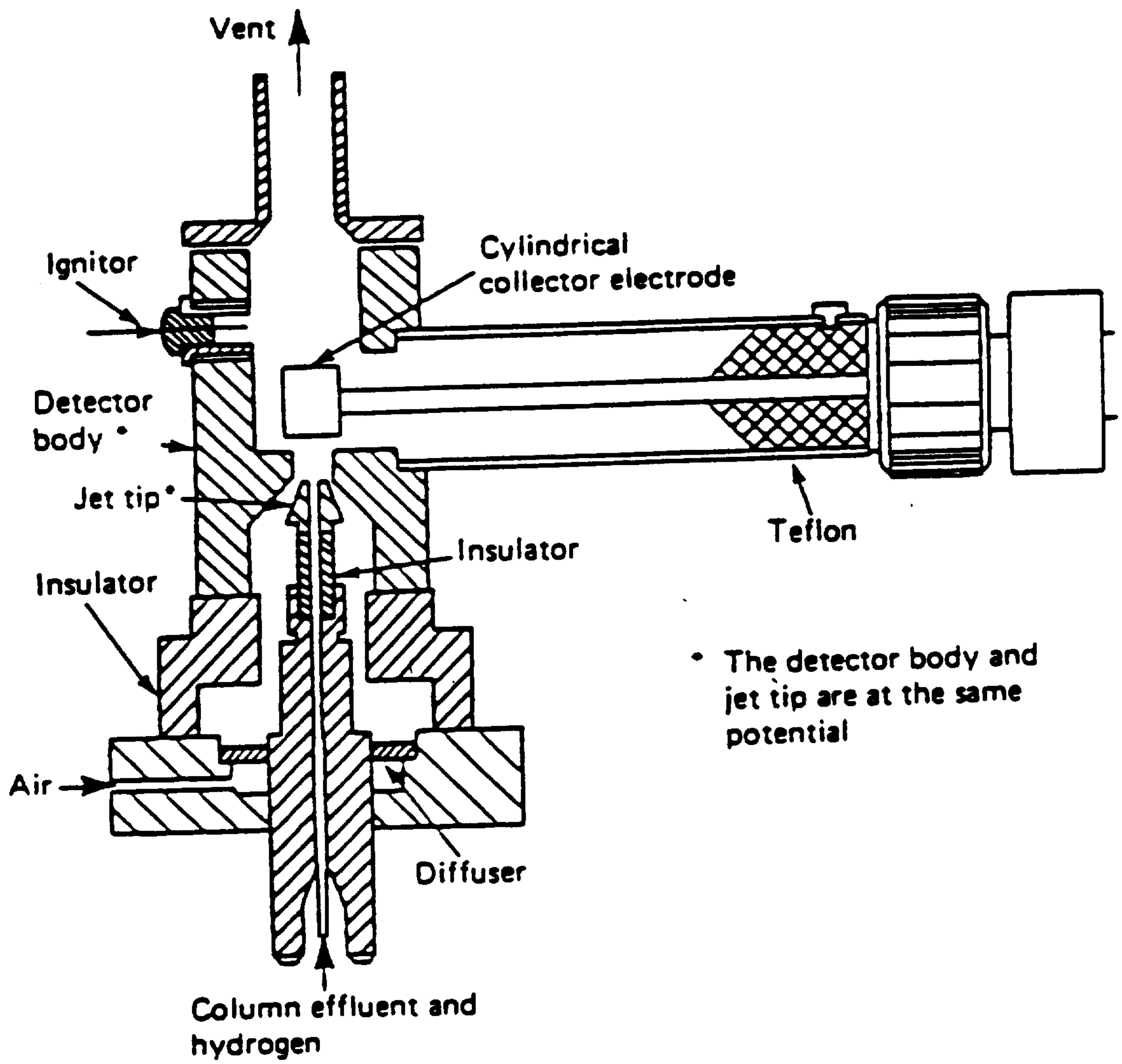
SENSOR DESCRIPTION:

The Flame Ionization Detector measures the change in ionization current inside a chamber. Gas eluting from a gas chromatograph (GC) is combined with hydrogen, which is the fuel for a hydrogen-air flame. Hydrocarbons which flow through this flame are dissociated into ions that are collected on a charged plate. The current flow is a measure of the carbon atoms being burned and thus the hydrocarbons in the GC carrier gas.

REFERENCE:

Lawrence Berkeley Laboratory Environmental Instrumentation Survey, "Instrumentation Environmental Monitoring", Vol.2, Water, John & Wiley & Sons Inc. 1986.

Ben E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.



C.6 Flame Ionization Detector (FID)

SENSOR NAME : **Flame Photometric Detector (FPD)**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: All WRM	
SENSOR TYPE: CH		OPERATION: Spectroscopy	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER:	--- W*
RESOLUTION: 1.0E -11 G	TEMP. RANGE: ---	WEIGHT:	--- LB*
NO. OF DETECTABLE MICROBES: 4.0	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: Sulfur, Phosphorus		CYCLE TIME:	--- MIN.
SELECTIVITY RATING: 6.0		LIFETIME:	--- YEARS

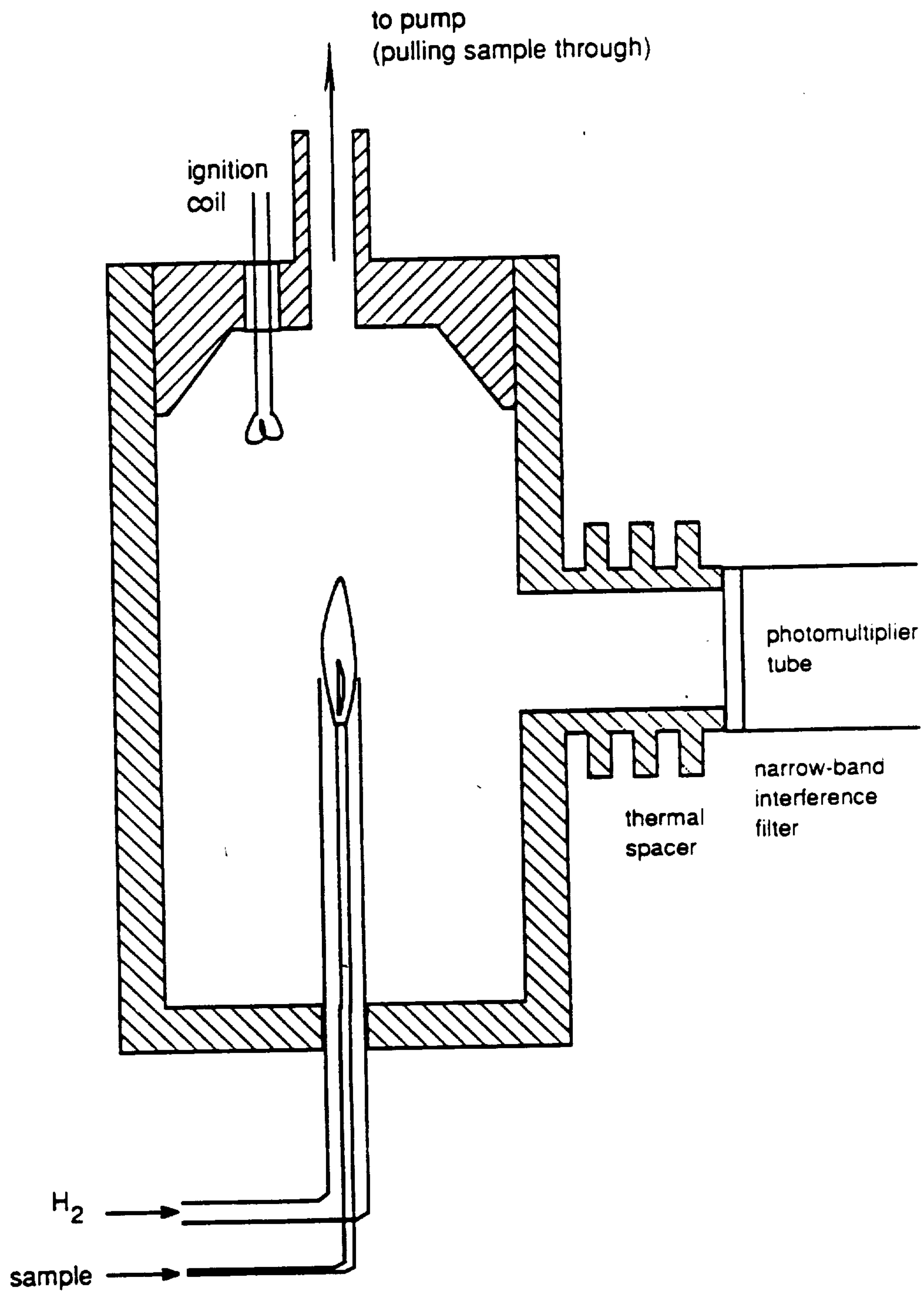
* Design specific information, to be determined.

SENSOR DESCRIPTION:

Most organic and other volatile compounds containing sulfur or phosphorus produce chemi-luminescent species when burned in a hydrogen-rich flame. In a Flame Photometric Detector the sample gas passes into a fuel-rich H2/O2 or H2/air mixture which produces simple molecular species and excites them to higher electronic states. These excited species subsequently return to their ground states and emit characteristic molecular band spectra. This is monitored by a photomultiplier tube through a suitable filter, thus making the detector selective to other elements, including halogens and nitrogen.

REFERENCE:

Ben E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.



C.7 Flame Photometric Detector (FPD)

SENSOR NAME : **Fluorescence Detector**

SENSOR INFORMATION

SUBSYSTEM: WRM	TECHNOLOGY: All WRM	
SENSOR TYPE: CH	OPERATION: Spectroscopy	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER: --- W*
RESOLUTION: 1.0E -8 G	TEMP. RANGE: ---	WEIGHT: --- LB*
NO. OF DETECTABLE MICROBES: 9.0	PRESS. RANGE: ---	VOLUME: --- FT^3*
DETECTABEL SPECIES: Molecule with momentum, rotation, and vibration		CYCLE TIME: --- MIN.
SELECTIVITY RATING: 6.0		LIFETIME: --- YEARS

* Design specific information, to be determined.

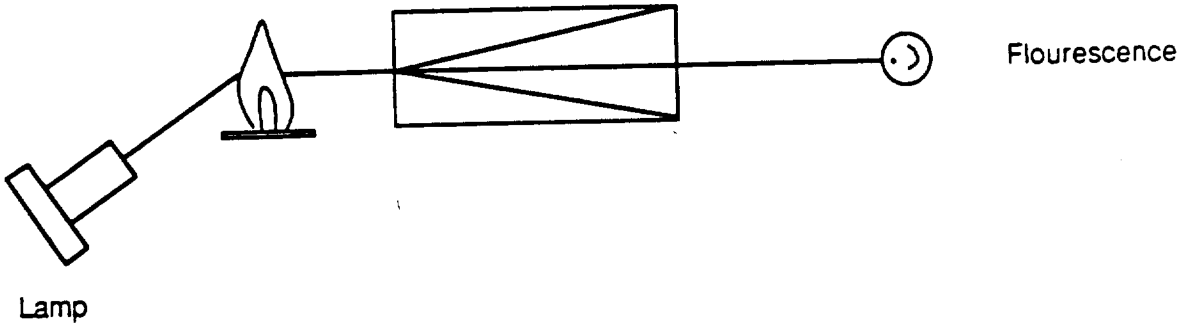
SENSOR DESCRIPTION:

The Fluorescence Detector is an absorbance detector in which the sample is energized by a monochromatic light source. Compounds capable of absorbing the light energy release it as fluorescence emission. The fluorescence detector is the most sensitive of the current high performance liquid chromatography detectors available.

REFERENCE:

Lenore S. Clesceri, Arnold E. Greenberg, and R. Rhodes Trussell, "Standard Methods for the Examination of Water and Wastewater", American Public Health Association, American Water Works Association, and Water Pollution Control Federation. 1989.

Lawrence Berkeley Laboratory Environmental Instrumentation Survey, "Instrumentation Environmental Monitoring", Vol. 2, Water, John & Wiley & Sons Inc., 1986.



C.8 Fluoroscence Spectroscopy Process

SENSOR NAME : **Fourier Transform Infrared (FTIR)**

SENSOR INFORMATION

SUBSYSTEM: CO2 REDUCTION, CO2 RFMOVE, WRM.

TECHNOLOGY: All in these Subsystems

SENSOR TYPE: CH

OPERATION: Fourier transformation + IR

ACCURACY: ± --- %

RESOLUTION: 1.0E -6 G

NO. OF DETECTABLE MICROBES: 8.0

DETECTABEL SPECIES: Compound with dipole

SELECTIVITY RATING: 9.0

Operational Environment

TEMP. RANGE: ---

PRESS. RANGE: ---

POWER: --- W*

WEIGHT: 40 LB*

VOLUME: 3.5 FT^3*

CYCLE TIME: --- MIN.

LIFETIME: --- YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

Operation of FTIR is basically the same as IR, except for the analysis method. Many gaseous and liquid compounds absorb infrared radiation to some degree. The degree of absorption at specific wavelengths depends on molecular structure and concentration. Radiation exiting the sample must be analyzed to determine absorbance. An interferogram can be created containing frequency and intensity information. Analysis of the interferogram using a Fourier transform yields the frequencies and intensities of IR light absorbed.

REFERENCE:

Scott J. Selover "Evaluation of Approaches to Space Based Environmental Monitoring", Material and Process Laboratories Lockheed Missiles and Space Co., Inc., Oct. 1988.

Sensor Figure Not Included

SENSOR NAME : **Fuel Cell Oxygen-Measuring Instrument**

SENSOR INFORMATION

SUBSYSTEM: All		TECHNOLOGY: All	
SENSOR TYPE: CH		OPERATION: Fuel Cell Oxygen Diffusion	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER:	--- W*
RESOLUTION: --- G	TEMP. RANGE: ---	WEIGHT:	--- LB*
NO. OF DETECTABLE MICROBES: 3.0	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: O2		CYCLE TIME:	--- MIN.
SELECTIVITY RATING: 3.0		LIFETIME:	--- YEARS

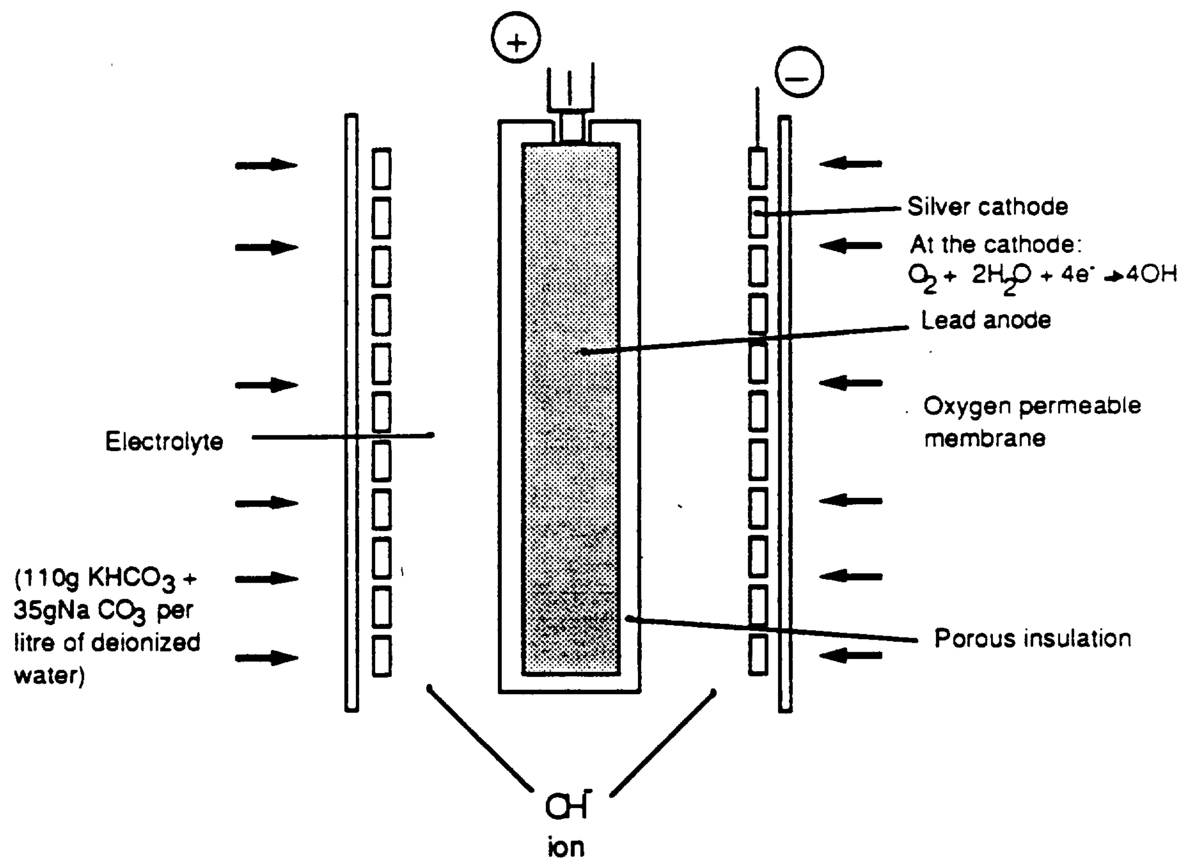
* Design specific information, to be determined.

SENSOR DESCRIPTION:

Galvanic or fuel cells differ from polarographic cells and high temperature ceramic sensors because they require no external source of power to drive them. A lead anode is made in the geometric form that maximizes the amount of metal available for reaction with a convex disc cathode. Both electrode are immersed in an aqueous potassium hydroxide electrolyte. Diffusion of oxygen through the membrane enables the reaction to take place. The electrical output of the cell can be related to the partial pressure of oxygen on the gas side of the membrane in a manner analogous to that described for membrane-covered polarographic cells.

REFERENCE:

B. E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.



C.9 Oxygen Cell

SENSOR NAME : **High Performance Liquid Chomatography (HPLC)**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: All WRM	
SENSOR TYPE: CH		OPERATION: Liquid chromatography	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER:	--- W*
RESOLUTION: 1.0E -12 G	TEMP. RANGE: ---	WEIGHT:	96 LB*
NO. OF DETECTABLE MICROBES: 9.0	PRESS. RANGE: ---	VOLUME:	6.1 FT^3*
DETECTABEL SPECIES: Synthetic Organic Compounds, Pesticide, Phenolics, PAH, Oil		CYCLE TIME:	--- MIN.
SELECTIVITY RATING: 8.5		LIFETIME:	--- YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

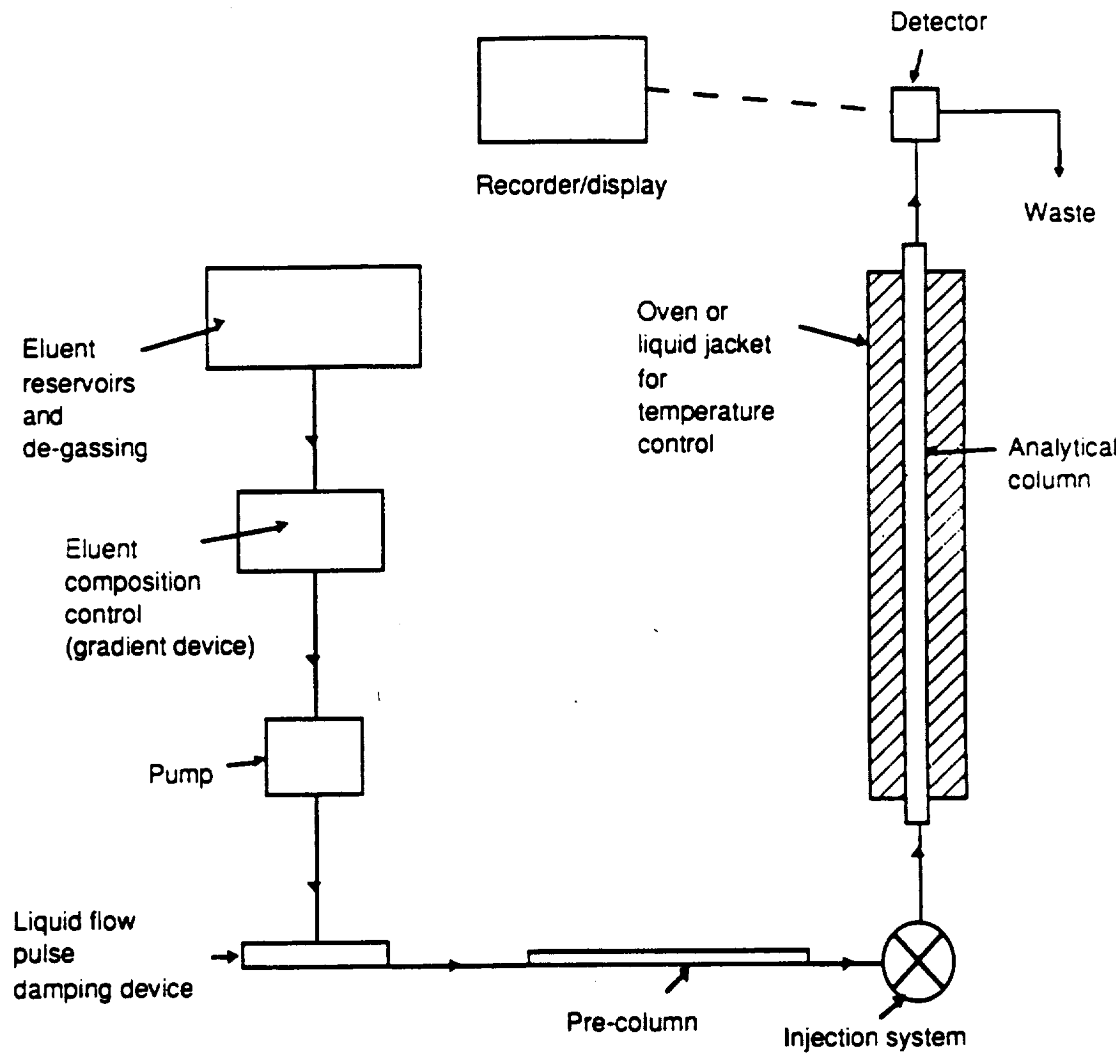
Although gas chromatograph methods are widely used, they can detect only 10% of the organic compounds found in water. HPLC methods may be capable of detecting much of the remaining 90%. HPLC works basically the same as GC except liquid is the moving phase, and high pressures and narrow columns allow shorter intervals and smaller volumes of samples to be analyzed. Changing the moving phase mid-column is essential because it plays a more important role than in GC. Refractive index, absorption, or fluorescence are used as detection methods.

REFERENCE:

Lawrence Berkeley Laboratory Environmental Instrumentation Survey, "Instrumentation Environmental Monitoring", Vol. 2, Water, John Wiley & Sons Inc., 1986.

Ben E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.

L. S. Clesceri, A. E. Greenberg, and R. R. Trussell, "Standard Methods for the Examination of Water and Wastewater", American Public Health Association, 17th Edition, 1989.



C.10 High Performance Liquid Chromatography (HPLC)

SENSOR NAME : **High Temperature Ceramic Sensor Oxygen Probes**

SENSOR INFORMATION

SUBSYSTEM: ALL		TECHNOLOGY: All
SENSOR TYPE: CH		OPERATION: Surface Potential Change Related to O2 Contents
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER: --- W*
RESOLUTION: --- G	TEMP. RANGE: 600°C to 1200°C	WEIGHT: --- LB*
NO. OF DETECTABLE MICROBES: 3.0	PRESS. RANGE: ---	VOLUME: --- FT^3*
DETECTABEL SPECIES: O2		CYCLE TIME: --- MIN.
SELECTIVITY RATING: 3.0		LIFETIME: --- YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

Just as an electrical potential can be developed at a glass membrane which is a function of the ratio of the hydrogen concentration on either side, a pure zirconia tube maintained at high temperature will develop a potential between its surfaces that is function of the partial pressure of oxygen which is in contact with its surfaces. This is the principle involved in the oxygen probes.

REFERENCE:

B. E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.

D. E. Williams and P. T. Moseley, "Progress in the Development of Solid State Gas Sensors", Measurement + Control, Volume 21, March 1988.

Sensor Figure Not Included

SENSOR NAME : **Inductively Coupled Plasma Emission (ICPE)**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: All WRM	
SENSOR TYPE: CH		OPERATION: Atomic Emission	
ACCURACY: ± --- %	Operational Environment	POWER:	--- W*
RESOLUTION: 1.0E -8 G	TEMP. RANGE: ---	WEIGHT:	800 LB*
NO. OF DETECTABLE MICROBES: 7.0	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: Major ions, Metals		CYCLE TIME:	10.00 MIN.
SELECTIVITY RATING: 9.0		LIFETIME:	--- YEARS

* Design specific information, to be determined.

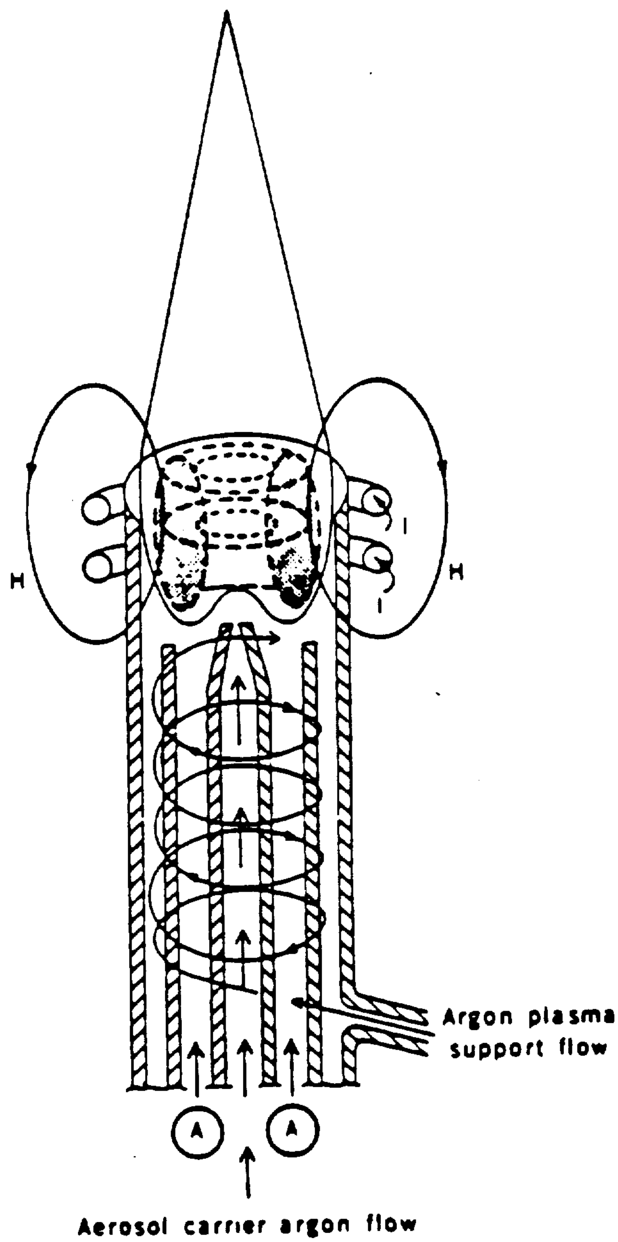
SENSOR DESCRIPTION:

High temperature plasmas excite atomic emission very efficiently. Ionization of a high percentage of atoms produces good ionic emission spectra. The ICP provides an optically "thin" source that is not subject to self-absorption except at very high concentrations. Therefore, linear dynamic ranges of four to six orders of magnitude can be observed for many elements. The efficient excitation provided by the ICP results in low detection limits for many elements. This characteristic coupled with an extended dynamic range, permits effective multielement determination of metals.

REFERENCE:

Lenore S. Clesceri, Arnold E. Greenberg, and R. Rhodes Trussell, "Standard Methods for the Examination of Water and Wastewater", American Public Health Association, 17th Edition, 1989.

Ben E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.



C.11 Typical Inductively Coupled Plasma Configuration

SENSOR NAME : **Infrared Spectroscopy (IR)**

SENSOR INFORMATION

SUBSYSTEM: CO2 REDUCTION, CO2 REMOVE, WRM.		TECHNOLOGY: ALL in subsystem	
SENSOR TYPE: CH		OPERATION: Spectroscopy	
ACCURACY: ± --- %	Operational Environment	POWER:	--- W*
RESOLUTION: 1.0E -6 G	TEMP. RANGE: ---	WEIGHT:	--- LB*
NO. OF DETECTABLE MICROBES: 8.0	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: CO , CO2, Compound with dipole		CYCLE TIME:	--- MIN.
SELECTIVITY RATING: 9.0		LIFETIME:	--- YEARS

* Design specific information, to be determined.

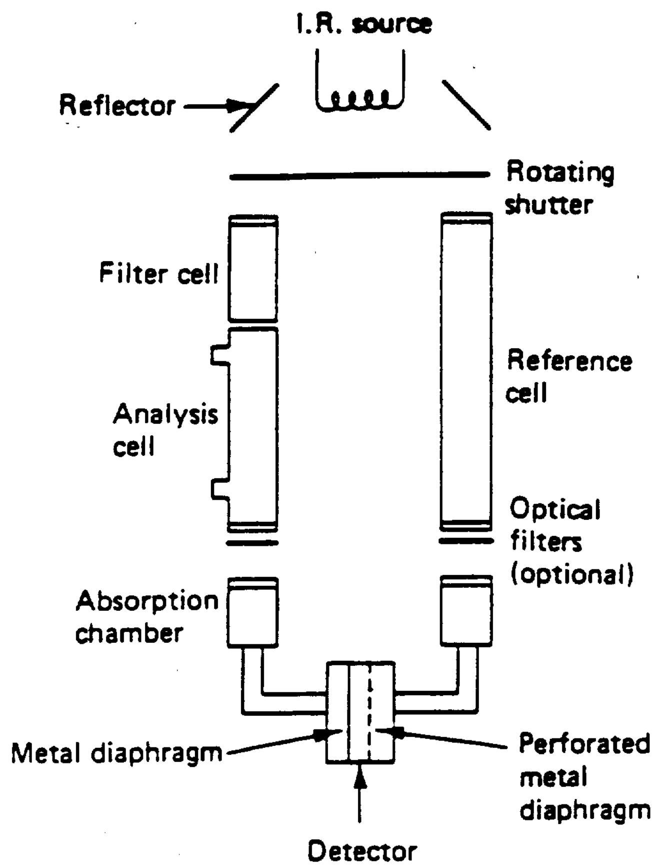
SENSOR DESCRIPTION:

Discrete absorption of infrared light occurs because of the vibrational and rotational motion of molecules. The infrared spectrum of a particular molecule depends on the energy absorption of the motions. Because each compound is constructed uniquely the vibrational and rotational modes of a particular compound provide a spectral absorption pattern uniquely characteristic of that molecule.

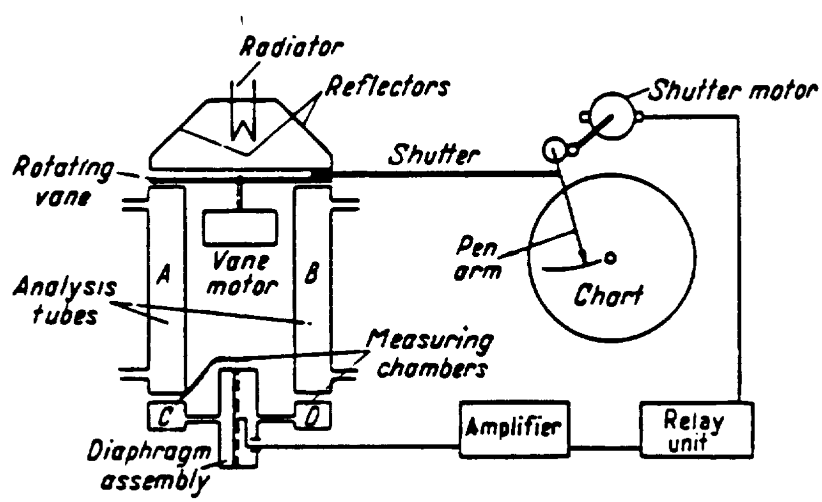
REFERENCE:

Lawrence Berkeley Laboratory Environmental Instrumentation Survey, "Instrumentation Environmental Monitoring", Vol. 2, Water, John Wiley & Sons Inc., 1986.

Ben E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.



(a)



(b)

C.12 (a) Luft-Type Infrared Gas Analyzer, (b) Infrared Gas of the Concentration Recorder

SENSOR NAME : **Metal Oxide**

SENSOR INFORMATION

SUBSYSTEM: CO2 REDUCTION

TECHNOLOGY: ACRS, SABATIER, CO2_E.

SENSOR TYPE: CH

OPERATION: Semiconductor

ACCURACY: ± --- %	<u>Operational Environment</u>	POWER: --- W*
RESOLUTION: 1.0E -8 G	TEMP. RANGE: ---	WEIGHT: --- LB*
NO. OF DETECTABLE MICROBES: 4.0	PRESS. RANGE: ---	VOLUME: --- FT^3*
DETECTABEL SPECIES: CO , CH4, Combustible, flammable gas		CYCLE TIME: --- MIN.
SELECTIVITY RATING: 2.0		LIFETIME: --- YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

Reduction of oxidizing gases interacting with absorbed oxygen on a hot surface causes a dramatic change in conductivity. Metal Oxide Sensors can indicate low levels of flammable gas and combustion products and are sensitive to low vapor concentrations. Metal Oxide Sensors are very small, cheap, and robust, but poor selectivity and reproducibility. Selectivity can be increased exhibit utilizing a sensor array and pattern recognition methods.

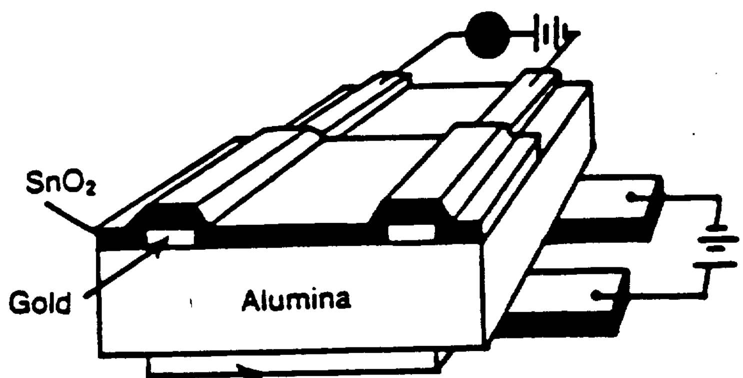
REFERENCE:

Bernard Hulley, "Chemical Sensors - an Overview", Measurement + Control, Vol. 21, March 1988.

T. A. Jones, "Trends in the Development of Gas Sensors", Measurement + Control, Vol. 22, July/August 1989.

C. Hierold and R. Muller, "Quantitative Analysis of Gas Mixtures with Non-Selective Gas Sensors", Sensors and Actuators, 17 (1989) .

Thin-film tin oxide gas sensor



C.13 Thin Film Tin Oxide Gas Sensor

SENSOR NAME : **Non-Dispersive Infrared Spectroscopy (NDIR)**

SENSOR INFORMATION

SUBSYSTEM: CO_2 REDUCTION, CO_2 REMOVAL.		TECHNOLOGY: BOSCH, SABATIER, CO2_E, 4BMS, 2BMS, SAWD	
SENSOR TYPE: CH		OPERATION: Spectroscopy	
ACCURACY: ± --- %	Operational Environment	POWER:	10 W*
RESOLUTION: 1.0E -11 G	TEMP. RANGE: -40°C to 60°C	WEIGHT:	6 LB*
NO. OF DETECTABLE MICROBES: 5.0	PRESS. RANGE: ---	VOLUME:	0.1 FT^3*
DETECTABEL SPECIES: CO , CO_2, Hydrocarbon		CYCLE TIME:	0.05 MIN.
SELECTIVITY RATING: 9.0		LIFETIME:	--- YEARS

* Design specific information, to be determined.

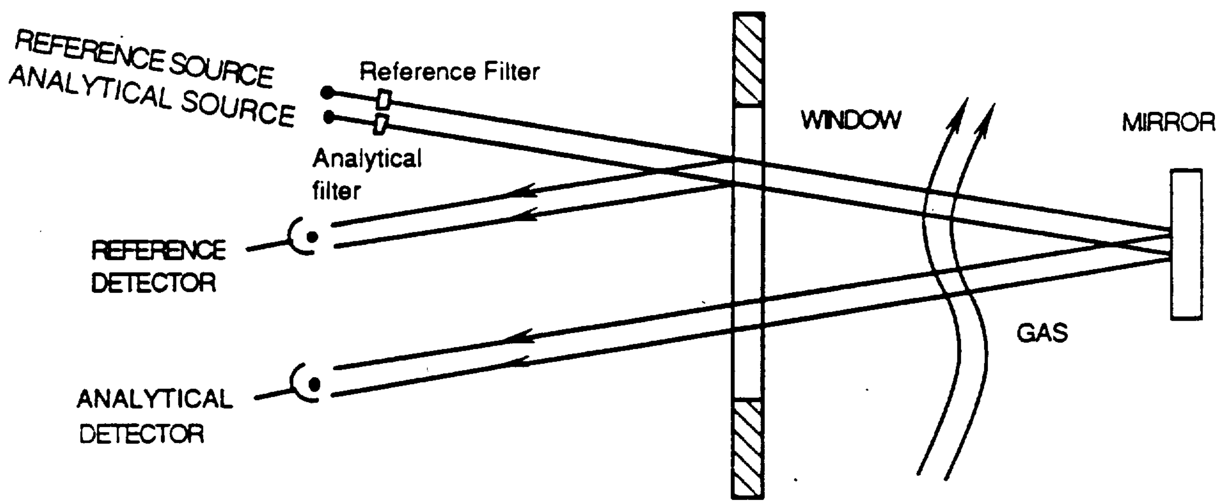
SENSOR DESCRIPTION:

When an infrared source is directed down a path of known length, the gas of interest absorbs specific wavelengths. Sample concentration can be determined by direct comparison of transmitted light. Problems due to reference cell leakage, dual detectors, or sources may vary, and uneven coating of optical surfaces by dirt may affect measurement. A compound which does not absorb infrared radiation cannot use this technique. Improvements in design have provided a solid state dual wavelength system with automatic drift compensation for aging and dirt accumulation. NDIR has been used for 40 years to measure CO_2, CO, and a few other gases and is safe, accurate, fast, reliable, and could easily be incorporated into a Major Constituent Analyzer. This technology also applies to the monitoring of combustible gases, which offers the user an economical, safe method of detection.

REFERENCE:

Ben E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co.
Ltd, 1985.

John W. Small, " Monitoring of Combustible Gases", Measurements & Control, June 1988.



C.14 Non-Dispersive Infrared Spectroscopy (NDIR)

SENSOR NAME : **Nuclear Magnetic Resonance (NMR)**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: All WRM	
SENSOR TYPE: CH		OPERATION: Resonance Spectroscopy	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER:	--- W*
RESOLUTION: 1.0E -6 G	TEMP. RANGE: ---	WEIGHT:	--- LB*
NO. OF DETECTABLE MICROBES: 8.0	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: Synthetic Organic Compounds, Oil		CYCLE TIME:	--- MIN.
SELECTIVITY RATING: 7.5		LIFETIME:	--- YEARS

* Design specific information, to be determined.

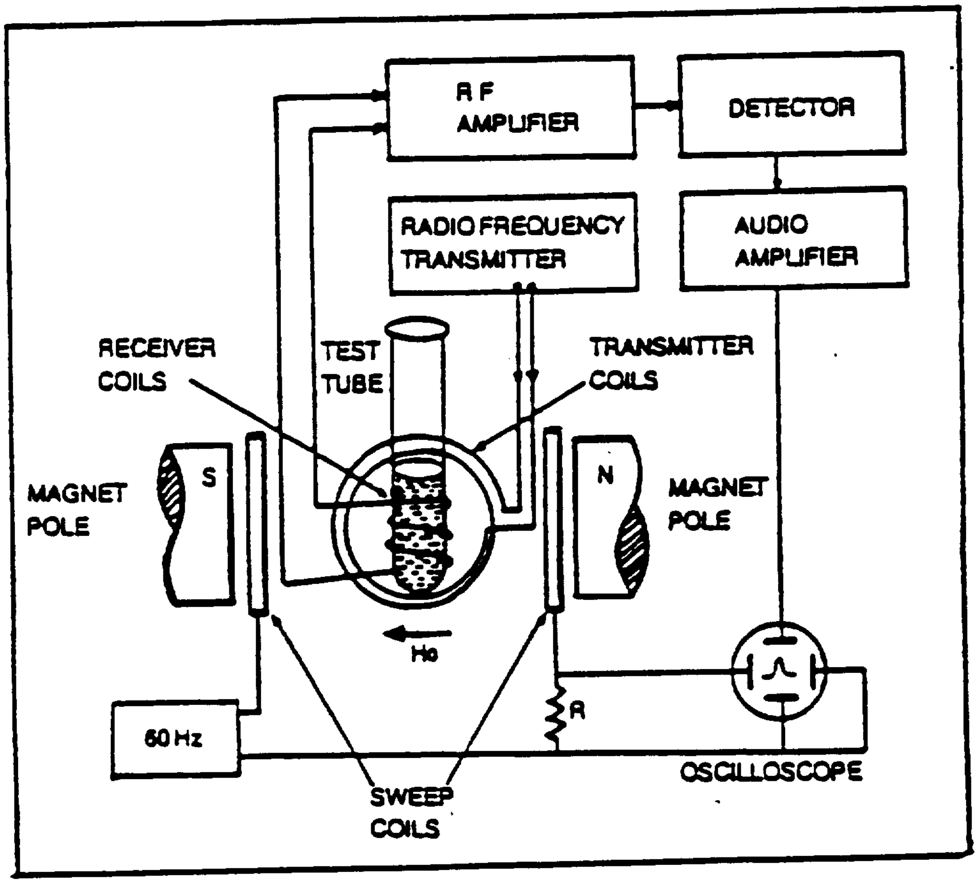
SENSOR DESCRIPTION:

The basis of this technique is the resonant interaction between a high frequency field and the nuclei of a compound placed in an external magnetic field. When the nucleus absorbs energy from the resonant field it goes to an excited state then releases the energy in the form of light when it returns to the ground state. Isotopes with both the number of neutrons and the number of protons being even (C12, O16, S32) do not have any moment and can not be detected by this technique.

REFERENCE:

Ben E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.

Robert H. Perry, Don W. Green, and Jame O. Maloney, "Perry's Chemical Engineers' Handbook", - Hill Book Company, 6th Edition, 1984.



C.15 Nuclear Magnetic Resonance Spectrometer (NMR)

SENSOR NAME : **Paramagnetic Oxygen Analyzers**

SENSOR INFORMATION

SUBSYSTEM: ALL		TECHNOLOGY: All	
SENSOR TYPE: CH		OPERATION: Oxygen's Paramagnetic Property	
ACCURACY: ± --- %	Operational Environment	POWER:	--- W*
RESOLUTION: --- G	TEMP. RANGE: ---	WEIGHT:	--- LB*
NO. OF DETECTABLE MICROBES: 2.0	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: O2		CYCLE TIME:	--- MIN.
SELECTIVITY RATING: 2.0		LIFETIME:	--- YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

Many process analyzers for oxygen make use of fact that oxygen alone, is the only common gas that is paramagnetic. The magnetic properties of a substance can be related to its electronic structure. In the oxygen molecule, two of the electrons in the outer shell are unpaired, therefore the magnetic moment of the molecule is not neutralized. This permanent magnetic moment is the origin of oxygen's paramagnetism. The paramagnetic properties of oxygen are exploited in two types of process analyzers: the so called 'magnetic wind' or thermal magnetic instruments, and magnetodynamic instruments.

REFERENCE:

B. E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.

Sensor Figure Not Included

SENSOR NAME : **Photo-ionization Detector (UV) or (PID)**

SENSOR INFORMATION

SUBSYSTEM: WRM	TECHNOLOGY: All WRM		
SENSOR TYPE: CH	OPERATION: Light Ionization		
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER:	--- W*
RESOLUTION: 1.0E -11 G	TEMP. RANGE: ---	WEIGHT:	--- LB*
NO. OF DETECTABLE MICROBES: 6.0	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: Organics (no low molecule weight hydrocarbon)		CYCLE TIME:	--- MIN.
SELECTIVITY RATING: 5.0		LIFETIME:	--- YEARS

* Design specific information, to be determined.

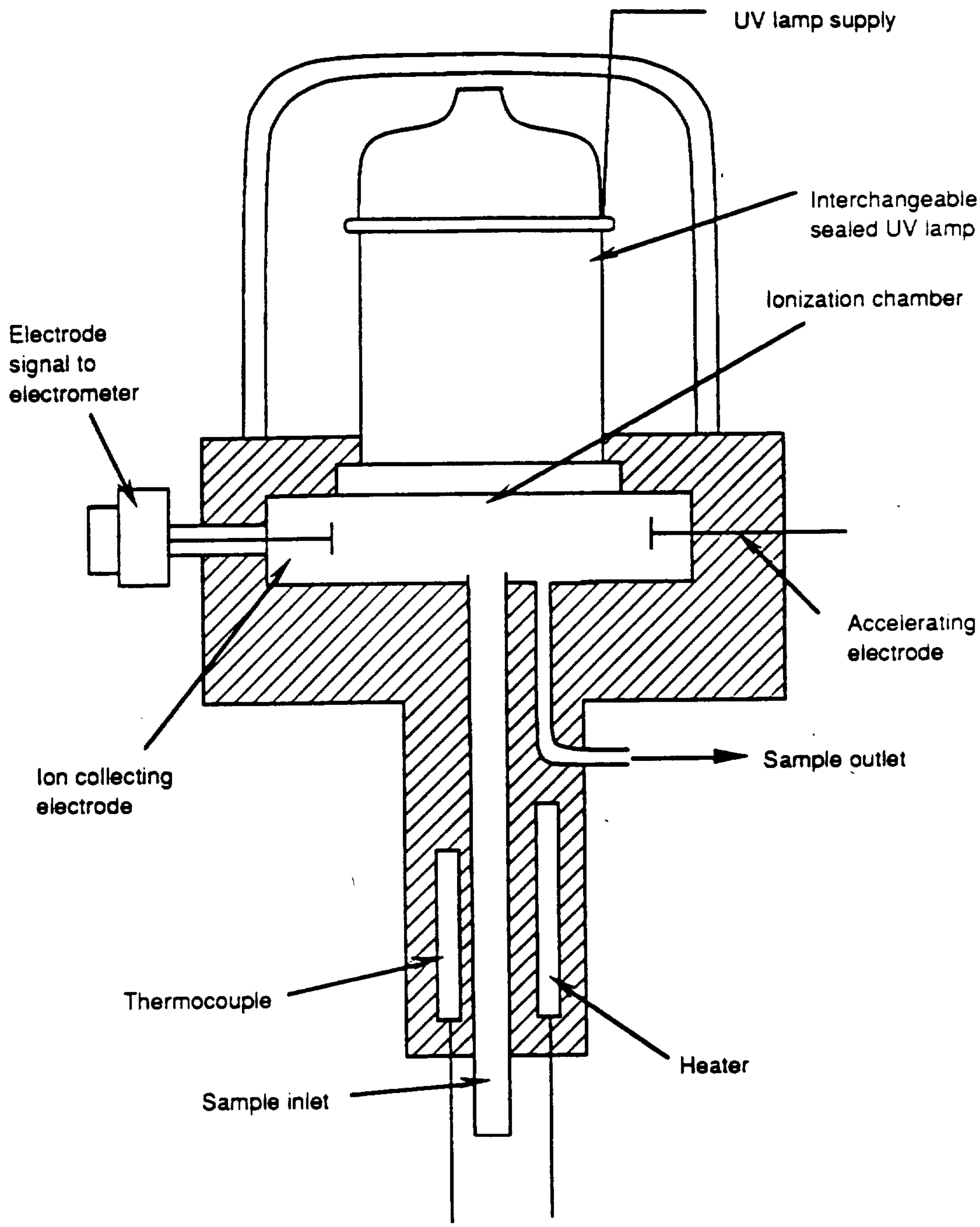
SENSOR DESCRIPTION:

A gas stream is directed past an interchangeable sealed lamp which produces monochromatic radiation in the UV region. A signal is generated when a compound in the gas is ionized by the light from the lamp. The ions generated are collected on a charged plate and are measured with an electrometer amplifier. The low energy of the UV radiation produces predominantly molecular ions. The response of the PID is determined mainly by the ionization potential of the molecule.

REFERENCE:

Lawrence Berkeley Laboratory Environmental Instrumentation Survey, "Instrumentation Environmental Monitoring", Vol. 2, Water, John & Wiley & Sons Inc., 1986.

Ben E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.



C.16 Photoionization Detector (UV)

SENSOR NAME : **Polarographic Process Oxygen Analyser**

SENSOR INFORMATION

SUBSYSTEM: All	TECHNOLOGY: All		
SENSOR TYPE: CH	OPERATION: Polarographics		
ACCURACY: ± --- %	Operational Environment	POWER:	--- W*
RESOLUTION: --- G	TEMP. RANGE: ---	WEIGHT:	--- LB*
NO. OF DETECTABLE MICROBES: 2.0	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: O2		CYCLE TIME:	--- MIN.
SELECTIVITY RATING: 2.0		LIFETIME:	0.5 YEARS

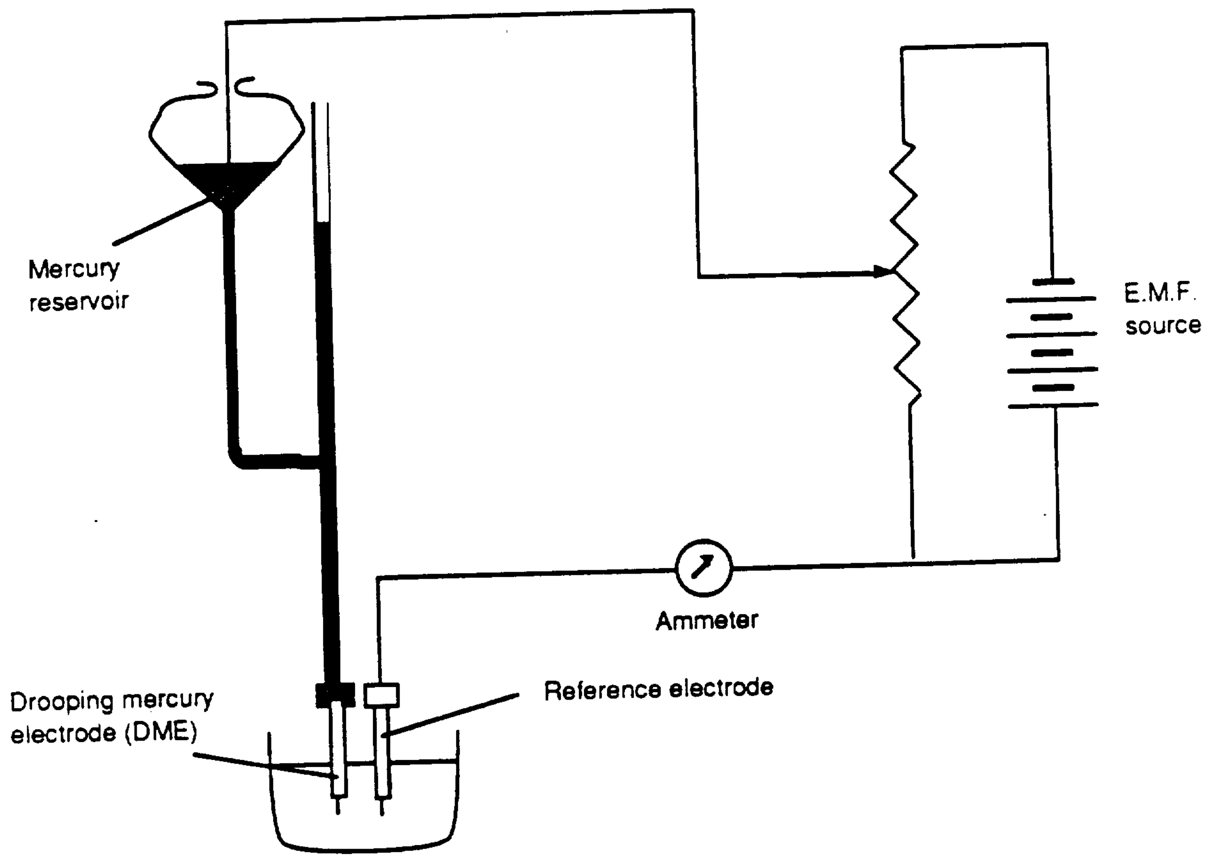
* Design specific information, to be determined.

SENSOR DESCRIPTION:

This oxygen analyzer uses the amperometric method of measurement for the continuous measurement of oxygen in flue gases, inert gas monitoring, and other applications. Oxygen diffuses through a thin membrane and reacts with the cathode, the corresponding anodic reaction takes place. For the reaction to continue, however, an external potential must be applied between cathode and anode. Oxygen will then continue, to be reduced at the cathode, causing a current to flow, the magnitude of which is proportional to the partial pressure of oxygen in the sample gas.

REFERENCE:

B. E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.



C.17 Polargraphic System

SENSOR NAME : **Potentiometric**

SENSOR INFORMATION

SUBSYSTEM: CO_2 REDUCTION, CO_2 REMOVAL	TECHNOLOGY: All in these Subsystem.	
SENSOR TYPE: CH	OPERATION: Electrochemical	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER: --- W*
RESOLUTION: 1.0E -7 G	TEMP. RANGE: ---	WEIGHT: --- LB*
NO. OF DETECTABLE MICROBES: 6.0	PRESS. RANGE: ---	VOLUME: --- FT^3*
DETECTABEL SPECIES: H_2, O_2, SO_2, CO, CL_2		CYCLE TIME: --- MIN.
SELECTIVITY RATING: 5.0		LIFETIME: --- YEARS

* Design specific information, to be determined.

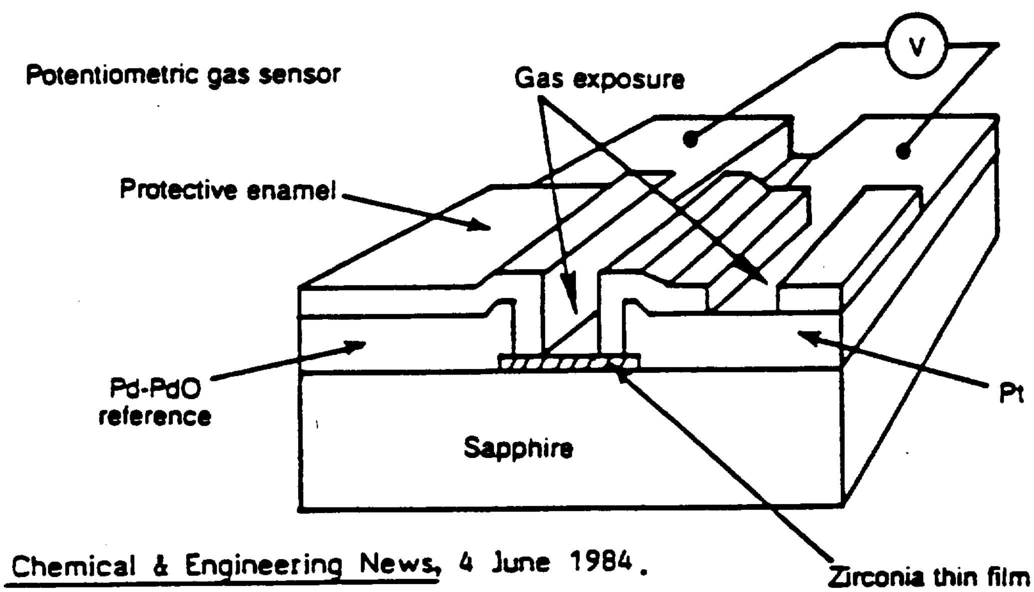
SENSOR DESCRIPTION:

The sensing electrode is in contact with an ionic solution separated from the sample by a semipermeable membrane. The species of interest permeate the membrane and react with the ion electrolyte causing a change in cell chemical potential. The electromotive force developed in the cell is proportional to the activity or effective concentration of the gaseous species of interest. These sensors are highly susceptible to interference from other compounds such as NO_2, SO_2, and H_2S.

REFERENCE:

H. V. Venkatasetty, "Electrochemical Multigas Sensors for Air Monitoring Assembly", SAE 881082, 1988.

Hank Wohltjen, "Chemical Microsensors and Microinstrumentation", Analytical Chemistry, Vol. 56, No. 1, Jan. 1984.



Source: Chemical & Engineering News, 4 June 1984.

C.18 Potemtiometric Gas Sensor

SENSOR NAME : **Semiconductor**

SENSOR INFORMATION

SUBSYSTEM: CO2 REDUCTION	TECHNOLOGY: ACRS, BOSCH, SABATIER.	
SENSOR TYPE: CH	OPERATION: Measuring the Change of Conductivity	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER: --- W*
RESOLUTION: --- G	TEMP. RANGE: ---	WEIGHT: --- LB*
NO. OF DETECTABLE MICROBES: 6.0	PRESS. RANGE: ---	VOLUME: --- FT^3*
DETECTABEL SPECIES: Combustible gases, Other gases		CYCLE TIME: --- MIN.
SELECTIVITY RATING: 4.0		LIFETIME: --- YEARS

* Design specific information, to be determined.

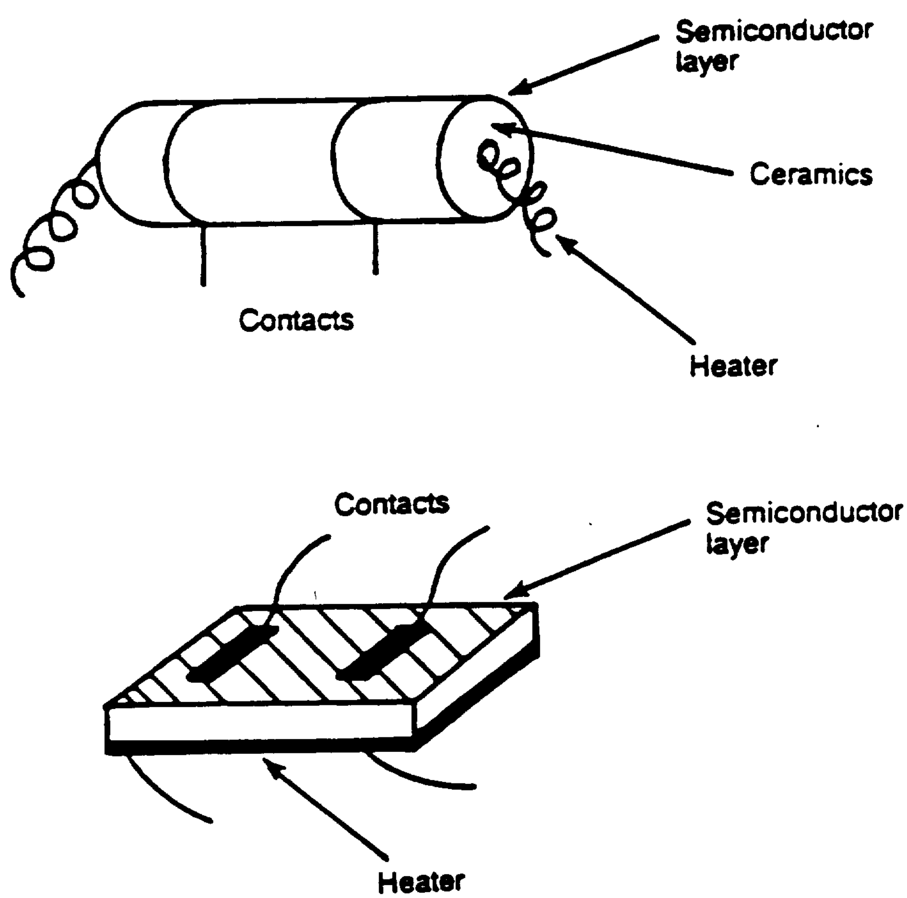
SENSOR DESCRIPTION:

The electrical conductivity of many metal oxide semiconductors is changed when a gas molecule is adsorbed on the semiconductor surface. Adsorption involves the formation of bonds between the gas molecule and the semiconductor by the transfer of electrical charge. This charge transfer changes the electronic structure of the semiconductor, altering its conductivity. The conductivity changes are related to the number of gas molecules adsorbed on the surface, and hence to the concentration of the adsorbed species in the surrounding atmosphere. Semiconductor detectors are mainly used as low cost devices for detection of flammable gases. The main defect of the devices at present is their lack of selectivity.

REFERENCE:

B. E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.

D. E. Williams and P. T. Mosely, "Progress in the Develpment of Solid State Gas Sensors", Measurment + Control, Volume 21, March 1988.



C.19 Semiconductor Gas Sensor

SENSOR NAME : **Surface Acoustic Wave (SAW)**

SENSOR INFORMATION

SUBSYSTEM: CO2 REDUCTION, O2 GENERATION, WRM.

TECHNOLOGY: All in these Subsystems.

SENSOR TYPE: CH

OPERATION: Surface Acoustic Wave

ACCURACY: ± --- %

RESOLUTION: 1.0E -6 G

NO. OF DETECTABLE MICROBES: 5.0

DETECTABEL SPECIES: H2, SO2, H2O

SELECTIVITY RATING: 2.0

<u>Operational Environment</u>

TEMP. RANGE: ---

PRESS. RANGE: ---

POWER: --- W*

WEIGHT: --- LB*

VOLUME: --- FT^3*

CYCLE TIME: --- MIN.

LIFETIME: --- YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

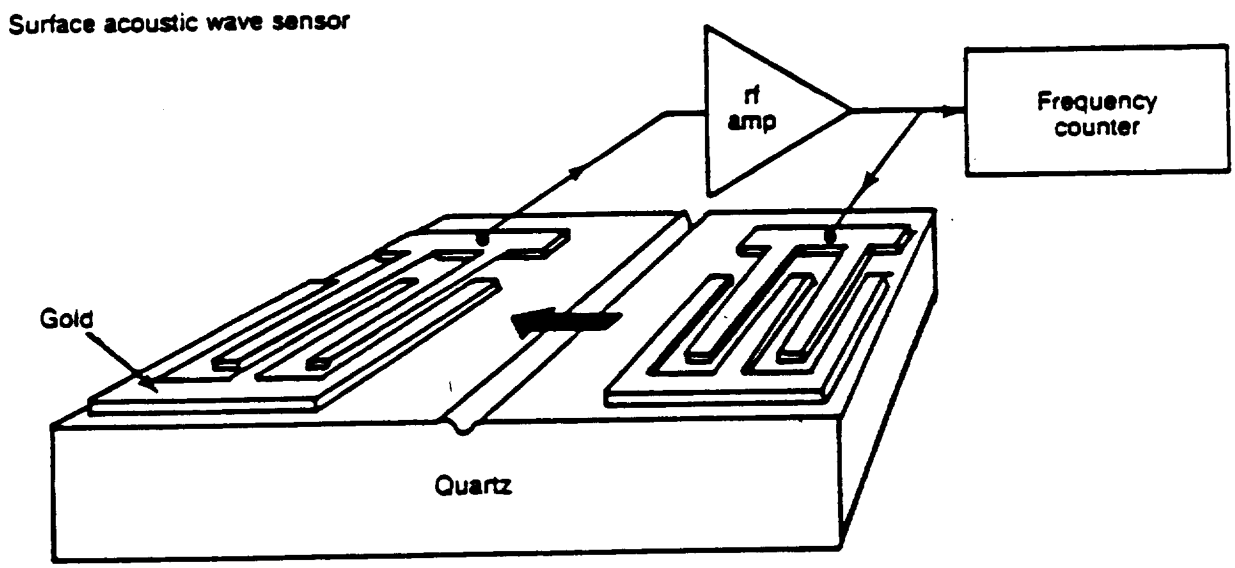
These chemical microsensors use the surface acoustic wave phenomena for detection. The device consist of a piezoelectric substrate with interdigital electrode arrays microfabricated at each end. When excited by a radio frequency (RF) voltage of the appropriate frequency, a synchronous mechanical wave is created in the piezoelectric substrate. This surface wave propagates from the transmitting electrode array across to an identical receiving array where it is converted back to a RF voltage. Any material adsorbed on the surface will produce large changes in wave amplitude and velocity. This can be used to detect H2O, SO2, H2, and organophosphorous compounds below ppm concentrations as well as pressure, temperature, and vapor level.

REFERENCE:

Hank Wohltjen, "Chemical Microsensors and Microinstrumentation", Analytical Chemistry, Vol. 56, No. 1, Jan. 1984.

T. A. Jones, "Trends in the Development of Gas Sensors", Measurement + Control, Vol. 22, July/August 1989.

A. Damico and E. Verona, "SAW Sensors", Sensors and Actuators, 17 (1989), P55-66.



C.20 Surface Acoustic Wave Sensor (SAW)

SENSOR NAME : **Thermal Conductivity Detectors (TCD)**

SENSOR INFORMATION

SUBSYSTEM: ALL	TECHNOLOGY: All		
SENSOR TYPE: CH	OPERATION: Kinetic Theory		
ACCURACY: ± --- %	Operational Environment	POWER:	--- W*
RESOLUTION: 1.0E -6 G	TEMP. RANGE: Room Temp	WEIGHT:	--- LB*
NO. OF DETECTABLE MICROBES: 10.0	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: Universal		CYCLE TIME:	--- MIN.
SELECTIVITY RATING: 2.0		LIFETIME:	--- YEARS

* Design specific information, to be determined.

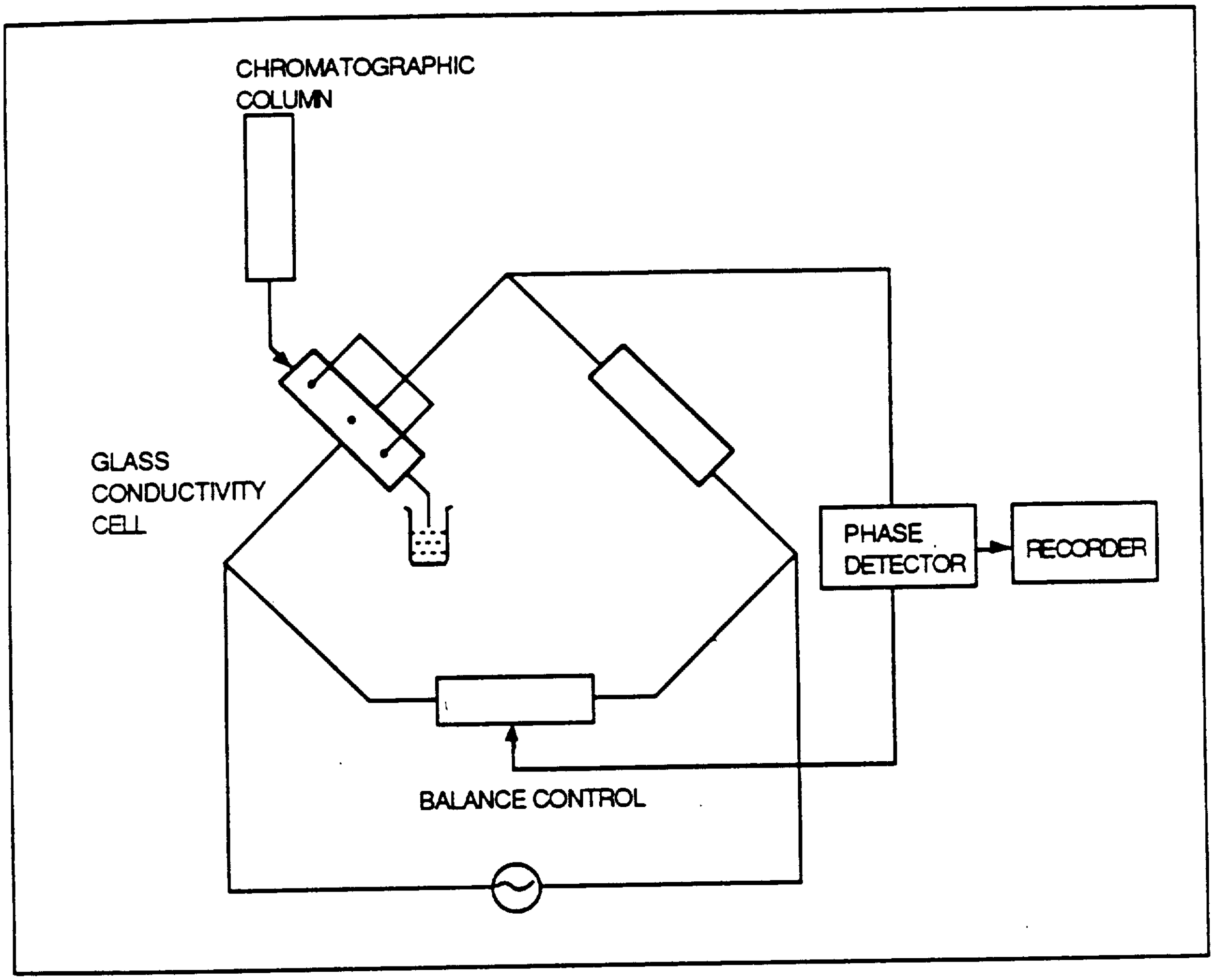
SENSOR DESCRIPTION:

The thermal conductivity detector (TCD) is among the most commonly used gas detection devices. It measures the changes in the concentration (based on kinetic theory) of the species to be detected. TCD is primarily used to analyze binary or pseudo-binary mixtures.

REFERENCE:

Lawrence Berkeley Laboratory Environmental Instrumentation Survey, "Instrumentation Environmental Monitoring", Volume 2, Water, John Wiley & Sons Inc., 1986.

Ben E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.



C.21 Conductivity Detector

SENSOR NAME : **Thin Layer Chromatography (TLC)**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: TIMES, VCD, AES, VPCAR, RO, MF, SCWO, WE
SENSOR TYPE: CH		OPERATION: Chromatography
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER: --- W*
RESOLUTION: 1.0E -6 G	TEMP. RANGE: ---	WEIGHT: --- LB*
NO. OF DETECTABLE MICROBES: 8.0	PRESS. RANGE: ---	VOLUME: --- FT^3*
DETECTABEL SPECIES: Organics, Oil, Pesticide		CYCLE TIME: --- MIN.
SELECTIVITY RATING: 7.0		LIFETIME: --- YEARS

* Design specific information, to be determined.

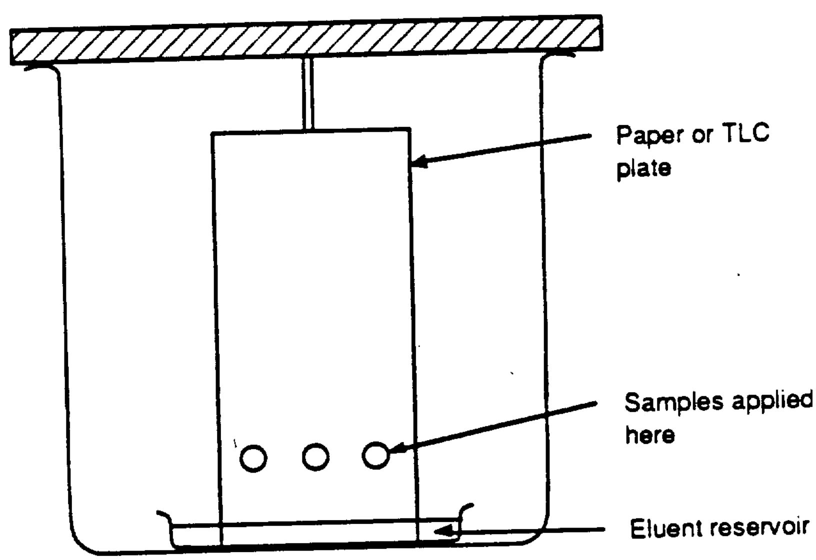
SENSOR DESCRIPTION:

Thin Layer Chromatography (TLC) is a form of adsorption chromatography useful for organic microanalysis. In TLC the separation is carried out on a thin layer of an adsorbing substance such as silica gel coated onto a glass or plastic plate. TLC is rapid, provides high resolution, and requires little pre-analysis sample cleanup. High performance TLC can run many different samples simultaneously, is faster than HPLC, and in some cases the sensitivity is better.

REFERENCE:

Lawrence Berkeley Laboratory Environmental Instrumentation Survey, "Instrumentation Environmental Monitoring", Volume 2, Water, John Wiley & Sons Inc., 1986.

Ben E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.



C.22 Ascending Eluent Used With Thin Layer Chromatography

SENSOR NAME : **Ultrasonic Detector**

SENSOR INFORMATION

SUBSYSTEM: WRM	TECHNOLOGY: All WRM	
SENSOR TYPE: CH	OPERATION: Sound Speed Related on Density	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER: --- W*
RESOLUTION: 1.0E -9 G	TEMP. RANGE: ---	WEIGHT: --- LB*
NO. OF DETECTABLE MICROBES: 10.0	PRESS. RANGE: ---	VOLUME: --- FT^3*
DETECTABEL SPECIES: Universal		CYCLE TIME: --- MIN.
SELECTIVITY RATING: 2.0		LIFETIME: --- YEARS

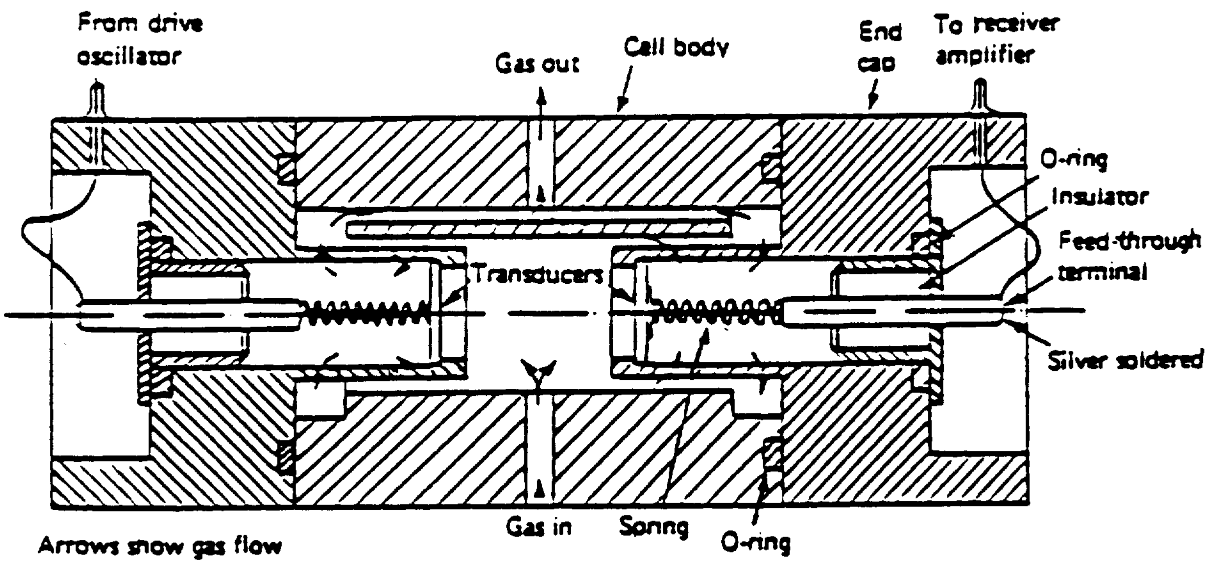
* Design specific information, to be determined.

SENSOR DESCRIPTION:

The velocity of sound in a gas is inversely proportional to the square root of its molecular weight. By measuring the speed of sound in a binary mixture its composition can be deduced. This technique is the basis of the ultrasonic detector. A precise temperature measurement and complex electronic circuitry are required by this detector.

REFERENCE:

Ben E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.



C.23 Ultrasonic Detector

SENSOR NAME : **Enzymes**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: All in WRM.	
SENSOR TYPE: CH/BIO		OPERATION: Enzyme + Electrode	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER:	--- W*
RESOLUTION: 1.0E -9 G	TEMP. RANGE: ---	WEIGHT:	--- LB*
NO. OF DETECTABLE MICROBES: 4.0	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: Drugs, Antigens, Antibodies, Metabolites		CYCLE TIME:	--- MIN.
SELECTIVITY RATING: 7.0		LIFETIME:	--- YEARS

* Design specific information, to be determined.

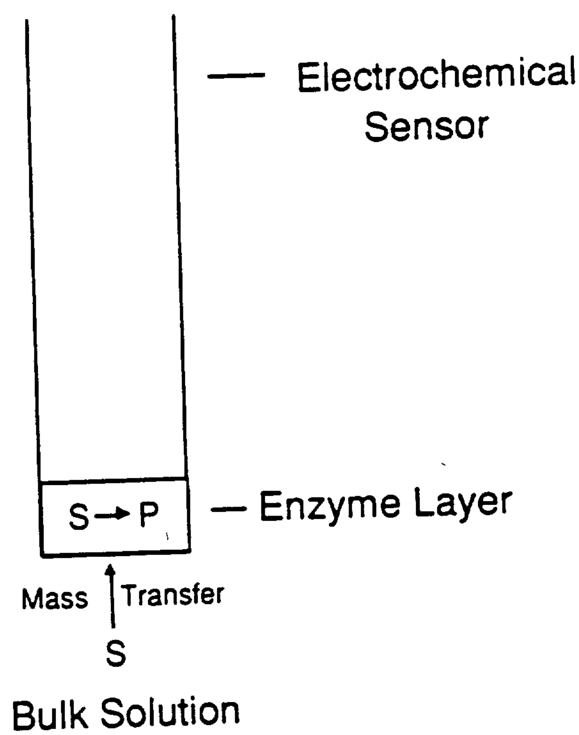
SENSOR DESCRIPTION:

Enzymes are the original biocatalysts used in biosensors. They are natural protein catalysts that affect reactions and usually act on unique substrates. The most common form of enzyme-based electrochemical biosensor is the enzyme electrode which consists of a thin layer of enzyme immobilized on the surface of an electrochemical sensor. The enzyme is chosen to catalyze a reaction which generates a product or consumes a co-reactant which can be monitored electrochemically. The electrochemically generated signal provides a measure of the desired substrate concentration. These sensors have lifetimes measured in days/weeks and must be calibrated regularly, but lifetimes are being enhanced by several methods. Enzyme sensors generally suffer from instability of the enzyme layer.

REFERENCE:

Steven L. Brooks and Anthony P. F. Turner, "Biosensors for Measurement and Control", Measurement + Control, Vol. 20, May 1987.

R. K. Kobos, "Enzyme-Based Electrochemical Biosensors", Trends in Analytical Chemistry, Vol. 6, No. 1, 1987.



C.24 Principle of Operation of Enzyme Electrodes

SENSOR NAME : **Gas Chromatograph/Mass Spectroscopy (GC/MS)**

SENSOR INFORMATION

SUBSYSTEM: ALL

TECHNOLOGY: All

SENSOR TYPE: CH/BIO

OPERATION: GC/MS

ACCURACY: ± --- %

RESOLUTION: 1.0E -9 G

NO. OF DETECTABLE MICROBES: 9.0

DETECTABEL SPECIES: Universal

SELECTIVITY RATING: 8.5

<u>Operational Environment</u>

TEMP. RANGE: ---

PRESS. RANGE: ---

POWER: --- W*

WEIGHT: --- LB*

VOLUME: --- FT^3*

CYCLE TIME: --- MIN.

LIFETIME: --- YEARS

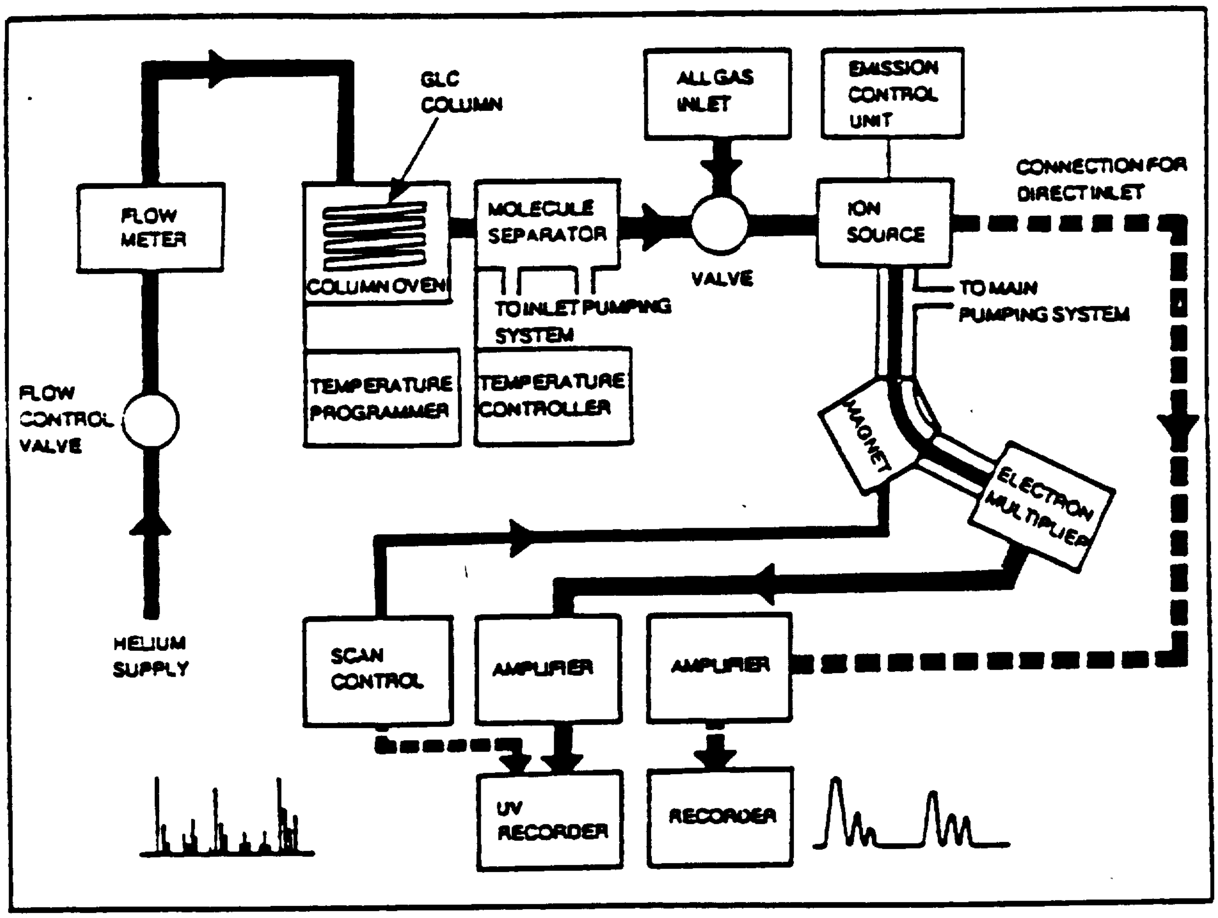
* Design specific information, to be determined.

SENSOR DESCRIPTION:

Combined gas chromatography - mass spectroscopy is used for the determination of chemicals in complex mixtures. The gas chromatograph provides good - to - excellent separation of multicomponent mixtures. Mass spectrometers designed to receive the GC effluent for instant mass spectroscopic analysis are capable of producing a mass spectrum of this effluent every 1-3 sec. Sensitivity of detection and confidence of identification depends on the mass spectrum of each compound. Generally, identification is feasible on the nanogram level if the GC column has made a good separation.

REFERENCE:

Lawrence Berkeley Laboratory Environmental Instrumentation Survey, "Instrumentation Environmental Monitoring", Vol. 2, Water, John Wiley & Sons Inc., 1986.



C.25 Schematic of Gas Chromatograph Mass Spectrometer (GC/MS)

SENSOR NAME : **Gas Chromatography (GC)**

SENSOR INFORMATION

SUBSYSTEM: ALL	TECHNOLOGY: All		
SENSOR TYPE: CH/BIO	OPERATION: Chromatograph		
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER:	--- W*
RESOLUTION: 1.0E -9 G	TEMP. RANGE: ---	WEIGHT:	90 LB*
NO. OF DETECTABLE MICROBES: 8.0	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: Synthetic Organic Compounds, DO, Phenol, Pesticide, Thm, TO		CYCLE TIME:	30.00 MIN.
SELECTIVITY RATING: 7.0		LIFETIME:	--- YEARS

* Design specific information, to be determined.

SENSOR DESCRIPTION:

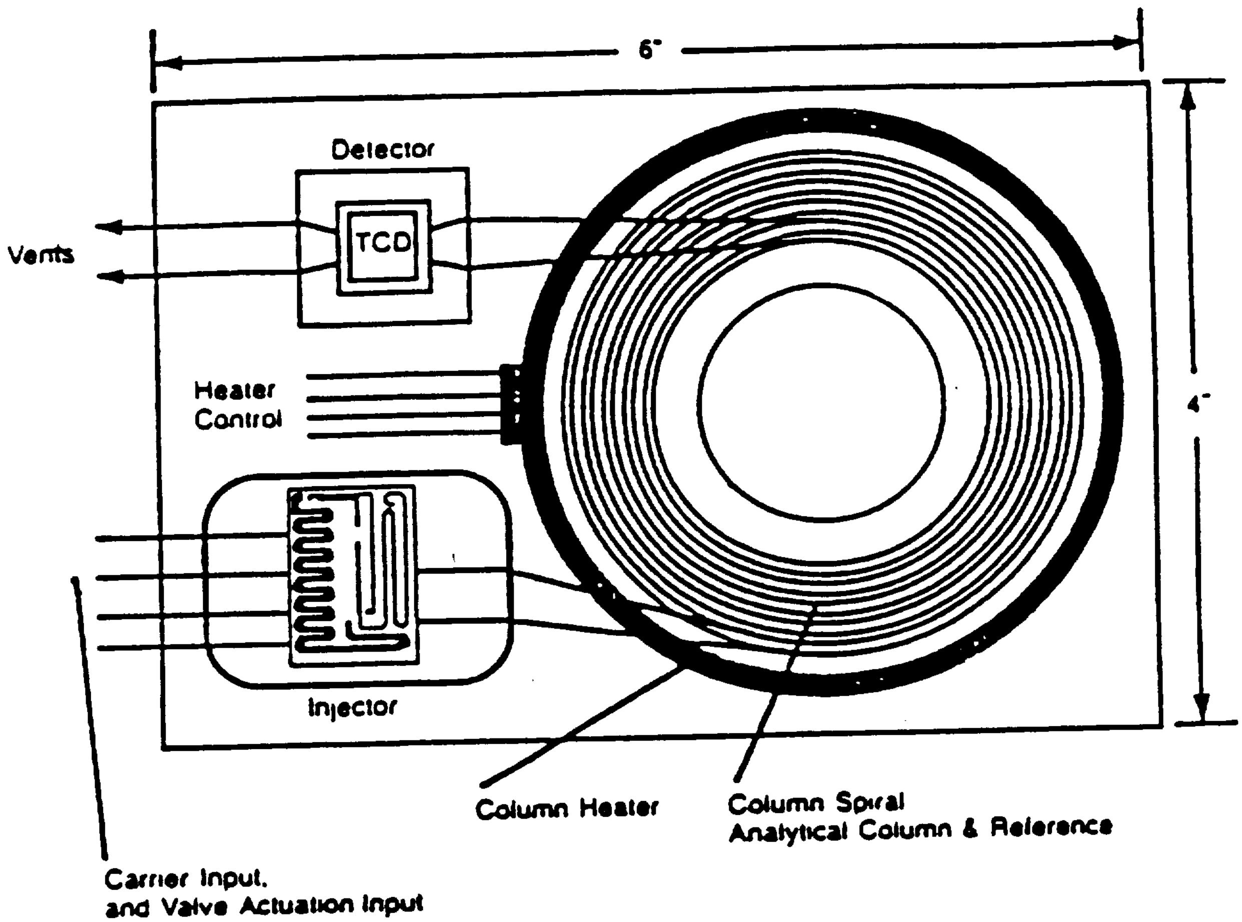
Almost all synthetic organic compounds can be determined qualitatively by GC. GC is a method whereby moderately to highly volatile compounds are propelled via carrier gas (moving phase) through a tube containing a stationary interactive medium (stationary phase) that delays transit of the sample compounds according to their physio-chemical properties. The compounds are separated and emerge from the tube at different time intervals. For a given substrate under given conditions each compound has a charateristic retention time which can be used for tentative identification. Extensive complications of retention times of different compounds on different substrates are available. Positive identification can be made by collecting each compounds it elutes and analyzing by other means (detector) such as MS, FTIR, FID, TCD, etc. Retention times can be difficult to reproduce, and only relatively voliatile compounds can be detected.

REFERENCE:

Lawrence Berkeley Laboratory Environmental Instrumentation Survey, "Instrumentation for Environmental Monitoring", Volume 2, Water, 1986.

Ben E. Noltingk, "Jones' Instrument Technology. Volume 2 Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd. 1985.

Scott J. Selover, "Evaluation of Approaches to Space Based Environmental Monitoring", Material and Process Laboratories Lockheed Missiles and Space Co., Inc., Oct. 1987.



C.26 Gas Chromatography (GC)

SENSOR NAME : **Mass Spectroscopy (MS)**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: All WRM	
SENSOR TYPE: CH/BIO		OPERATION: Ion Dispersion	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER:	--- W*
RESOLUTION: 1.0E -12 G	TEMP. RANGE: ---	WEIGHT:	--- LB*
NO. OF DETECTABLE MICROBES: 9.0	PRESS. RANGE: ---	VOLUME:	--- FT^3*
DETECTABEL SPECIES: Synthetic Organic Compounds, Pesticide, Oil		CYCLE TIME:	0.50 MIN.
SELECTIVITY RATING: 8.0		LIFETIME:	--- YEARS

* Design specific information, to be determined.

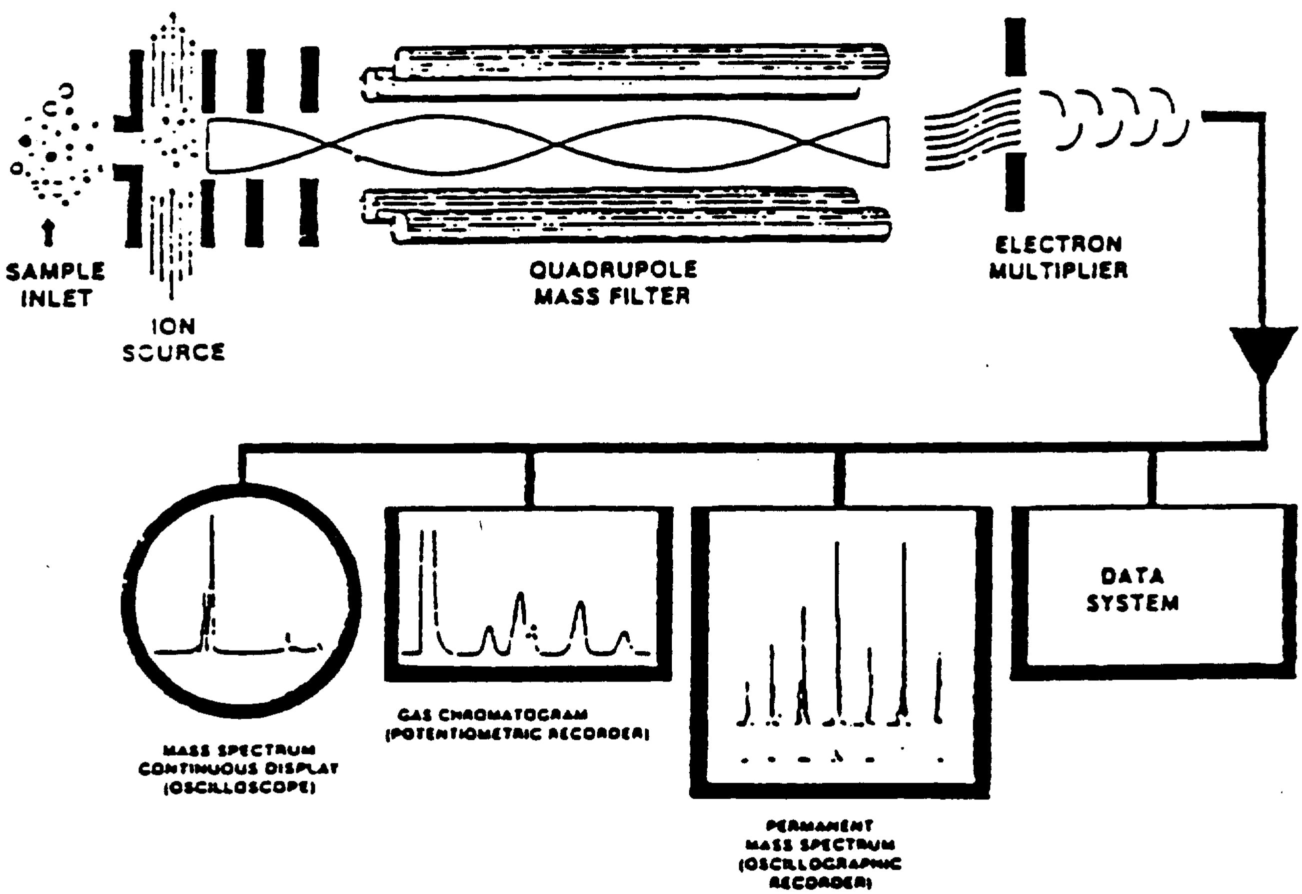
SENSOR DESCRIPTION:

Mass spectrometry involves ionization of a sample in a vacuum. The ions produced are accelerated, deflected, and focused by electrical and/or magnetic fields. Mass differences allow ions to be dispersed according to mass/charge ratio (M/q). Since singly charged ions predominate, the difference is a simple function of mass. Excess energy imparted by the ionization proces may be released by various mechanisms involving rupture of the parent ion into neutral and ionic fragments. These, plus the parent ion, constitute a mass spectrum which can be identified by comparison to a database of MS spectra. Quadrapole, magnetic deflection, and time of flight (TOF) are types of analyzers currently available.

REFERENCE:

Lawrence Berkeley Laboratory Environmental Instrumentation Survey, "Instrumentation Environmental Monitoring", Vol. 2, Water, John Wiley & Sons Inc., 1986.

Ben E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.



C.27 Schematic of Quadrapole Mass Spectrometer

SENSOR NAME : **Tandem Mass Spectrometry (MS/MS)**

SENSOR INFORMATION

SUBSYSTEM: ALL		TECHNOLOGY: All	
SENSOR TYPE: CH/BIO		OPERATION: Couple of Two or More MS	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER:	--- W*
RESOLUTION: 1.0E -11 G	TEMP. RANGE: ---	WEIGHT:	20 LB*
NO. OF DETECTABLE MICROBES: 10.0	PRESS. RANGE: ---	VOLUME:	1.0 FT^3*
DETECTABEL SPECIES: Universal		CYCLE TIME:	6.00 MIN.
SELECTIVITY RATING: 10.0		LIFETIME:	--- YEARS

* Design specific information, to be determined.

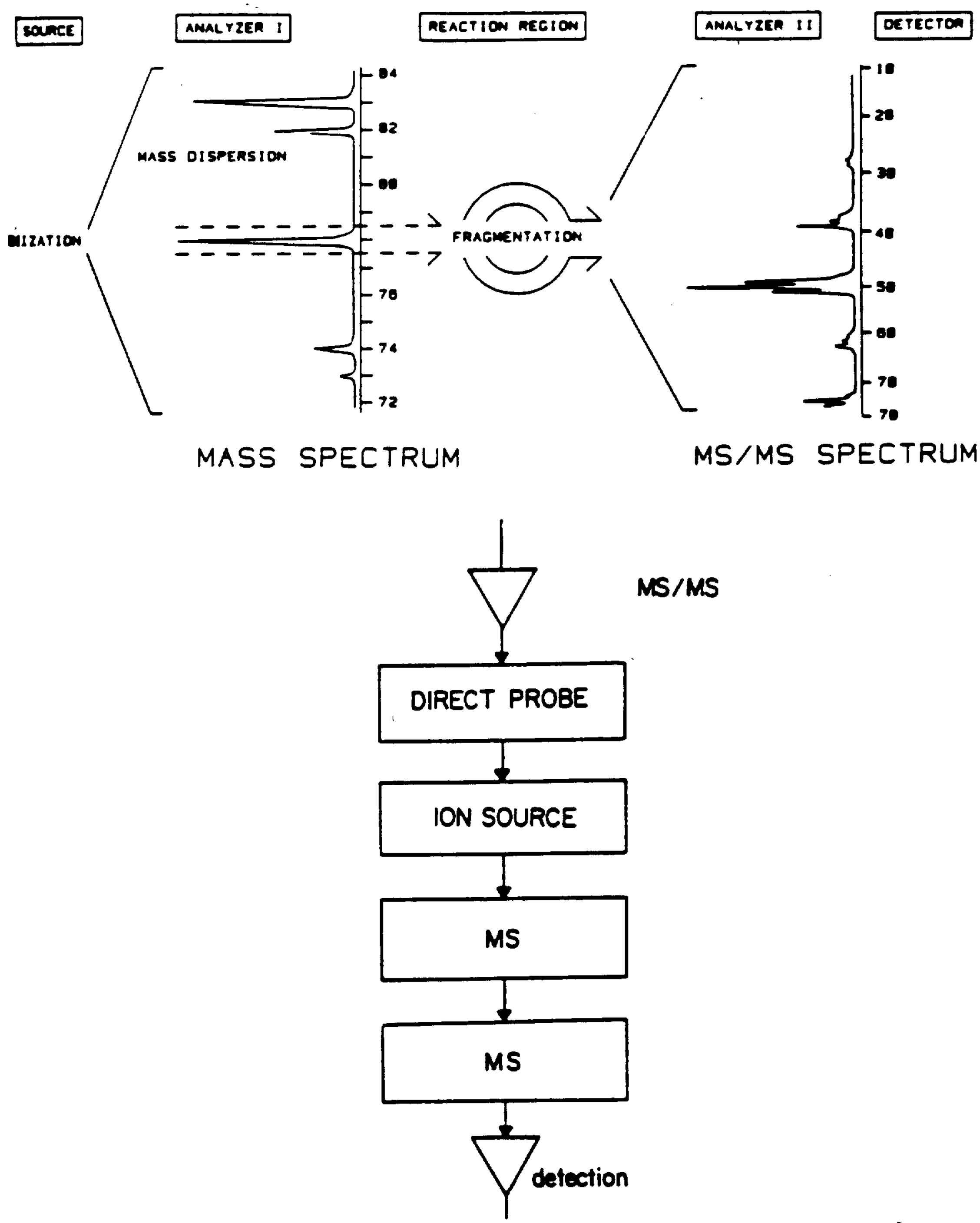
SENSOR DESCRIPTION:

MS/MS is a technique that uses mass spectrometry to perform both separation and identification of analytes. This is the coupling of two (or more) mass analyzers with the capability at their interface to fragment the unique-mass ions from MS-I to yield characteristic product ions of many masses to be separated. In this technique a single ion mass, characteristic of a particular compound, is selected for examination. All other ions are physically excluded by the spectrometer. The single molecular weight ions, called parent ions, are then decomposed to fragments for analysis. The identification of a particular analyte is based on the observation of specific patterns of fragment ions, also known as daughter ions.

REFERENCE:

Scott J Selover, "Evaluation of Approaches to Space Based Environmental Monitoring", Material and Process Laboratories Lockheed Missiles and Space Co., Inc., Oct. 1987.

F. W. McLafferty, "Tandem Mass Spectrometry", John Wiley & Sons, Inc. 1983.



C.28 Tandem Mass Spectrometer (MS/MS)

Appendix D

Conductivity Sensors

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Conductivity Sensors

List of Figures

Conductivity Sensors Reference Summary

Sensor	Reference No.
1. Conductometric Analysis	2, 3, 4
2. Electrodeless Conductometric Measurements	1, 4, 5, 6
3. Oscillometric Analysis	4

References

1. B. H. Vassos, "Elecroanalytical Chemistry", John Wiley & Sons, 1983
2. Harry N. Norton, "Sensor and Analyzer Handbook", Prentice Hall, Inc., 1982.
3. Lawrence Berkeley Laboratory Environmental Instrumentation Survey, "Instrurmentation for Environmental Monitoring", Vol.2, Water, John & Sons, Inc.,1986.
4. R. H. Perry, D. W. Green, and J. O. Maloney, "Perry's Chemical Engineers' Handbook", McGraw-Hill Book Co., 6th Edition, 1984.
5. R. S. Khandpur, "Handbook of Modern Analytical Instruments", Tab Books, Inc., 1981.
6. "The pH and Conductivity Handbook", OMEGA Co.,1989.

Conductivity Sensors

Conductivity measurements are made primarily to determine the concentration of a solution or to determine the relative amount of a salt in an aqueous solution. The principles are that of *electrolytic conduction*, in which the charge carriers are provided by ionization, and *oscillometric analysis*.

SENSOR NAME : **Conductometric Analysis**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: All in WRM	
SENSOR TYPE: CONDU		OPERATION: Electrical	
ACCURACY: ± 1.00 %	Operational Environment	POWER:	--- W*
MIN. RANGE: 500 Ohm	TEMP. RANGE: 0°C to 100°C	WEIGHT:	--- LB*
MAX. RANGE: 1000 Ohm	PRESS. RANGE: ---	VOLUME:	--- FT^3*
	PHASE: Liquid		

* Design specific information, to be determined.

SENSOR DESCRIPTION:

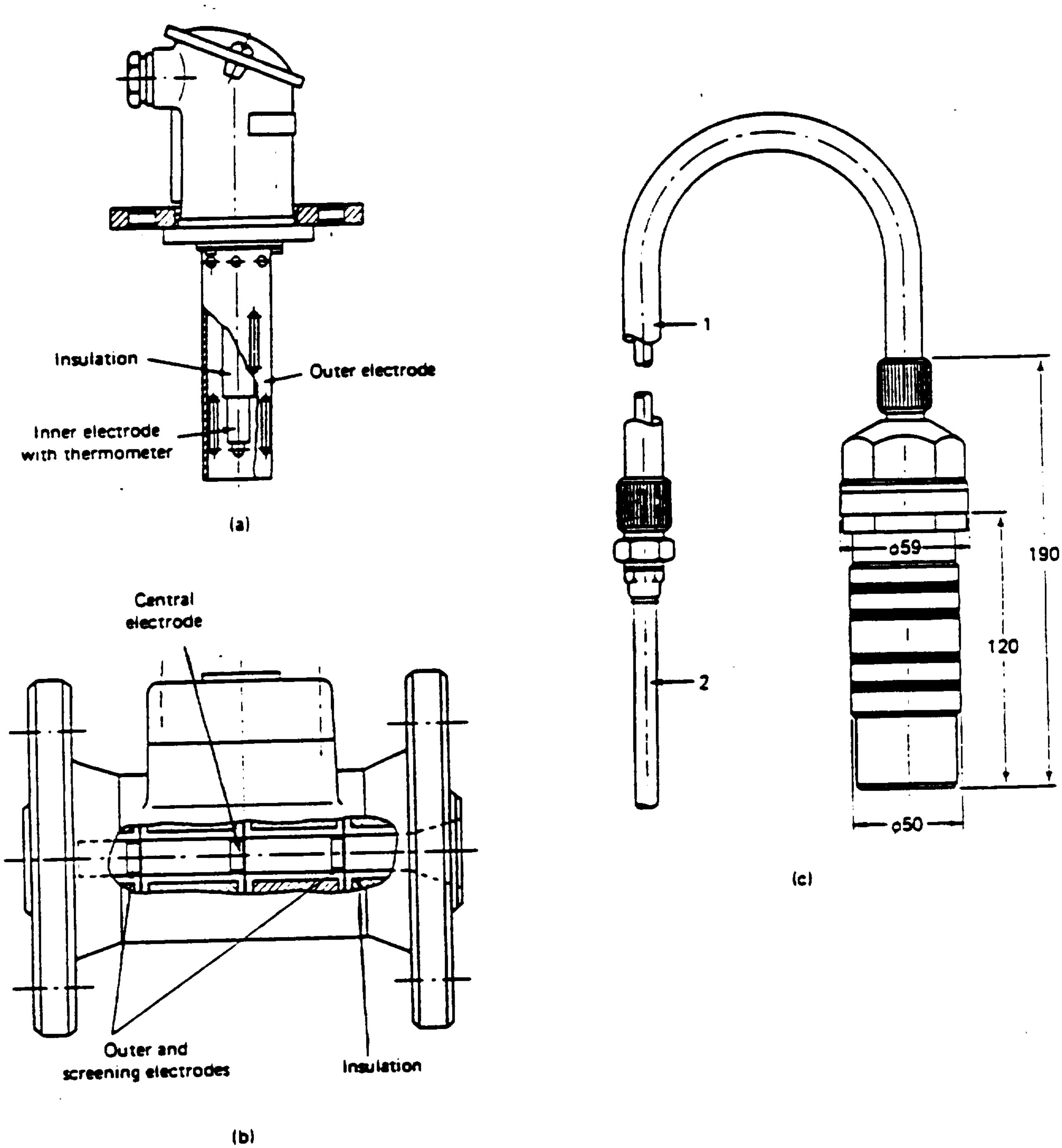
Solutions of electrolytes in ionizing solvents, e.g., water, conduct current when an electrical potential is applied across electrodes immersed in the solution. Conductance is a function of ion concentrations, ion charge, and ion mobility. Conductometric analyzers utilize a conductivity cell and electronic measurements circuits which consist of the audio frequency oscillator, an alternating wheatstone bridge, and an electronic compensator for temperature variation. Conductivity cells are basic structure, consisting of two electrodes firmly spaced within an insulating chamber such that the measured impedance over the anticipated span of ion concentration will be in range 500 to 1000 ohms. Conductance measurements are ideally suited for measurement of the concentration of a single strong electrolyte in dilute solutions.

REFERENCE:

R. H. Perry, D. W. Green, and J. O. Maloney, "Perry's Chemical Engineers' Handbook", McGraw - Hill Book Company, 6th Edition, 1984.

Harry N. Norton, "Sensor and Analyzer Handbook", Prentice Hall Inc., 1982.

Lawrence Berkeley Laboratory Environmental Instrumentation Survey, "Instrumentation for Environmental Monitoring", Volume 2 , Water, 1986.



D.1 Conductivity Sensor Configurations: (a) Immersion Probe; (b) Flanged Flow Chamber Sensor; (c) Sensor With Four Ring Electrode

SENSOR NAME : **Electrodeless Conductometric Measurements**

SENSOR INFORMATION

SUBSYSTEM: WRM	TECHNOLOGY: All in WRM	
SENSOR TYPE: CONDU	OPERATION: Electrodeless	
ACCURACY: ± 1.00 %	<u>Operational Environment</u>	POWER: --- W*
MIN. RANGE: --- Ohm	TEMP. RANGE: 0°C to 100°C	WEIGHT: LB*
MAX. RANGE: --- Ohm	PRESS. RANGE: ---	VOLUME: 3.000 0.200 FT^3*
	PHASE: Liquid	

* Design specific information, to be determined.

SENSOR DESCRIPTION:

Special electrodeless systems for the measurement of conductance have been devised. The resistance of a closed solution loop is measured by the extent to which the loop couples two transformer coils. Electrodeless conductance measurements are especially useful for solutions containing abrasive or fibrous solids and conductive and highly corrosive materials. Typical examples include hydrofluoric acid, 98 percent sulfuric acid, molten ammonium nitrate, cement slurry, and drilling mud. This method offers the advantage of placing the electrodes outside the solution container and out of direct contact with it. This eliminates the possibility and danger of electrolysis or electrode polarization.

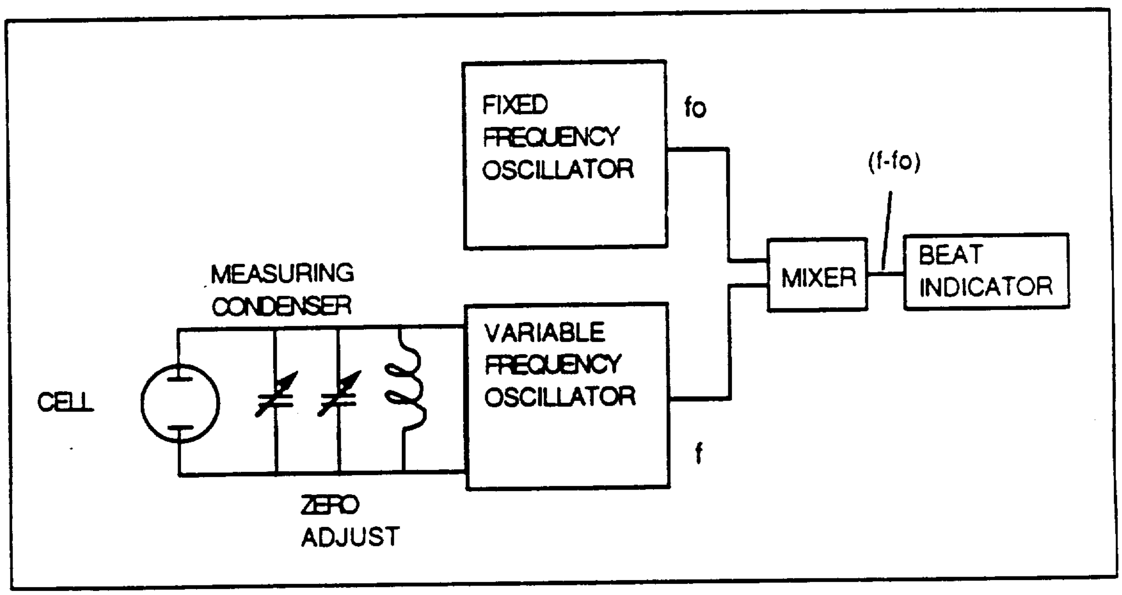
REFERENCE:

R. H. Perry, D. W. Green, and J. O. Maloney, "Perry's Chemical Engineers' Handbook", McGraw - Hill Book Company, 6th Edition, 1984.

B. H. Vassos, "Electroanalytical Chemistry", John Wiley & Sons, 1983.

R. S. Khandpur, "Handbook of Modern Analytical Instruments", Tab Books Inc., 1981.

An OMEGA Technology Company, "The pH and Conductivity Handbook", 1989.



D.2 Electrodeless Conductivity Meter

SENSOR NAME : **Oscillometric Analysis**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: All in WRM
SENSOR TYPE: CONDU		OPERATION: Oscillation
ACCURACY: ± --- %	Operational Environment	POWER: --- W*
MIN. RANGE: --- Ohm	TEMP. RANGE: ---	WEIGHT: --- LB*
MAX. RANGE: --- Ohm	PRESS. RANGE: ---	VOLUME: --- FT^3*
	PHASE: Liquid/Solid	

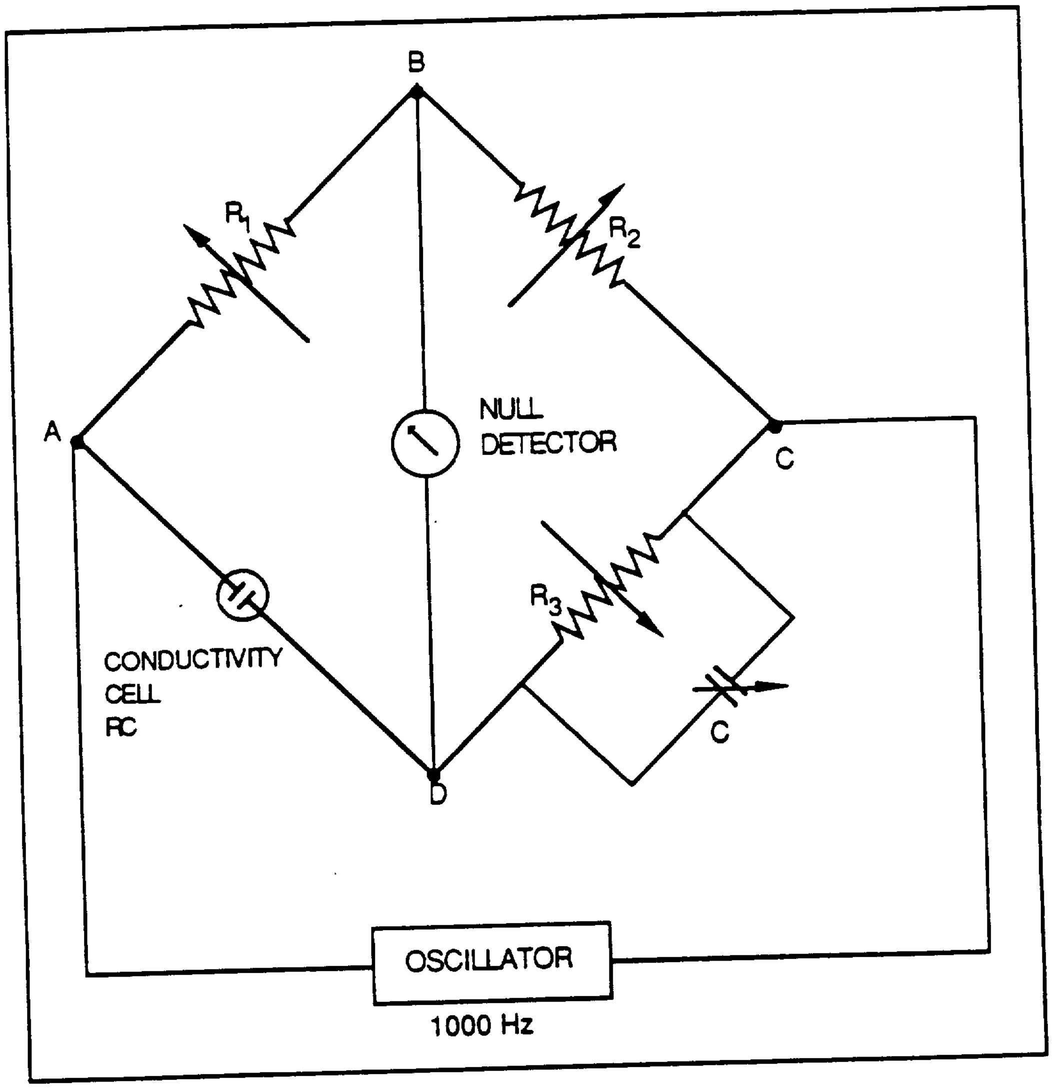
* Design specific information, to be determined.

SENSOR DESCRIPTION:

In oscillometry, the properties measured are conductance and dielectric constant. For most measurements, a cell containing the sample is placed between the plates of a capacitor or inside a coil. The capacitor or coil is part of a radio frequency resonant coil. Some oscillometric instruments have sensing heads that are pressed against bulk materials or are held to close tolerance within a specified distance of a moving web or film. Oscillometry is frequently used for the measurement of water content, since water has a dielectric constant 15 to 20 times greater than most materials. Typical applications are moisture in granular materials, water in hydrocarbon and organic liquids, and water in fibers and paper.

REFERENCE:

R. H. Perry, D. W. Green, and J. O. Maloney. "Perry's Chemical Engineers' Handbook", McGraw - Hill Book Company, 6th Edition, 1984.



D.3 Oscillation Conductivity Meter

Appendix E

Flow Measurement Sensors

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Flow Measurement

Sensor	Page No.

List of Figures

Title	Page No.

Flow Measurement Sensors Reference Summary

References

1. George C. Barney, "Intelligent Instrumentation", Prentice Hall, 1988.
2. H. Hencke, "Piwzoresistive Pressure Transducers for Effective Flow Measurements", Measurement & Control, Vol. 22, SOct. 1989.
3. Alan S. Morris, "Principles of Measurement and Instrumentation", Prentice Hall, 1988.
4. Alan Young, Ph. D., "Coriolis Mass Flow Measurements", Measurement & Control, Sept. 1988.
5. K. S. Mylvaganam, "Ultrasonic Gas Flowmeters", Measurement & Control, Dec. 1989.
6. Urs Endress, "Mass Flow", Measurement & Control, April 1989.
7. "Differential-Pressure Flowmeters", Measurement & Control, Sept. 1988.
8. "Electromagnetic Flowmeters", Measurement & Control, April 1989.
9. "Mass Flowmeters", Measurement & Control, Sept. 1989.
10. "Positive Displacement Flowmeters", Measurement & Control, Oct. 1988.
11. "Turbine Flowmeters", Measurement & Control, Feb. 1988.
12. "Vortex Flowmeters", Measurement & Control, June 1989.

Flow Measurement Sensors

The common classes of flow measuring instruments can be summarized as follows:

1. Differential Pressure Meters
2. Variable Area Meters
3. Positive Displacement Meters
4. Tubine Flowmeters
5. Electromagnetic Flowmeters
6. Vortex-Shedding Flowmeters
7. Ultrasonic Flowmeters
8. Laser Doppler Flowmeters
9. Coriolis Flowmeters
10. Temperature Flowmeters

SENSOR NAME : **Coriolis Flowmeter (Gyroscopic)**

SENSOR INFORMATION

SUBSYSTEM: All		TECHNOLOGY: ---	
SENSOR TYPE: FLOW		OPERATION: Mass Flowmeter Based on Coriolis Force	
METHOD (of Measurement): Mass			
ACCURACY: ± 0.20 %	<u>Operational Environment</u>	POWER:	--- W*
MIN. RANGE: 0 lb/min	TEMP. RANGE: < 300°C	WEIGHT:	--- LB*
MAX. RANGE: 20000 lb/min	PRESS. RANGE: < 2000 Psig	VOLUME:	--- FT^3*
	PHASE: Gas/Liquid	PRESS. LOSS:	--- Psi*

* Design specific information, to be determined.

SENSOR DESCRIPTION:

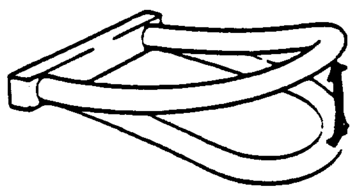
Coriolis mass flowmeters operate according to Newton's Second Law of Motion: F = ma. All of the flow is directed through a horseshoe shaped tube vibrated at its natural frequency by an electromagnetic drive system. Its vibration is similar to that of a tuning fork, typically having an amplitude of les than 1 mm. The fluid density can be derived from this natural frequency. As the fluid moves through the tube it is forced to take on the tube's vertical momentum. During half the cycle, when the tube is moving upward, fluid flowing into the meter pushes downward against the tube resisting the upward force. Consequently, fluid flowing out of the meter, having been forced upward, now resists having its vertical momemtum decreased and pushes upward against the tube. This combination of resistive forces causes the flow sensor tube to twist. This is called the "Coriolis Effect". The amount that the sensor tube twists is directly proportional to the mass flow rate of the fluid flowing through it.

REFERENCE:

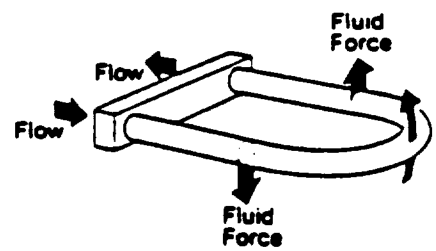
"Mass Flowmeters", Measurements & Control, Sept. 1989.

Urs Endress, "Mass Flow", Measurements & Control, April 1989.

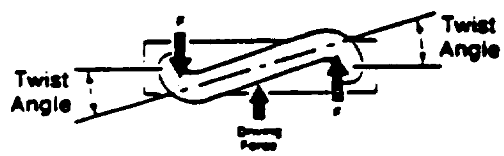
Alan Young, Ph.D., "Coriolis Mass Flow Measurements', Measurements & Control", Sept. 1988.



1. Vibrating flow tube.



2. Fluid forces reacting to vibration of flow tube.



3. End view of flow tube showing twist.

E.1 Coriolis Mass Flowmeter

SENSOR NAME : **Differential Pressure Flowmeter (piezoelectric)**

SENSOR INFORMATION

SUBSYSTEM: All	TECHNOLOGY: ---	
SENSOR TYPE: FLOW	OPERATION: Piezoelectric Effect	
METHOD (of Measurement): Speed		
ACCURACY: ± 0.50 %	Operational Environment	POWER: --- W*
MIN. RANGE: ---	TEMP. RANGE: ---	WEIGHT: --- LB*
MAX. RANGE: ---	PRESS. RANGE: ---	VOLUME: --- FT^3*
	PHASE: ---	PRESS. LOSS: --- Psi*

* Design specific information, to be determined.

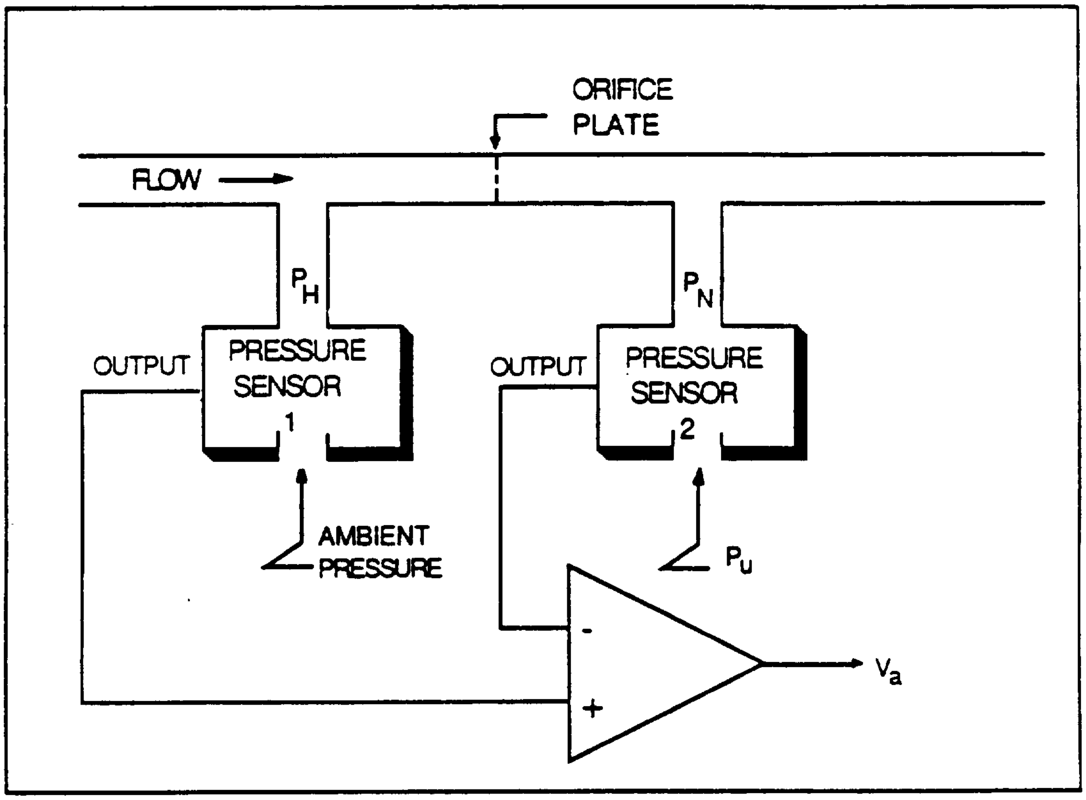
SENSOR DESCRIPTION:

The piezoelectric flowmeter is the most sensitive type of differential pressure flowmeter. Changes in pressure produce different output voltages from the piezoelectric device. An orifice plate produces a differential pressure which can be related to flow velocity by a simple equation. Energy loss in the system is not negligible, and many types of orifice plates have been designed to reduce pressure loss.

REFERENCE:

H. Hencke, "Piezoresistive Pressure Transducers for Effective Flow Measurements", Measurement + Control, Vol. 22, Oct. 1989.

"Differential-Pressure Flowmeters", Measurements & Control, Sept. 1988.



E.2 Differential Pressure Flowmeter

SENSOR NAME : **Differential Pressure Flowmeter (venturi meter)**

SENSOR INFORMATION

SUBSYSTEM: All	TECHNOLOGY: ---	
SENSOR TYPE: FLOW	OPERATION: Venturi	
METHOD (of Measurement): Speed		
ACCURACY: ± 1.00 %	Operational Environment	POWER: --- W*
MIN. RANGE: ---	TEMP. RANGE: < 540°C	WEIGHT: --- LB*
MAX. RANGE: ---	PRESS. RANGE: < 6000 Psig	VOLUME: --- FT^3*
	PHASE: ---	PRESS. LOSS: --- Psi*

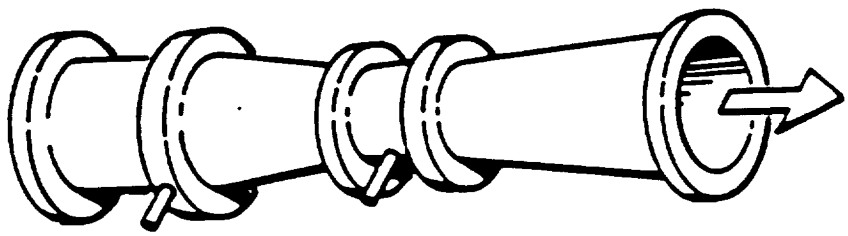
* Design specific information, to be determined.

SENSOR DESCRIPTION:

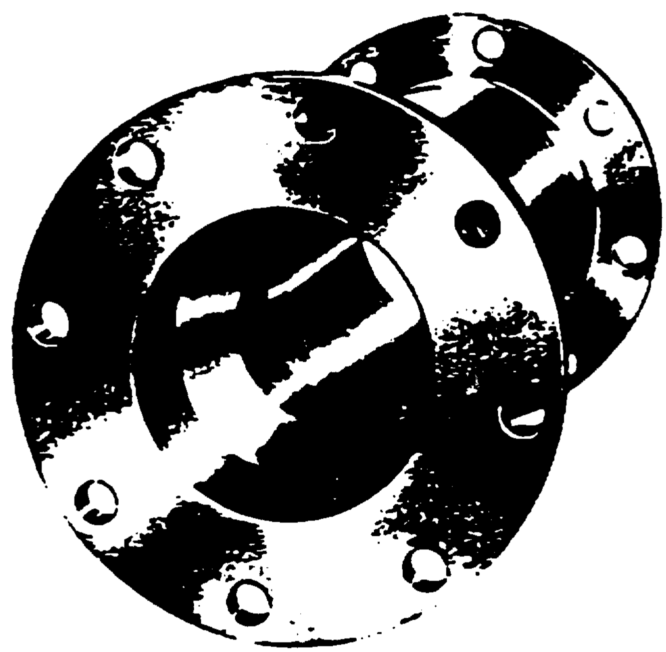
A venturi meters utilizes a precisely sized throat to provide desired pressure differential at a specified flow rate. A venturi is used to measure fluid flowrate when pressure losses must be minimized. They require no maintenance, have no moving parts, and are therefore especially attractive for hard-to-handle media such as corrosives, propellants, liquid metals, and where high pressure and/or temperatures exist. Total unrecoverable loss rarely exceeds 10% of measured delta pressure. Cavitating venturies offer unique flow control capabilities that have been exploited in the rocket industry for over 20 years.

REFERENCE:

"Differential-Pressure Flowmeters", Measurements & Control, Sept. 1988.



Classical venturi.



E.3 Venturi Tude

SENSOR NAME : **Electromagnetic Flowmeter**

SENSOR INFORMATION

SUBSYSTEM: All	TECHNOLOGY: ---	
SENSOR TYPE: FLOW	OPERATION: Faraday Law	
METHOD (of Measurement): Speed		
ACCURACY: ± 1.00 %	<u>Operational Environment</u>	POWER: --- W*
MIN. RANGE: 0.01 GPM	TEMP. RANGE: Independent	WEIGHT: --- LB*
MAX. RANGE: 165000 GPM	PRESS. RANGE: Independent	VOLUME: --- FT^3*
	PHASE: Gas/Liquid	PRESS. LOSS: --- Psi*

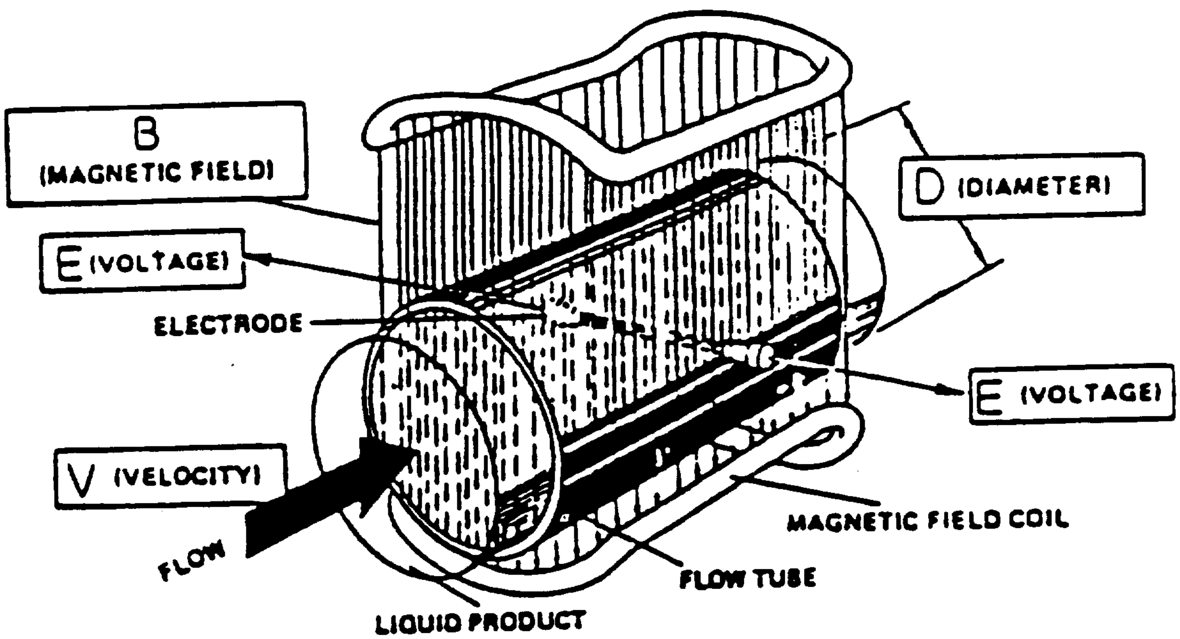
* Design specific information, to be determined.

SENSOR DESCRIPTION:

Magnetic flowmeters were developed to measure the volume flow rate of conductive fluids. The operation is based on Faraday's law of electromagnetic induction which states that the voltage induced in a conductor moving through a magnetic field is proportional to the velocity of the conductor. The conductive liquid passes through the magnetic field generating a voltage proportional to the average velocity of the liquid through the meter cross section. Liquids should have a conductivity of at least one micromho per centimeter. The accuracy is 0.5% of rate and the range is wide: from 0.01 to 165,000 GPM.

REFERENCE:

"Electromagnetic Flowmeters", Measurements & Control, April 1989.



$$E \propto VDB$$

E = INDUCED VOLTAGE
V = AVERAGE LIQUID VELOCITY
D = DISTANCE BETWEEN ELECTRODES (PIPE I.D.)
B = MAGNETIC FIELD

E.4 Eletromagnetic Flowmeter

SENSOR NAME : **Laser Doppler Flowmeter (LDF)**

SENSOR INFORMATION

SUBSYSTEM: All

TECHNOLOGY: ---

SENSOR TYPE: FLOW

OPERATION: Doppler Shift

METHOD (of Measurement): Speed

ACCURACY: ± 5.00 %

MIN. RANGE: ---

MAX. RANGE: ---

Operational Environment

TEMP. RANGE: 120°C

PRESS. RANGE: Pipework limitation

PHASE: Liquid

POWER: --- W*

WEIGHT: --- LB*

VOLUME: --- FT^3*

PRESS. LOSS: --- Psi*

* Design specific information, to be determined.

SENSOR DESCRIPTION:

LDF gives direct measurments of flow velocity for liquids containing suspended particles flowing in a transparent pipe. Light from a laser is focused by an optical system to a point in the flow. The movement of particles causes a Doppler shift of the shattered light and produces a signal in a photodetector which is related to the fluid velocity. A very wide range of fluid velocities between 1 micro m/s and 800 m/s can be measured by this technique.

REFERENCE:

Alan S. Morris, Principles of Measurement and Instrumentation, Chapter 16, Prentice Hall, 1988.

Sensor Figure Not Included

SENSOR NAME : **Positive Displacement Flowmeters**

SENSOR INFORMATION

SUBSYSTEM: All

TECHNOLOGY: ---

SENSOR TYPE: FLOW

METHOD (of Measurement): Mass

OPERATION: Meters a Known Quantity in Fixed Time

ACCURACY: ± 0.50 %	Operational Environment	POWER: --- W*
MIN. RANGE: 0.5 GPM	TEMP. RANGE: 300°C	WEIGHT: --- LB*
MAX. RANGE: 5000 GPM	PRESS. RANGE: < 1400 Psig	VOLUME: --- FT^3*
	PHASE: Gas/Liquid	PRESS. LOSS: --- Psi*

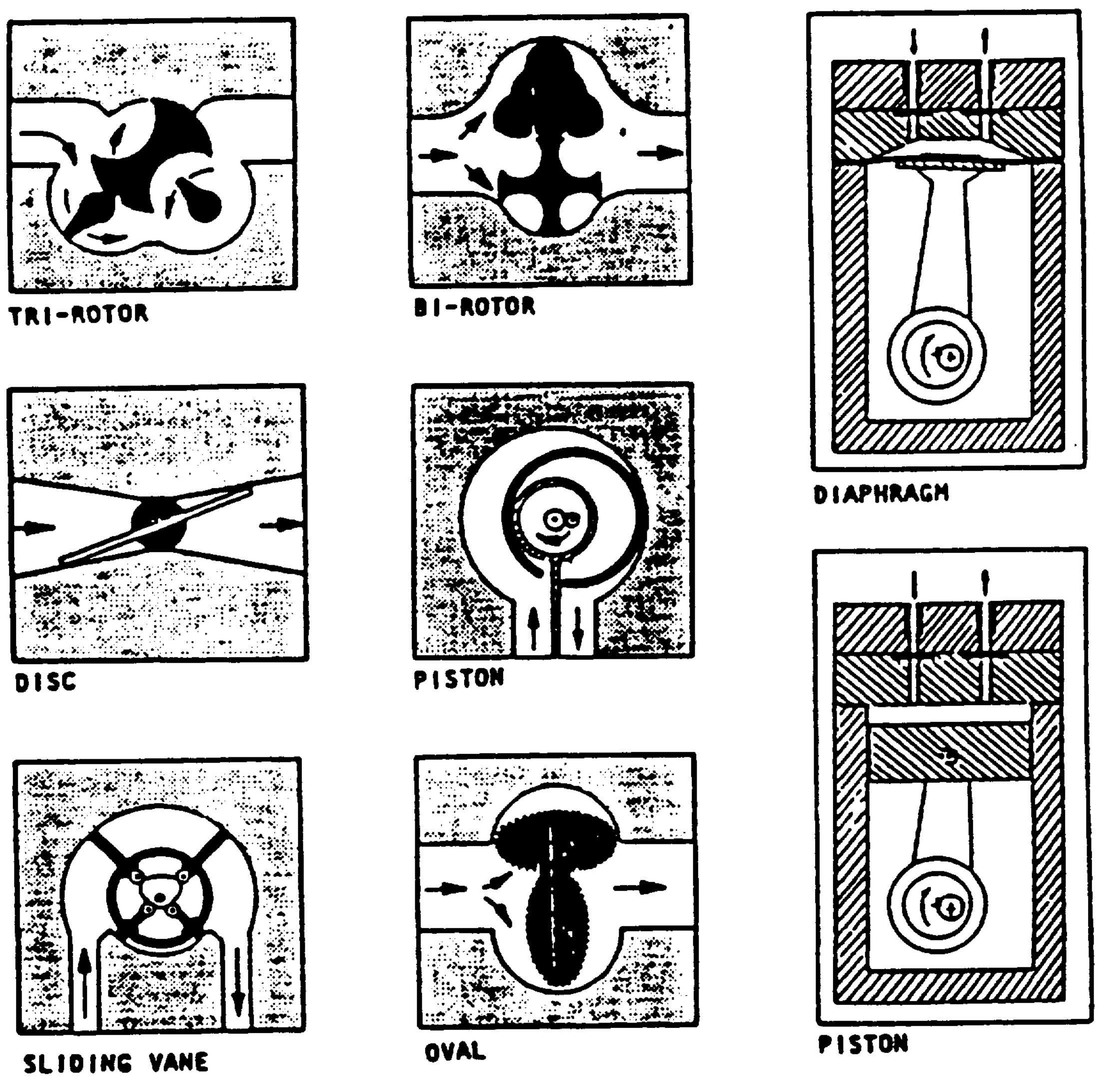
* Design specific information, to be determined.

SENSOR DESCRIPTION:

A metering pump is a positive displacement pump that accurately determines the amount of fluid present by various means: moving pistons or membranes, rotary elements, or flexible elements in which the fluid is propelled by squeezing (peristaltic action), etc.

REFERENCE:

"Positive Displacement Flowmeters", Measurements & Control, Oct., 1988.



E.5 Positive Displacement Flowmeter

SENSOR NAME : **Temperature Based Flowmeter**

SENSOR INFORMATION

SUBSYSTEM: All	TECHNOLOGY: ---	
SENSOR TYPE: FLOW	OPERATION: Temperature Diffence Related to Mass	
METHOD (of Measurement): Mass		
ACCURACY: ± 2.00 %	Operational Environment	POWER: --- W*
MIN. RANGE: ---	TEMP. RANGE: 100°C	WEIGHT: --- LB*
MAX. RANGE: ---	PRESS. RANGE: 2MPa	VOLUME: --- FT^3*
	PHASE: ---	PRESS. LOSS: --- Psi*

* Design specific information, to be determined.

SENSOR DESCRIPTION:

Temperature rise flowmeters are mass flowmeters. By inputting thermal energy into the flow, by wrapped wires or other means, and measuring temperature change the mass flow rate can be inferred from the specific heat and thermal conductivity data for the flowing fluid.

REFERENCE:

"Mass Flowmeters", Measurements & Control, Sept. 1989.

Sensor Figure Not Included

SENSOR NAME : **Temperature Based Flowmeter (Heat Loss)**

SENSOR INFORMATION

SUBSYSTEM: All

TECHNOLOGY: ---

SENSOR TYPE: FLOW

OPERATION: Heat Transfer Related to the Velocity

METHOD (of Measurement): Speed

ACCURACY: ± 1.00 %
MIN. RANGE: ---
MAX. RANGE: ---

Operational Environment
TEMP. RANGE: 750°C
PRESS. RANGE:
PHASE: Gas/Liquid

POWER: --- W*
WEIGHT: --- LB*
VOLUME: --- FT^3*
PRESS. LOSS: --- Psi*

* Design specific information, to be determined.

SENSOR DESCRIPTION:

The "rate of heat loss" flowmeter is best characterized by the familiar hot wire anemometer enclosed in a pipe. Heat loss determines the mean temperature of the wire, which in turn determines its resistance. Change in resistance then becomes a function of velocity. The flow measured is affected by velocity distribution in the pipe, Reynolds number, and viscosity characteristics of the fluid.

REFERENCE:

"Mass Flowmeters", Measurements & Control, Sept. 1989.

George C. Barney, "Intelligent Instrumentation", Prentice Hall, 1988.

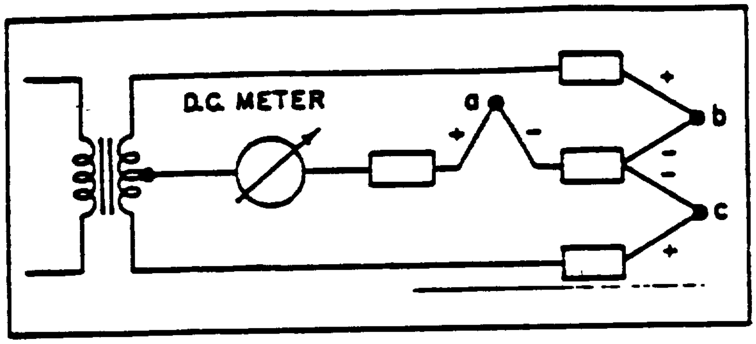


FIGURE 1. Flowmeter circuit that uses thermo-couples.

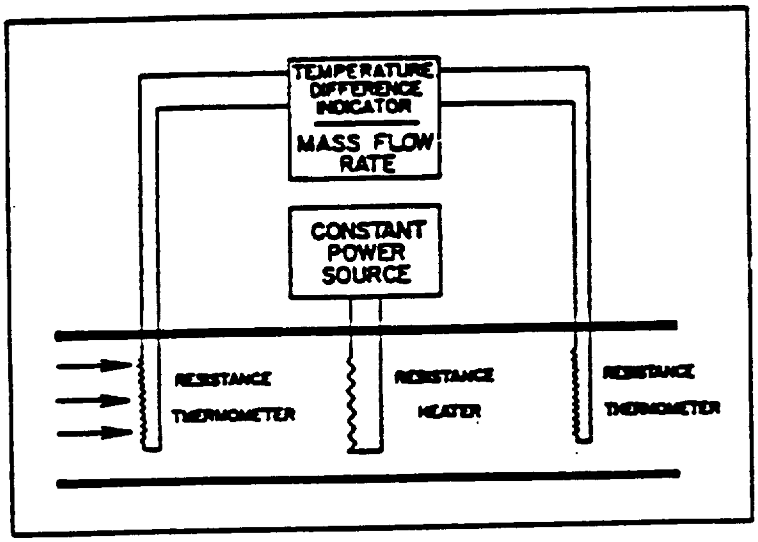


FIGURE 2 Flowmeter in which entire stream is heated by an internal heat source.

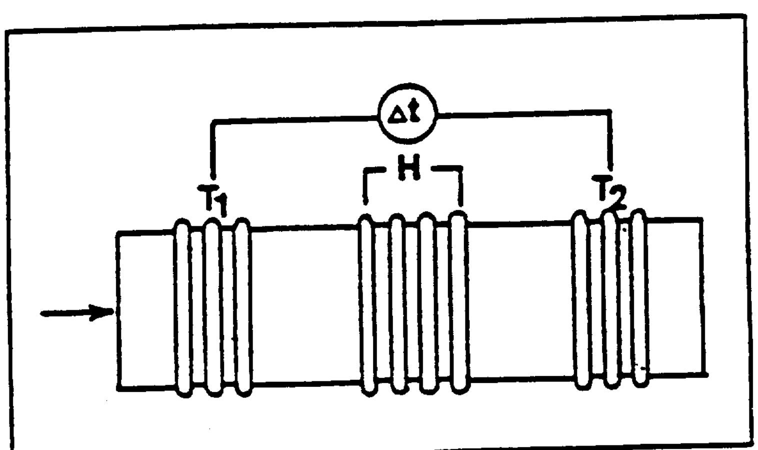


FIGURE 3 Flowmeter in which only boundary layer of flow is heated by an external heat source.

E.6 Thermocouple Flowmeter

SENSOR NAME : **Turbine Flowmeter**

SENSOR INFORMATION

SUBSYSTEM: All

TECHNOLOGY: ---

SENSOR TYPE: FLOW

METHOD (of Measurement): Speed

OPERATION: Measures Rotational Speed Turbine

ACCURACY: ± 0.25 %	Operational Environment	POWER: --- W*
MIN. RANGE: 0.001 GPM	TEMP. RANGE: 250 °C	WEIGHT: --- LB*
MAX. RANGE: 50000 GPM	PRESS. RANGE: 20MPa	VOLUME: --- FT^3*
	PHASE: Gas/Liquid	PRESS. LOSS: --- Psi*

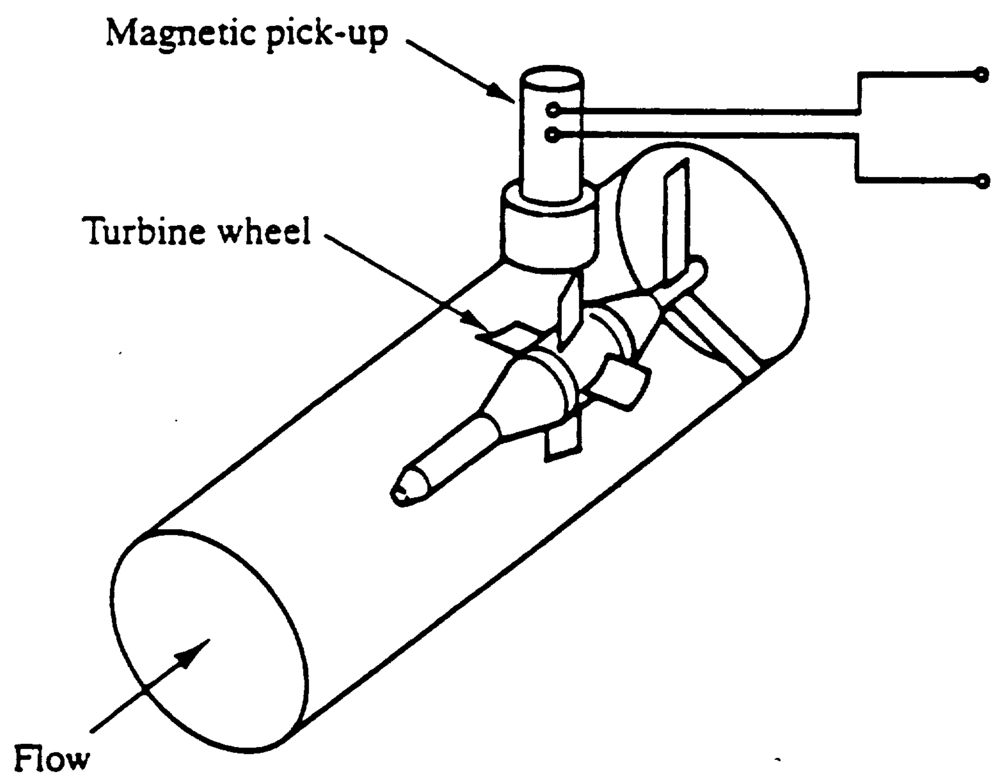
* Design specific information, to be determined.

SENSOR DESCRIPTION:

Flow velocity driving a turbine located inside the flow is the concept behind turbine flowmeters. A magnetic pickup relays a pulsed signal whose frequency is related to flow velocity. Turbines may be used for gas or liquids with errors in the range of 1% to 3%. Gas flow is almost always corrected for temperature and pressure variations after measurement. Wide range and pulsed output make turbine meters attractive.

REFERENCE:

"Turbine Flowmeters", Measurements & Control, Feb. 1988.



E.7 Turbine Flowmeter

SENSOR NAME : **Ultrasonic Flowmeter**

SENSOR INFORMATION

SUBSYSTEM: All

TECHNOLOGY: ---

SENSOR TYPE: FLOW

METHOD (of Measurement): Speed

OPERATION: Measures Transit Time or Doppler Shift

ACCURACY: ± 2.50 %	<u>Operational Environment</u>	POWER: --- W*
MIN. RANGE: ---	TEMP. RANGE: 260 °C	WEIGHT: --- LB*
MAX. RANGE: ---	PRESS. RANGE: Pipework limitation	VOLUME: --- FT^3*
	PHASE: Liquid	PRESS. LOSS: --- Psi*

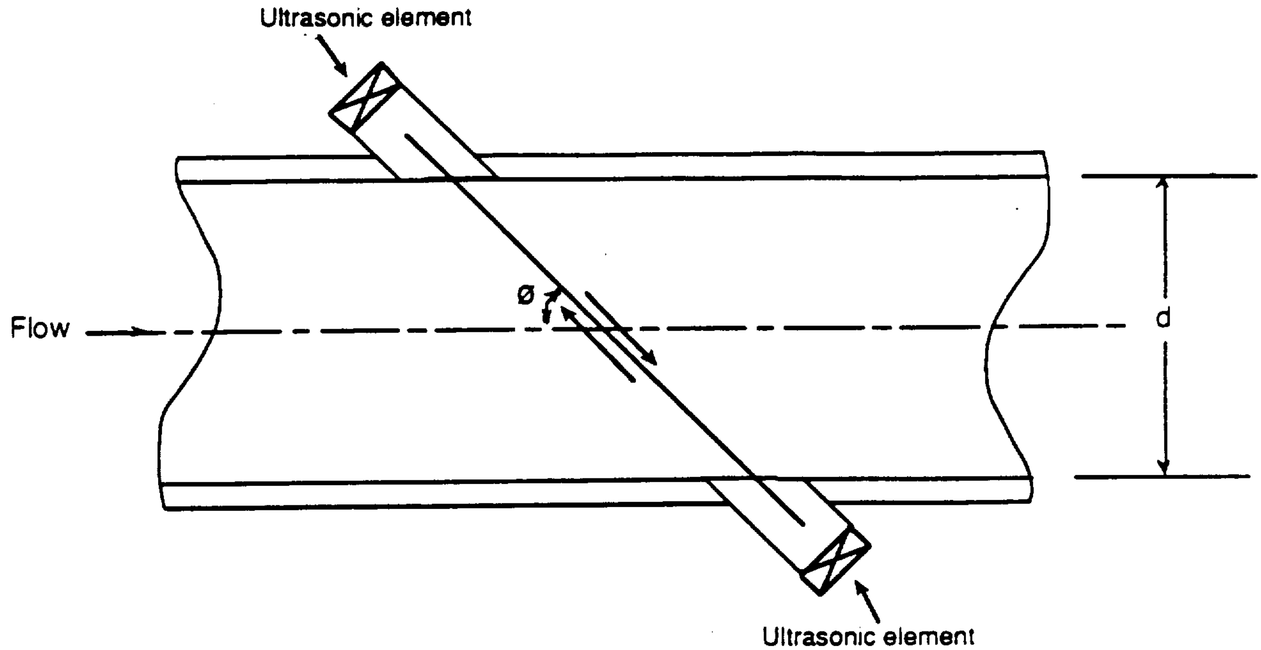
* Design specific information, to be determined.

SENSOR DESCRIPTION:

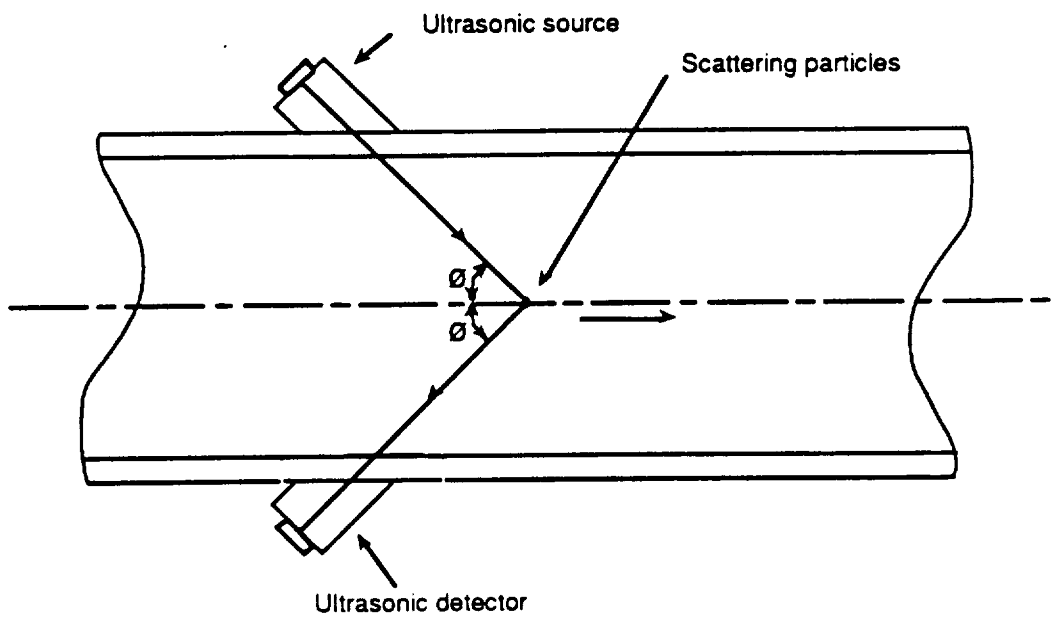
Orientation of an ultrasonic transmitter/receiver pair allows a difference in upstream and downstream transmission time to be related to flow velocity. Another type of ultrasonic flowmeter uses doppler shifts produced by reflective elements in the liquid to infer flow velocity. Newer models can measure flowrates from 0.03 m/s to 120 m/s. Ultrasonic flowmeters are compact, convenient, nonintrusive, and easy to maintain. They have no moving parts and respond quickly to flow changes.

REFERENCE:

K. S. Mylvaganam, "Ultrasonic Gas Flowmeters", Measurements & Control, Dec. 1989.



(A): Transit time ultrasonic flow meter



(B): Doppler shift ultrasonic flowmeter

E.8 Ultrasonic Flowmeter

SENSOR NAME : **Vortex Shedding Flowmeter**

SENSOR INFORMATION

SUBSYSTEM: All	TECHNOLOGY: ---	
SENSOR TYPE: FLOW	OPERATION: Uses a Bluff Body to Produce Vortices	
METHOD (of Measurement): Speed		
ACCURACY: ± 1.00 %	Operational Environment	POWER: --- W*
MIN. RANGE: 1 GPM	TEMP. RANGE: 400 °C	WEIGHT: --- LB*
MAX. RANGE: 10000 GPM	PRESS. RANGE: 1500 Psig	VOLUME: --- FT^3*
	PHASE: ---	PRESS. LOSS: --- Psi*

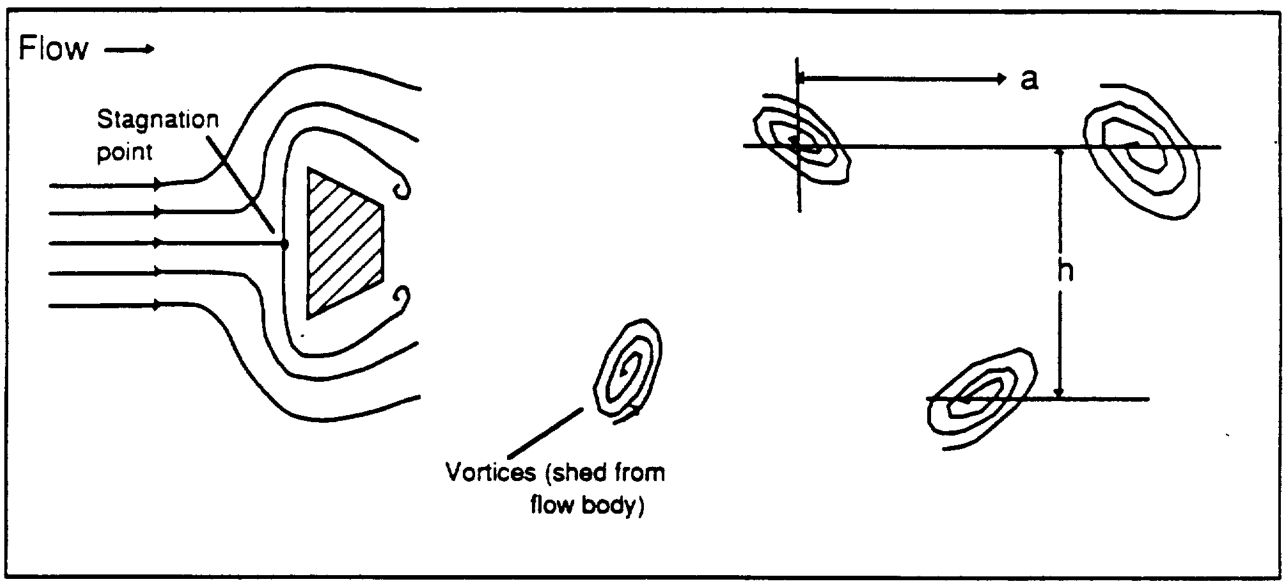
* Design specific information, to be determined.

SENSOR DESCRIPTION:

Vortex shedding is the name given to the natural effect that occurs when a gas or liquid flows around a blunt, tapered object. A flow unable to follow the shape of its downstream side separates from the surface of the object leaving a highly turbulent wake that takes the form of a continuous series of eddies which are swept downstream. The frequency of formation of these eddies can be directly related to flow velocity and diameter of the flow element. Sensing of the vortex is accomplished by measuring velocity, pressure, or thermal fluctuations produced.

REFERENCE:

"Vortex Flowmeters", Measurements & Control, June 1989.



E.9 Vortex Flowmeter

Appendix F

Moisture/Humidity Sensors

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Moisture/Humidity Sensors

List of Figures

Moisture/Humidity Sensors Reference Summary

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7. Piezoelectric Method	5
8. Psychrometer	3,5
9. Remote Moisture Sensor	
10. Resistance Method (Conductance)	3,5,7
11. Coulometric Sensor	1

References

1. B. E. Noltingk, "Jones' Instrument Technology, 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.
2. H. A. Slight, "Thoughts on Moisture Measurement", Measurement & Control, Vol. 22, 1989.
3. Harry N. Norton, "Sensor and Analyzer Handbook", Prentice Hall, Inc., 1982.
4. R. F. Pragnell, "The Modern Condensation Dewpoint Hygrometer", Measurement & Control, Vol. 22, April 1989.
5. R. H. Perry, D. W. Green, and J. O. Maloney, "Perry's Chemical Engineers' Handbook", McGraw-Hill Book Co., 6th Edition, 1984.
6. "The Temperature Handbook", OMEGA Co., 1989.
7. Ernest O. Doebelin, "Measurement Systems Application and Design", McGraw-Hill, 1983.

Moisture/Humidity Sensors

Measurement of moisture in gas, liquid or solid is done by one of the following techniques:

1. Properties of water (dependent on moisture), i.e., conductivity, dew point, dielectric constant, infrared absorption, microwave absorption.

2. Change in properties of a material (due to water content), i.e., aluminum oxide, hair hygrometer, wet-dry bulb...

3. Extraction of water techniques, i.e., electrolytic, gas chromatography, Karl Fischer titration...

SENSOR NAME : **Capacitance Method**

SENSOR INFORMATION

SUBSYSTEM: CO_2 Reduction, O_2 Generation, WRM	TECHNOLOGY: Bosch, WVE, All in WRM	
SENSOR TYPE: HUMID	OPERATION: Electrical	
ACCURACY: ± 0.10 %	Operational Environment	POWER: --- W*
MIN. RANGE: 0% RH	TEMP. RANGE: 450 °C	WEIGHT: --- LB*
MAX. RANGE: --- % RH	PRESS. RANGE: ---	VOLUME: --- FT^3*
	PHASE: Gas	

* Design specific information, to be determined.

SENSOR DESCRIPTION:

Several analyzers utilize the high dielectric constant of water for its detection in solutions. The alternating electric current through a capacitor containing all or part of the sample between the capacitor plates is measured. Selectivity and sensitivity are enhanced by increasing the concentration of moisture in the cell by filling the capacitor sample cell with a moisture specific sorbent as part of the dielectric. This both increases the moisture content and reduces the amount of other interfacing sample components.

REFERENCE:

R. H. Perry, D. W. Green, and J. O. Malony, "Perry's Chemical Engineers' Handbook", McGraw - Hill Book Company, 6th Edition, 1984.

Sensor Figure Not Included

SENSOR NAME : **Dew-point Sensor**

SENSOR INFORMATION

SUBSYSTEM: CO2 Reduction, O2 Generation, WRM

TECHNOLOGY: CO2_E, WVE, All in WRM

SENSOR TYPE: HUMID

OPERATION: Dew point

ACCURACY: ± 2.00 %

MIN. RANGE: 0% RH

MAX. RANGE: --- % RH

<u>Operational Environment</u>

TEMP. RANGE: -100°C to +85°C

PRESS. RANGE: ---

PHASE: Gas

POWER: 0.1 W*

WEIGHT: 2.0 LB*

VOLUME: 0.10 FT^3*

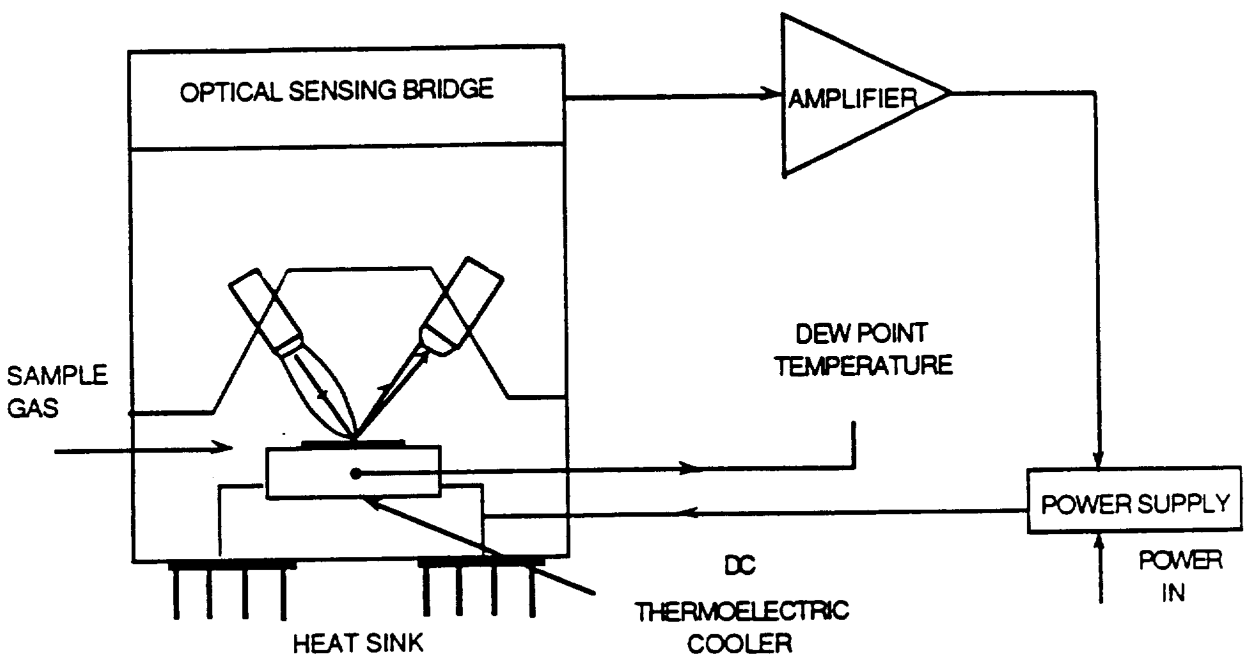
* Design specific information, to be determined.

SENSOR DESCRIPTION:

The dew point is the temperature at which the liquid and vapor phase of a liquid are in equilibrium (the temperature at which the vapor and solid phases are in equilibrium is usually called the frost point). At this temperature, only one value of saturation (water) vapor pressure exists. Hence, absolute humidity can be determined from this temperature as long as the total pressure is also known. The determination of the temperature at which moisture condenses on a plane mirror can be readily estimated. The temperature is measured by thermocouple or platinum resistance thermometer just behind the mirror surface and the onset of dew is detected by reflectivity measured by a lamp and photocell. A feedback circuit between the cell output and the heater/cooler circuit enables the dew point temperature to be followed automatically.

REFERENCE:

Harry N. Norton, "Sensor and Analyzer Handbook", Prentice Hall, Inc., 1982.
B. N. Noltingk, "Jones' Instrument Technology, 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd., 1985.
Ernest O. Doebelin, "Measurement Systems Application and Design", McGraw-Hill, 1983.



F.1 Dew Point Sensor

SENSOR NAME : **Electrolytic Hydrometer**

SENSOR INFORMATION

SUBSYSTEM: CO2 Reduction, O2 Generation, WRM

TECHNOLOGY: Bosch, WVE, All in WRM

SENSOR TYPE: HUMID

OPERATION: Electrochemical

ACCURACY: ± 3.00 %	<u>Operational Environment</u>	POWER:	9.0 W*
MIN. RANGE: 0% RH	TEMP. RANGE: -20°C to 90°C	WEIGHT:	7.0 LB*
MAX. RANGE: 98.00 % RH	PRESS. RANGE: ---	VOLUME:	2.50 FT^3*
	PHASE: Gas		

* Design specific information, to be determined.

SENSOR DESCRIPTION:

For measurement of low humidities (below 1000 ppm), the electrolytic hygrometer has traditionally been used for most applications. In this instrument water is absorbed from the sample gas by phosphorus pentoxide (P205) and is electrolyzed to form hydrogen and oxygen. The amount of current required for electrolysis varies as a function of water vapor absorbed, and hence of humidity. The current itself provides the sensor output indicative of humidity. Response is fast and accuracy is normally about ± 10%, although ± 5% can be achieved under ideal conditions.

REFERENCE:

Harry N. Norton, Sensor and Analyzer Handbook", Prentice Hall Inc., 1982.
R. F. Pragnell, "The Modern Condensation Dewpoint Hygrometer", Measurement + Control, Vol. 22, April, 1989.
An OMEGA Technology Company, "The Temperature Handbook", 1989.

Sensor Figure Not Included

SENSOR NAME : **Heat-of-Sorption Method**

SENSOR INFORMATION

SUBSYSTEM: CO2 Reduction, O2 Generation, WRM		TECHNOLOGY: Bosch, WVE, All in WRM	
SENSOR TYPE: HUMID		OPERATION: Absorption	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER:	--- W*
MIN. RANGE: 0% RH	TEMP. RANGE: ---	WEIGHT:	--- LB*
MAX. RANGE: --- % RH	PRESS. RANGE: ---	VOLUME:	--- FT^3*
	PHASE: Gas		

* Design specific information, to be determined.

SENSOR DESCRIPTION:

This analyzer detects moisture in vapors by measuring the heat of sorption of water onto a desiccant. Two cells containing desiccant and thermistors in a constant temperature zone are used. The analyzer dries a part of the sample stream. The dried sample and the process sample are directed alternately through the two cells, where one cell dries the wet stream and the wet cell is dried by the dry stream on a 1 to 2 minute cycle. The cell being dried is cooled by desorption of water, and the cell being wetted is warmed by sorption of water. The thermistor bridge measures the difference in temperature between the two cells.

REFERENCE:

R. H. Perry, D. W. Green, and J. O. Maloney, "Perry's Chemical Engineers' Handbook", McGraw - Hill Book Company, 6th Edition, 1984.

Sensor Figure Not Included

SENSOR NAME : **Infrared Instrument (IR)**

SENSOR INFORMATION

SUBSYSTEM: CO2 Reduction, O2 Generation, WRM

TECHNOLOGY: Bosch, WVE, All in WRM

SENSOR TYPE: HUMID

OPERATION: Spectroscopic

ACCURACY: ± --- %		<u>Operational Environment</u>		POWER:	--- W*
MIN. RANGE:	0% RH	TEMP. RANGE:	---	WEIGHT:	--- LB*
MAX. RANGE:	--- % RH	PRESS. RANGE:	---	VOLUME:	--- FT^3*
		PHASE:	Gas/Liquid		

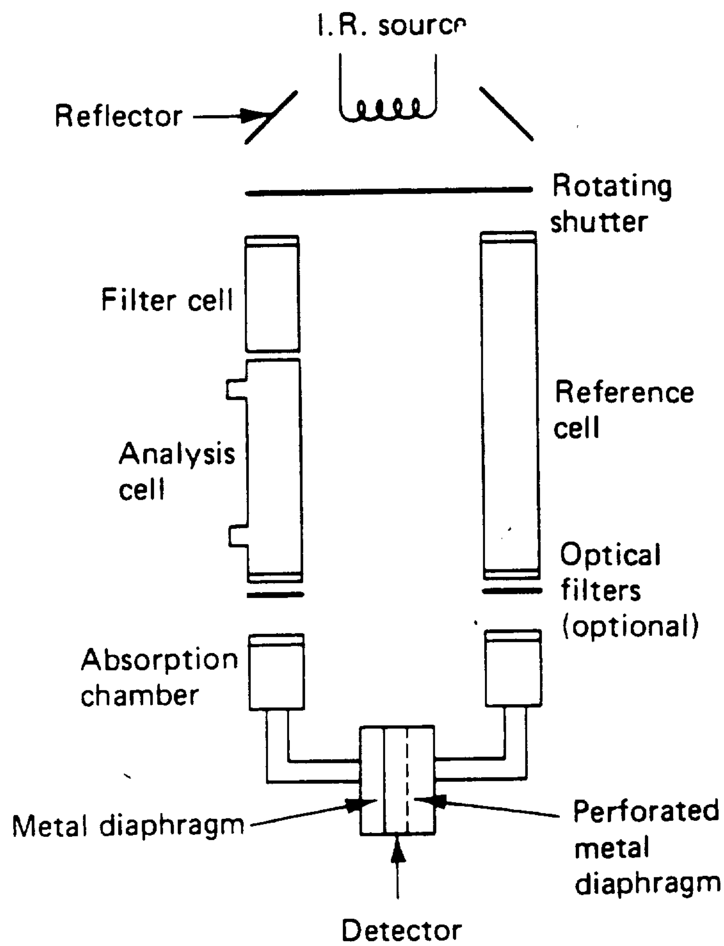
* Design specific information, to be determined.

SENSOR DESCRIPTION:

Infrared instruments are spectroscopic in nature. Operation is based on the partial and selective absorbtion of radiation, due to moisture content, at a specific wavelength. The IR absorption at a specific wavelength (charateristic of H2O) is measured for a sample volume of the measured fluid and for a volume of a reference fluid with known moisture content and the two readings are compared. Another system looks at two specific wavelength fluids and compares the attenuation (in IR energy incident on a photodetector) at the two "dips" in the spectral curve, only one of which shows a significant change due to absorption. The "dip" at the other wavelength is used as a reference.

REFERENCE:

Harry N. Norton, "Sensor and Analyzer Handbook", Prentice Hall Inc., 1982.
B. E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.



F.2 Luft-Type Infrared Gas Analyser for Moisture Detection

SENSOR NAME : **Microwave Instrument**

SENSOR INFORMATION

SUBSYSTEM: CO_2 Reduction, O_2 Generation, WRM

TECHNOLOGY: Bosch, WVE, All in WRM

SENSOR TYPE: HUMID

OPERATION: Spectroscopic

ACCURACY: ± 0.60 %	Operational Environment	POWER:	--- W*
MIN. RANGE: 0% RH	TEMP. RANGE: ---	WEIGHT:	--- LB*
MAX. RANGE: --- % RH	PRESS. RANGE: ---	VOLUME:	--- FT^3*
	PHASE: Liquid		

* Design specific information, to be determined.

SENSOR DESCRIPTION:

The water molecule has a dipole moment with rotational vibration frequencies which give absorption in the microwave S-band and X-band suitable for moisture measurement. A microwave moisture system consists basically of an oscillator (of constant frequency and power output to transmit the energy) a measuring cell, and a receiver. In-line systems are capable of discriminating changes of 0.1% moisture content with a practical accuracy of about ± 0.3% moisture. This technique also applies to solids.

REFERENCE:

B. E. Noltingk, "Jones' Instrument Technology 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.

H. A. Slight, "Thoughts on Moisture Measurement", Measurement + Control, Vol. 22, 1989.

Sensor Figure Not Included

SENSOR NAME : **Piezoelectric Method**

SENSOR INFORMATION

SUBSYSTEM: CO2 Reduction, O2 Generation, WRM

TECHNOLOGY: Bosch, WVE, All in WRM

SENSOR TYPE: HUMID

OPERATION: Piezoelectric method

ACCURACY: ± --- %		Operational Environment	POWER: --- W*
MIN. RANGE:	0% RH	TEMP. RANGE: ---	WEIGHT: --- LB*
MAX. RANGE:	--- % RH	PRESS. RANGE: ---	VOLUME: --- FT^3*
		PHASE: Gas	

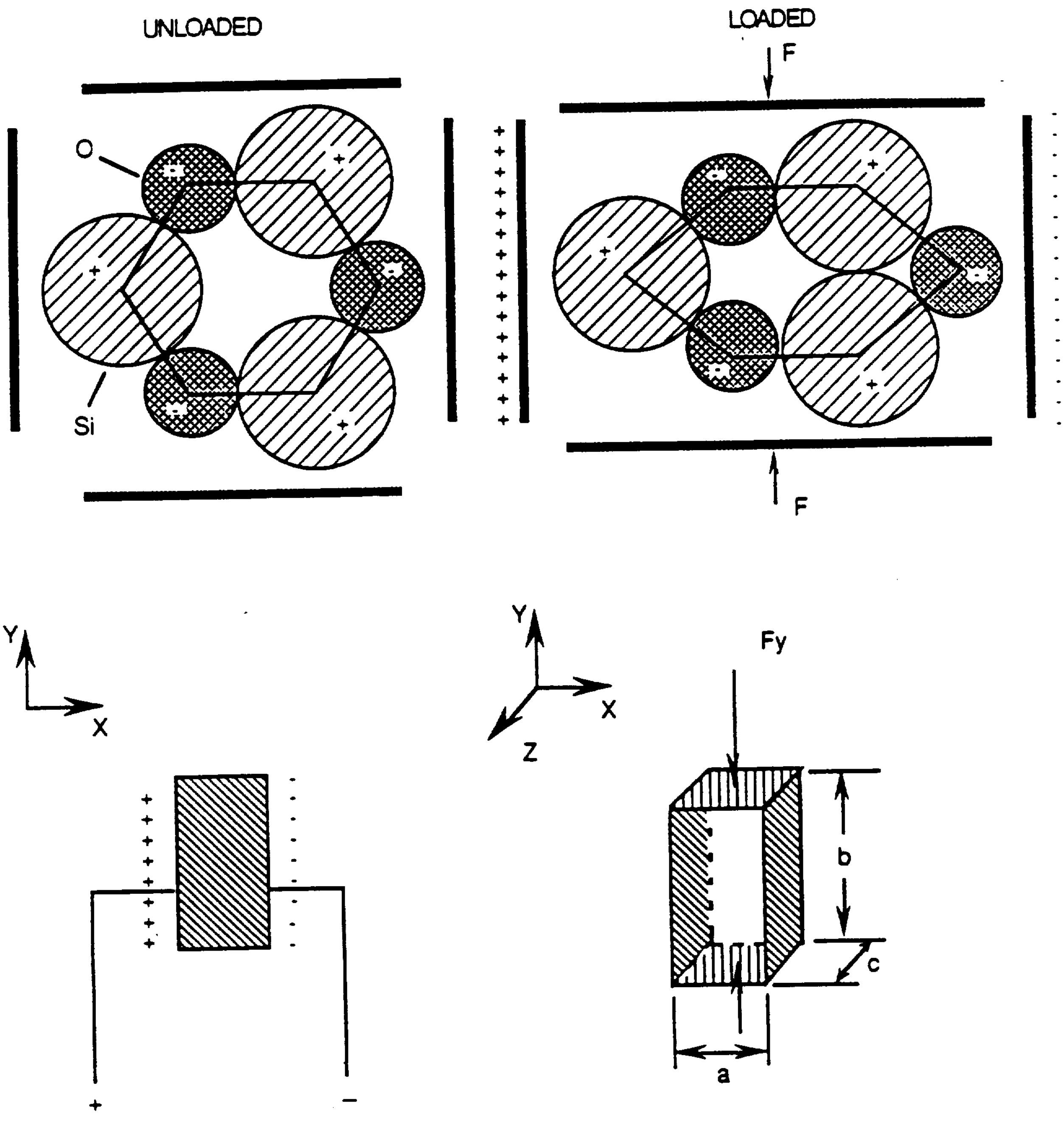
* Design specific information, to be determined.

SENSOR DESCRIPTION:

A piezoelectric crystal in a suitable oscillator circuit will oscillate at a frequency dependent on its mass. If the crystal has a stable hygroscopic film on its surface, the equivalent mass of the crystal varies with the mass of water sorbed in the film. Thus the frequency of oscillation depends on the water in the film. The analyzer contains two such crystals in matched oscillator circuits. Typically valves alternately direct the sample to one crystal and a dry gas to the other on a 30 second cycle. The oscillator frequencies of the two circuits are compared electronically, and the output is the difference between the two frequencies. This output is then representative of the moisture content of the sample.

REFERENCE:

R. H. Perry, D. W. Green, and J. O. Maloney, "Perry's Chemical Engineers' Handbook", McGraw - Hill Book Company, 6th Edition, 1984.



F.3 Piezoelectric Meter

SENSOR NAME : **Psychrometer**

SENSOR INFORMATION

SUBSYSTEM: CO2 Reduction, O2 Generation, WRM

TECHNOLOGY: CO2_E, WVE, All in WRM

SENSOR TYPE: HUMID

OPERATION: Wet - Dry tube

ACCURACY: ± 2.00 %

MIN. RANGE: 0% RH

MAX. RANGE: 100.00 % RH

Operational Environment

TEMP. RANGE: 0°C to 60°C

PRESS. RANGE: ---

PHASE: Gas

POWER: 0.1 W*

WEIGHT: 2.0 LB*

VOLUME: 0.10 FT^3*

* Design specific information, to be determined.

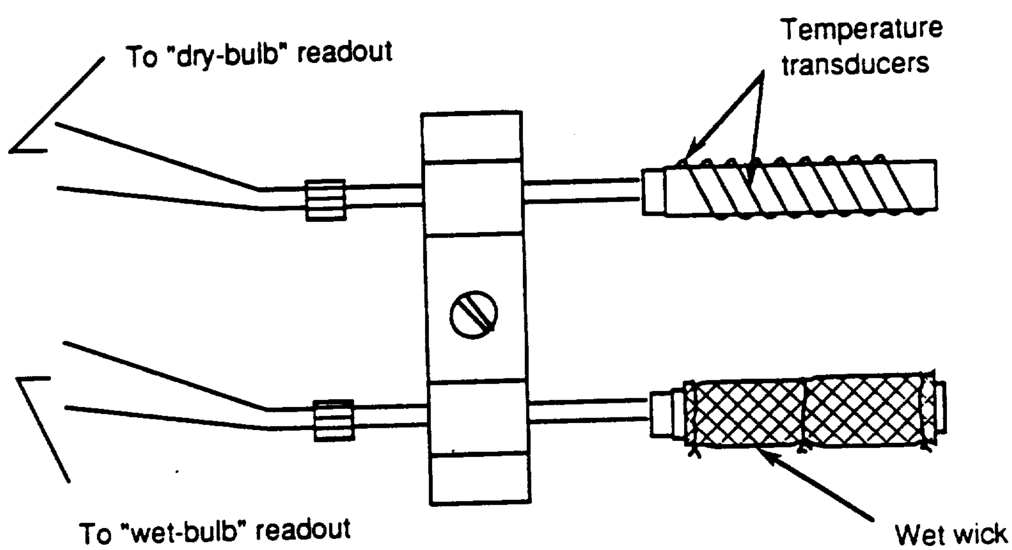
SENSOR DESCRIPTION:

The sensing elements of psychrometric sensors (i.e., those that measure humidity by the "wet and dry bulb" method) are temperature-sensing elements. Two separate elements are always used to provide readings from which relative humidity can be determined. One element (the "dry bulb") measures ambient temperature, the other element (the "wet bulb") is enclosed by a wick which is saturated with distilled water. The air is made to ventilate over the wick so that it cools the sensing element below ambient temperature by causing evaporation of water from the wick. This evaporation is dependent on the vapor pressure or moisture content of the air. Humidity (or moisture) is then determined from the two temperature readings using a table or chart (Psychrometric chart). This method is most useful at high relative humidities with accurate temperature measurement.

REFERENCE:

R. H. Perry, D. W. Green, and J. O. Maloney, "Perry's Chemical Engineers' Handbook", McGraw - Hill Book Company, 6th Edition, 1984.

Harry N. Norton, "Sensor and Analyzer Handbook", Prentice Hall, Inc., 1982.



F.4 Psychromtric Sensor

SENSOR NAME : **Remote Moisture Sensor**

SENSOR INFORMATION

SUBSYSTEM: CO_2 Reduction, O_2 Generation, WRM

TECHNOLOGY: CO2_E, WVE, All in WRM

SENSOR TYPE: HUMID

OPERATION: Electromagnetic or Spectroscopic

ACCURACY:	± --- %	<u>Operational Environment</u>		POWER:	--- W*
MIN. RANGE:	0% RH	TEMP. RANGE:	20°F to 140°F	WEIGHT:	--- LB*
MAX. RANGE:	--- % RH	PRESS. RANGE:	---	VOLUME:	--- FT^3*
		PHASE:	Gas		

* Design specific information, to be determined.

SENSOR DESCRIPTION:

REFERENCE:

Sensor Figure Not Included

SENSOR NAME : **Resistance Method (Conductance)**

SENSOR INFORMATION

SUBSYSTEM: CO2 Reduction, O2 Generation, WRM

TECHNOLOGY: Bosch, WVE, All in WRM

SENSOR TYPE: HUMID

OPERATION: Electrical Resistance

ACCURACY:	± 4.00 %	Operational Environment		POWER:	--- W*
MIN. RANGE:	0% RH	TEMP. RANGE:	---	WEIGHT:	--- LB*
MAX. RANGE:	--- % RH	PRESS. RANGE:	---	VOLUME:	--- FT^3*
		PHASE:	Gas		

* Design specific information, to be determined.

SENSOR DESCRIPTION:

Moisture can produce a marked increase in the electrical conductivity of a material. A number of resistive type sensors are available. The first successful resistive hygrometer used a hygroscopic film consisting of a 2 to 5% aqueous solution of lithium chloride with two electrodes so that the change in resistance of the film, due to a change in humidity, could be measured. The sensors normally depend on the changes in resistance of surfaces exposed to the atmosphere, the resistance being measured by means of a low potential gradient so that the electric current flow through the surface produces negligible heating.

REFERENCE:

R. H. Perry, D. W. Green, J. O. Maloney, "Perry's Chemical Engineers' Handbook", McGraw - Hill Book Company, 6th Edition, 1984.

Harry N. Norton, "Sensor and Analyzer Handbook", Prentice Hall, Inc., 1984.

Ernest O. Doebelin, "Measurement Systems Application and Design", McGraw-Hill, 1983.

Sensor Figure Not Included

SENSOR NAME : **Coulometric Sensor**

SENSOR INFORMATION

SUBSYSTEM:	TECHNOLOGY:	
SENSOR TYPE: HUMID	OPERATION: Absorption	
ACCURACY: ± --- %	<u>Operational Environment</u>	POWER: --- W*
MIN. RANGE: 0% RH	TEMP. RANGE: ---	WEIGHT: --- LB*
MAX. RANGE: --- % RH	PRESS. RANGE: ---	VOLUME: --- FT^3*
	PHASE: Gas	

* Design specific information, to be determined.

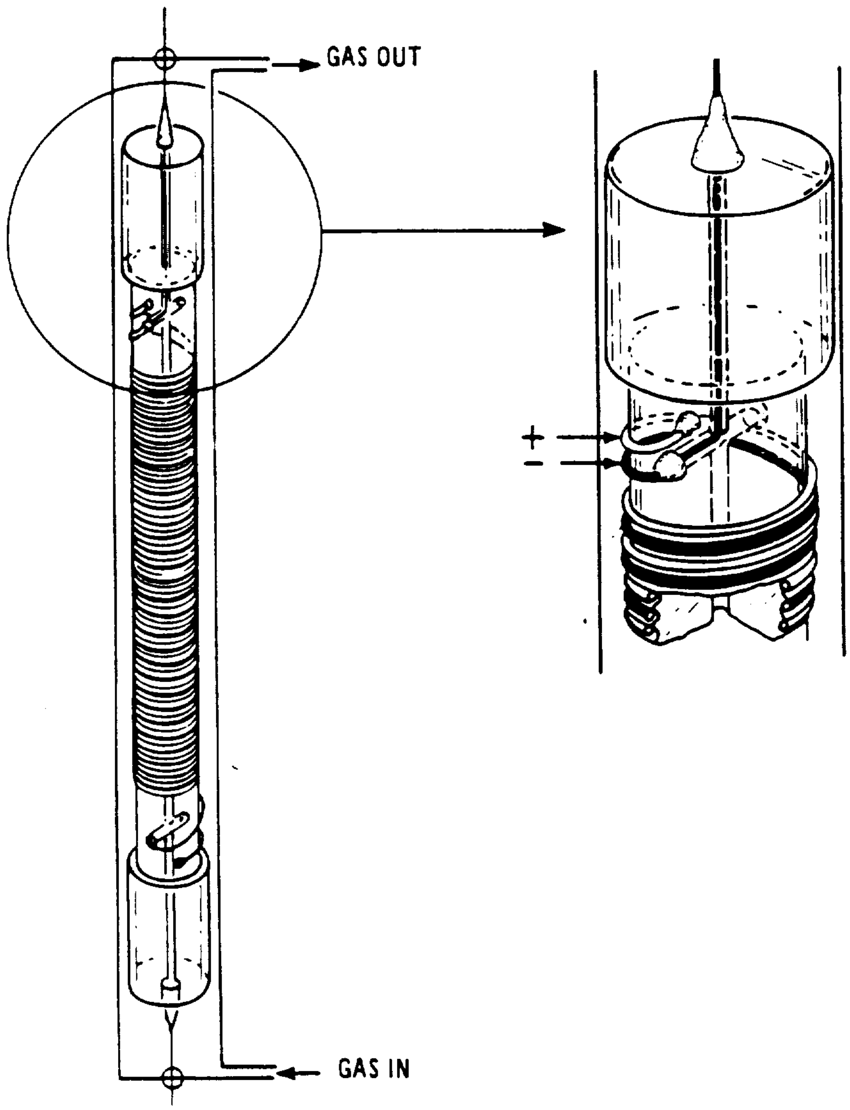
SENSOR DESCRIPTION:

In a coulometric sensor, the gas is passed at a constant rate through a sampling tube in which the moisture is absorbed onto a film of partially hydrated phosphoric anhydride (P2O5) coated on two platinum electrodes. A d.c. voltage is applied across the electrodes to decompose the water, the charge produced by the electrolysis being directly proportional to the mass of water absorbed. Thus, the current depends on the flow rate, which must be set and controlled accurately at a predetermined rate so that the current meter can be calibrated directly in ppm. The coulometric sensor is not suitable for use in gases containing significant amounts of hydrogen due to the use of platinum electrodes (gold or rhodium elements can reduce this effect).

The maximum moisture concentration measurable by this technique is in the range of 1000 to 3000 vppm, but care must be taken to ensure surges of moisture level do not wash of the P2O5.

REFERENCE:

B. N. Noltingk, "Jones' Instrument Technology, 2) Measurement of Temperature and Chemical



F.5 Coulometric Sensor

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Appendix G

Pressure Sensors

Pressure Sensors Reference Summary

List of Figures

Pressure Sensors Reference Summary

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1. Capacitive Pressure Transducers	1,3,8,9
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4. Piezoelectric Pressure Transducer	5,6,9
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10. Vibrationg Element Pressure Transducer	3,9,10
11. Electro-Optic Pressure Transducer	8,10
12. Piezoresistive Pressure Transducer	8,11,12,13,14

References

1. B. E. Noltingk, "Jones' Instrument Technology, 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.
2. George C. Barney, "Intelligent Instrumentation", Prentice Hall, 1988.
3. Harry N. Norton, "Sensor and Analyzer Handbook", Prentice Hall, Inc., 1982.
4. K. Gustafson, B. Hok, L. Jonsson, and C.Ovren, "Fiber Optic Pressure Sensor in Silicon Based on Fluorescence Decay"' Sensor and Actuators, Vol. 19, p. 327-332, 1989.
5. R. H. Perry, D. W. Green, and J. O. Maloney, "Perry's Chemical Engineers' Handbook", McGraw-Hill Book Co., 6th Edition, 1984.
6. PCB Piezotronics, Inc., "Piezoelectric Pressure Transducers", Measurement & Control, Oct. 1988.
7. "Strain Gage & Piezoresistive Pressure Transducers", Measurement & Control, April1989.
8. Ernest O. Doebelin, "Measurement Systems Application and Design", McGraw-Hill, 1983.
9. Donald G. Fink & Donald Christiansen, "Electronics Engineers' Handbook, 3rd Edition", McGraw-Hill, 1989.
10. Alan S. Morris, "Principles of Measurement and Instrumentation", Prentice Hall, 1988.
11. "The OMEGA Pressure, Strain, and Force Handbook", Vol. 27, Copyright 1989.
12. H. R. Winteler and G. H. Gautschi, "Piezoresistive Pressure Transducers", Kistler Instruments, Amherst, N. Y., 1979.
13. R. M. Whittier, "Basic Advantages of the Anisotropic Etched Transverse Gage Pressure Transducer", Prod. Dev. News, Vol. 16, No. 3, Endevco Corp., San Juan Capistrano, CA, 1980.
14. "Pressure Transducer Handbook", National Semiconductor Corp., Santa Clara, CA, 1977.

Pressure Sensors

Process pressure measuring devices may be divided into four groups:

1. Those which are based on the measurement of the height of a liquid column.

2. Those which are based on the measurement of the distortion of an elastic pressure chamber.

3. Electrical Sensing Devices.

4. Optic Pressure Sensor.

SENSOR NAME : **Capacitive Pressure Transducer**

SENSOR INFORMATION

SUBSYSTEM: All		TECHNOLOGY: All	
SENSOR TYPE: PRESS		OPERATION: Diaphragm	
ACCURACY: ± 0.20 %	<u>Operational Environment</u>	POWER:	--- W*
MIN. RANGE: 0 Psi	TEMP. RANGE: -50°C to 500°C	WEIGHT:	--- LB*
MAX. RANGE: 10000Psi	PRESS. RANGE: ---	VOLUME:	--- FT^3*

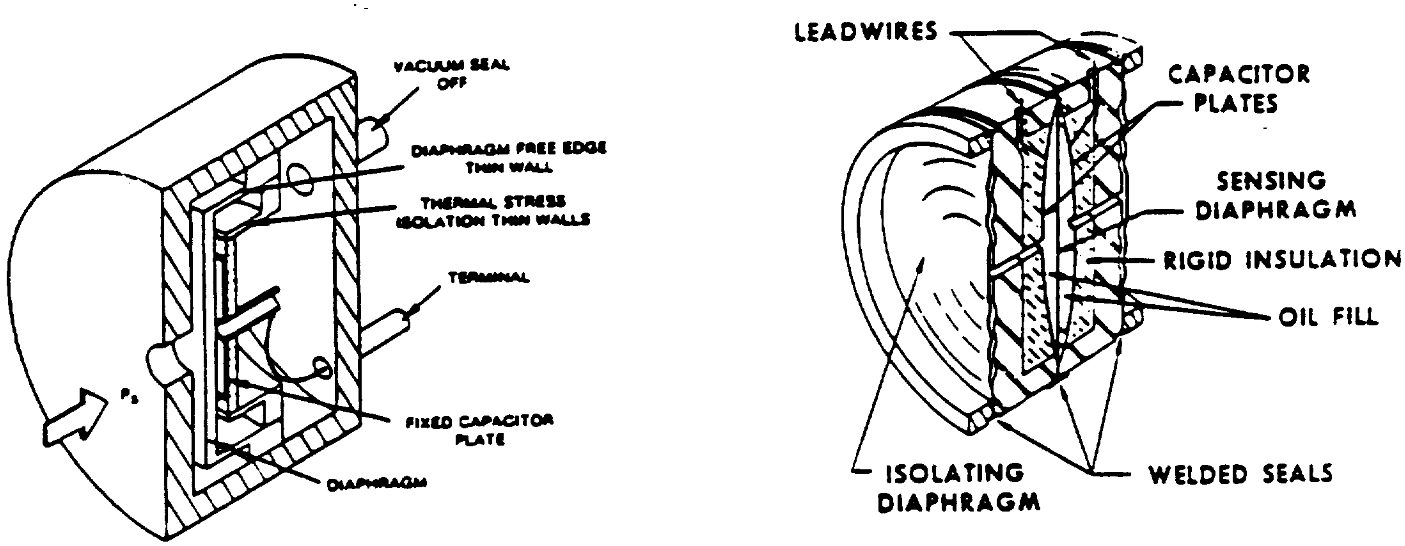
* Design specific information, to be determined.

SENSOR DESCRIPTION:

A capacitive pressure sensor is a variable capacitor, one plate of which consists of a diaphragm. Capacitive transduction is utilized in either of the following designs: 1) Single Stator: pressure is applied to a diaphragm which moves in relation to a stationary electrode (stator); 2) Dual Stator: pressure is applied to a diaphragm supported between two stationary electrodes. Electronic techniques are used to measure the deflection of a diaphragm and infer the pressure variation.

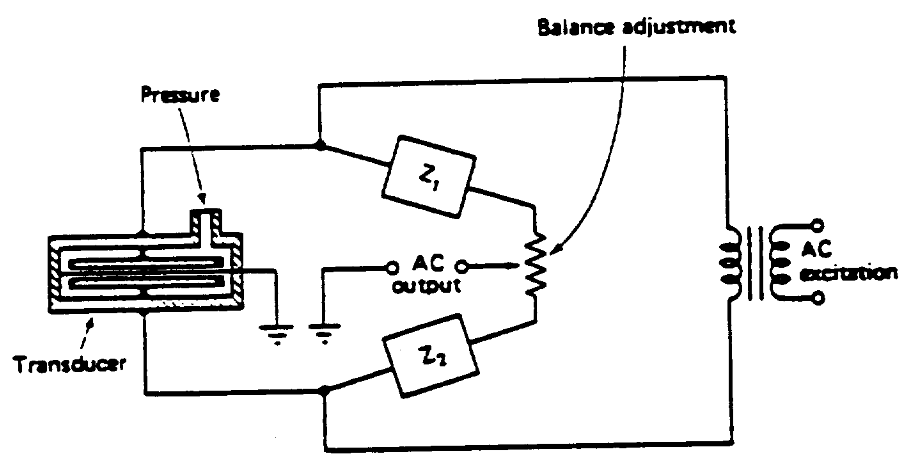
REFERENCE:

Harry N. Norton, "Sensor and Analyzer Handbook", Prentice Hall, Inc., 1982.
B. N. Noltingk, "Jones' Instrument Technology, 2) Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.
Donald G. Fink & Donald Christiansen, "Electronics Engineers' Handbook, 3rd Edition", McGraw-Hill, 1989.
Ernest O. Doebelin, "Measurement Systems Application and Design", McGraw-Hill, 1983.



(a) (b)

(a) Single stator capacitive absolute pressure transducer;
(b) Dual stator capacitive differential pressure transducer;



G.1 Capacative Pressure Transducer

SENSOR NAME : **Fiber Optic Pressure Sensor**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: All
SENSOR TYPE: PRESS		OPERATION: Fiber Optic & Fluorescence Decay
ACCURACY: ± 0.50 %	Operational Environment	POWER: --- W*
MIN. RANGE: 0 Psi	TEMP. RANGE: ---	WEIGHT: --- LB*
MAX. RANGE: 6000Psi	PRESS. RANGE: ---	VOLUME: --- FT^3*

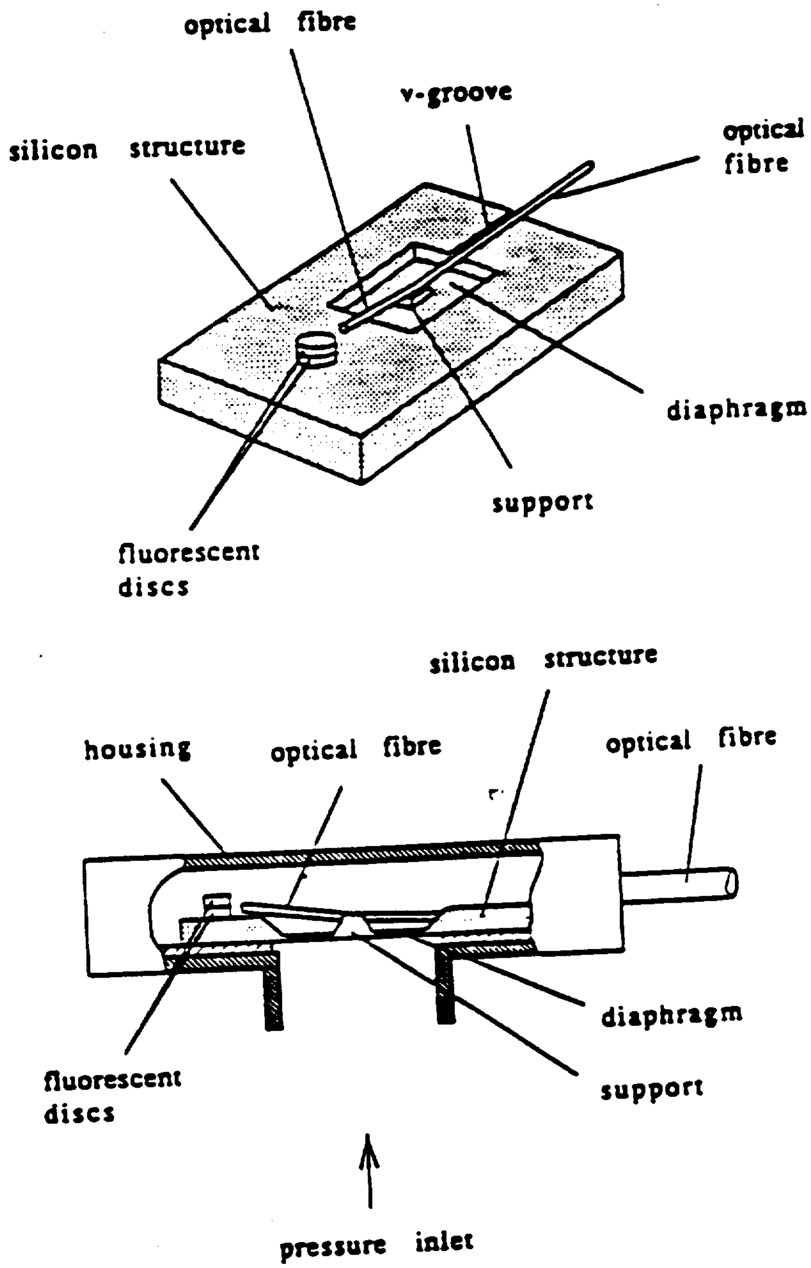
* Design specific information, to be determined.

SENSOR DESCRIPTION:

Neodymium-doped discs with different fluorescent lifetimes are stacked at the end of an optical fiber. The fiber is placed on a diaphragm which vertically deflects the fiber in relation to the discs when pressure is applied. As the fiber tip moves from one disc to the other the fluorescent signal in the fiber will have varying contribution from the two discs - contributions that will be pressure dependent. Phase sensitive detection schemes can then be used to detect the pressure dependent fluorescence emitted into the fiber. The use of fluoresence as the modulating effect in a fiber optic sensor is attracive for several reasons, e.g., optical simplicity, low drift, high strength, precision, and reliability.

REFERENCE:

K. Gustafson, B. Hok, L. Jonsson and C. Ovren, "Fiber Optic Pressure Sensor in Silicon Based on Fluorescence Decay", Sensor and Actuators, Vol 19, p327-332, 1989.
Donald G. Fink & Donald Christiansen, "Electronics Engineers' Handbook, 3rd Edition", McGraw-Hill, 1989.



G.2 Fiber Optic Pressure Transducer

SENSOR NAME : **Inductive Pressure Transducer**

SENSOR INFORMATION

SUBSYSTEM: All		TECHNOLOGY: All
SENSOR TYPE: PRESS		OPERATION: Diaphragm
ACCURACY: ± 0.20 %	<u>Operational Environment</u>	POWER: --- W*
MIN. RANGE: 0 Psi	TEMP. RANGE: ---	WEIGHT: --- LB*
MAX. RANGE: 145000Psi	PRESS. RANGE: ---	VOLUME: --- FT^3*

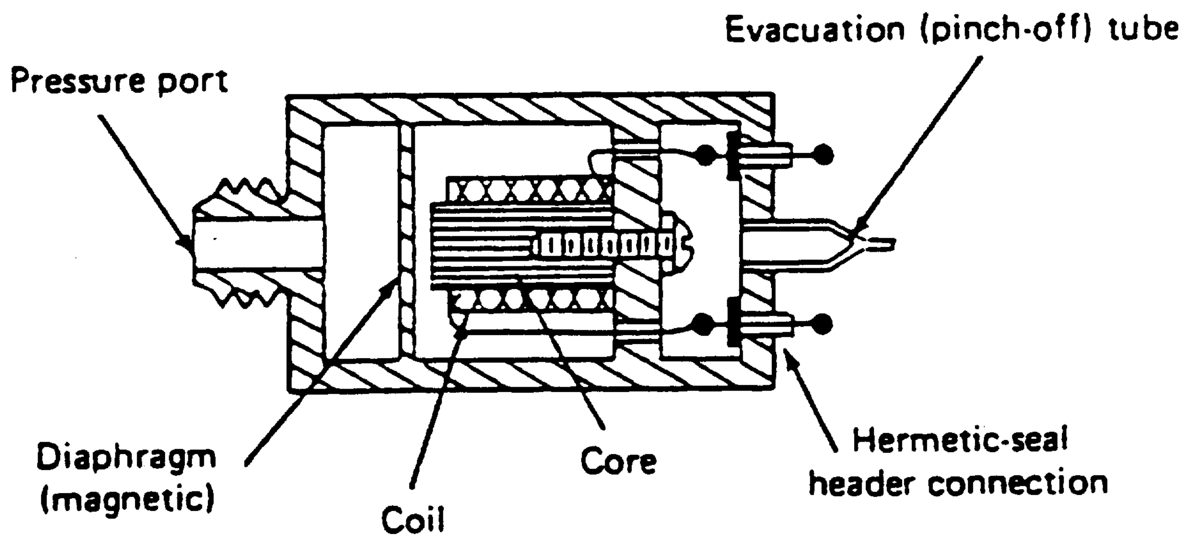
* Design specific information, to be determined.

SENSOR DESCRIPTION:

In an inductive pressure transducer the self-inductance of a single coil is varied by pressure-induced changes which displace a metallic diaphragm in close proximity to the coil. Some recent designs use a metallic diaphragm and a coil excited by ac current at RF frequencies. Changes in eddy currents in the diaphragm produce self-inductance changes. A second (reference) coil is often included in the same housing, which remains unaffected by pressure variations and provides compensation for temperature changes.

REFERENCE:

Harry N. Norton, "Sensor and Analyzer Handbook", Prentice Hall, Inc., 1982.
Donald G. Fink & Donald Christiansen, "Electronics Engineers' Handbook, 3rd Edition", McGraw-Hill, 1989.



G.3 Inductive Pressure Transducer

SENSOR NAME : **Piezoelectric Pressure Transducer**

SENSOR INFORMATION

SUBSYSTEM: All		TECHNOLOGY: All			
SENSOR TYPE: PRESS		OPERATION: Piezoelectric effect			
ACCURACY:	± 0.10 %	<u>Operational Environment</u>		POWER:	--- W*
MIN. RANGE:	0 Psi	TEMP. RANGE:	350°C	WEIGHT:	--- LB*
MAX. RANGE:	21756Psi	PRESS. RANGE:	---	VOLUME:	--- FT^3*

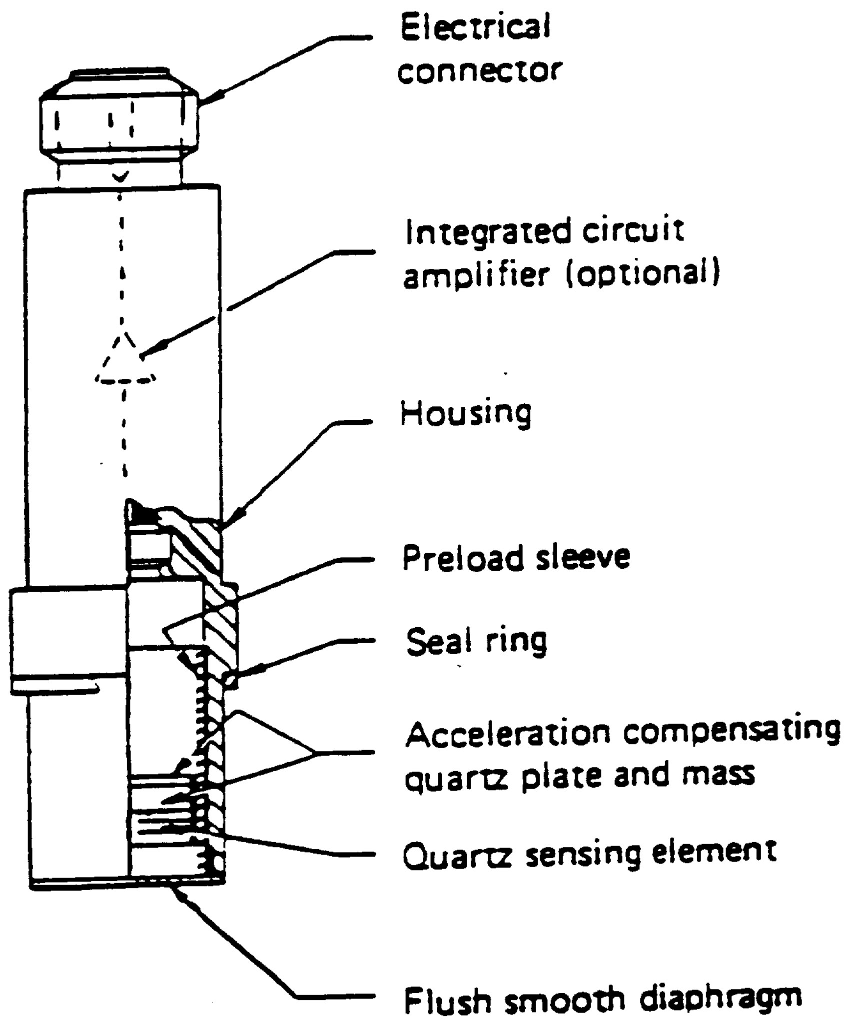
* Design specific information, to be determined.

SENSOR DESCRIPTION:

When stress is applied to certain types of crystals a positive or negative electrostatic charge forms on the surfaces. The transformation of mechanical stress on the crystal into electrical energy is referred to as the "piezoelectric effect". Piezoelectric pressure transducers generate a potential difference proportional to a pressure generated stress. These kinds of pressure transducer elements are classified as "active elements" i.e., they generate an electrical output proportional to mechanical stress on the diaphragm with no need for an external source of power. Because of the extremely high electrical impedance of piezoelectric crystals at low frequency, these transducers are usually not suitable for measurement of static process pressures.

REFERENCE:

R. H. Perry, D. W. Green, and J. O. Maloney, "Perry's Chemical Engineers' Handbook", McGraw - Hill Book Company, 6th Edition, 1984.
PCB Piezotronics, Inc., "Piezoelectric Pressure Transducers", Measurement & Control, October 1988.
Donald G. Fink & Donald Christiansen, "Electronics Engineers' Handbook, 3rd Edition", McGraw-Hill, 1989.



G.4 Piezoelectric Pressure Transducer

SENSOR NAME : **Potentiometric Pressure Transducer**

SENSOR INFORMATION

SUBSYSTEM: All		TECHNOLOGY: All	
SENSOR TYPE: PRESS		OPERATION: Diaphragm	
ACCURACY: ± 2.00 %	Operational Environment	POWER:	--- W*
MIN. RANGE: 0 Psi	TEMP. RANGE: ---	WEIGHT:	--- LB*
MAX. RANGE: 10000Psi	PRESS. RANGE: ---	VOLUME:	--- FT^3*

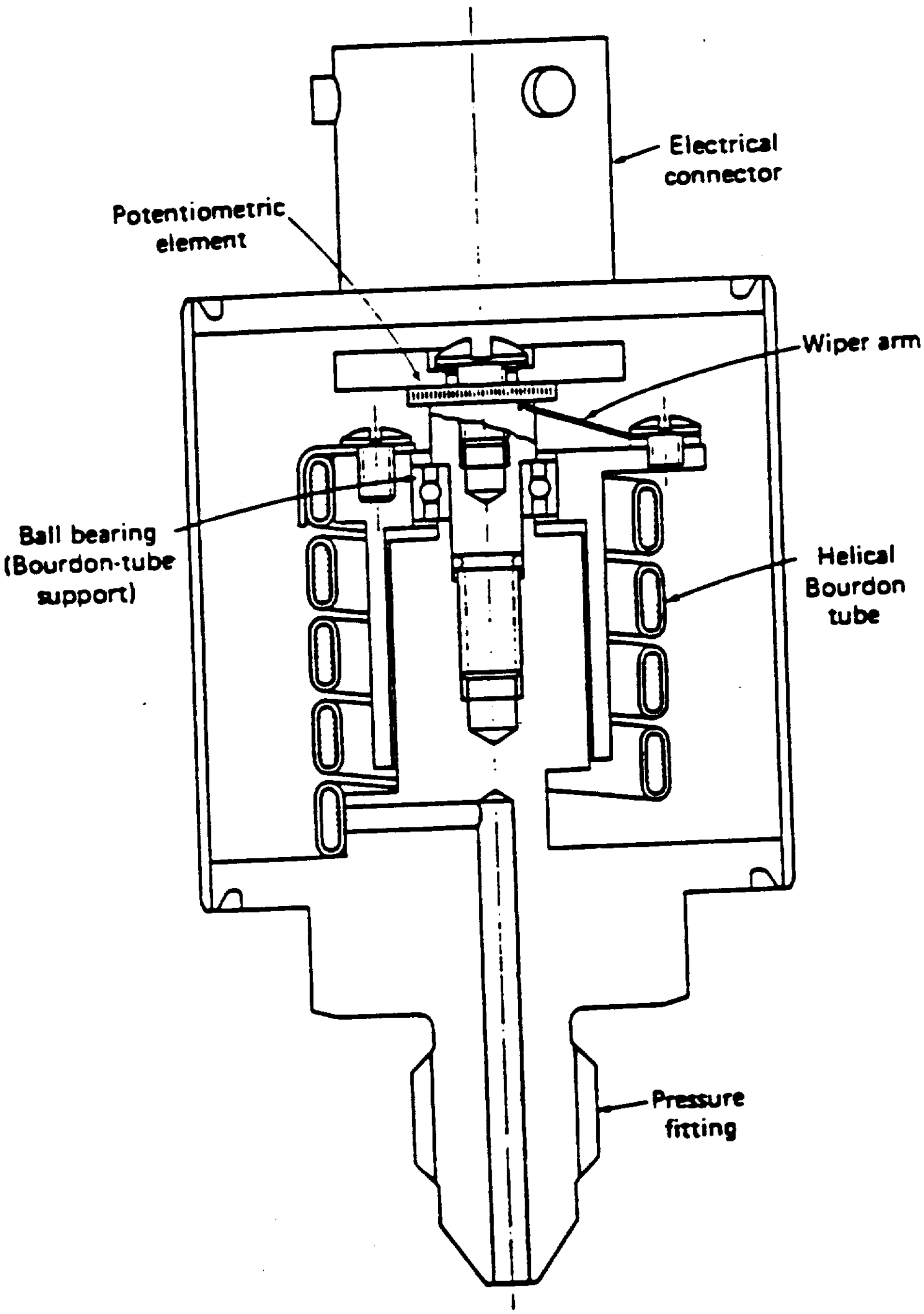
* Design specific information, to be determined.

SENSOR DESCRIPTION:

A potentiometric pressure transducer uses single or multiple capsules for relatively low pressure ranges and Bourdon tubes for high pressure ranges. A variation in pressure will cause a wiper arm connected to the Bourdon tube to slide over an exposed strip on a resistance element, changing the output voltage in proportion to the pressure.

REFERENCE:

Harry N. Norton, "Sensor and Analyzer Handbook", Prentice Hall, Inc., 1982.
Donald G. Fink & Donald Christiansen, "Electronics Engineers' Handbook, 3rd Edition", McGraw-Hill, 1989.



G.5 Potentiometric Pressure Transducer

SENSOR NAME : **Reluctive Pressure Transducer**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: All
SENSOR TYPE: PRESS		OPERATION: Electromagnetics
ACCURACY: ± 0.20 %	<u>Operational Environment</u>	POWER: --- W*
MIN. RANGE: 0 Psi	TEMP. RANGE: ---	WEIGHT: --- LB*
MAX. RANGE: 5000Psi	PRESS. RANGE: ---	VOLUME: --- FT^3*

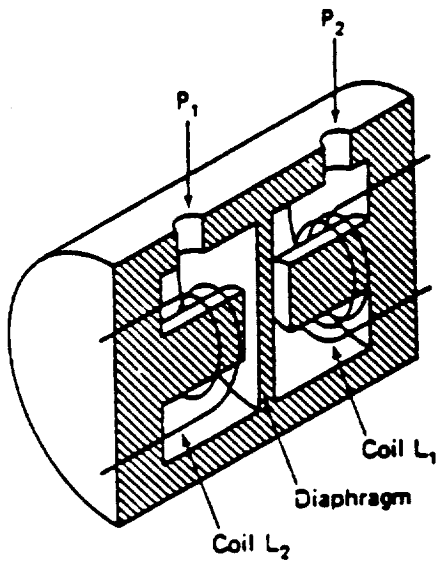
* Design specific information, to be determined.

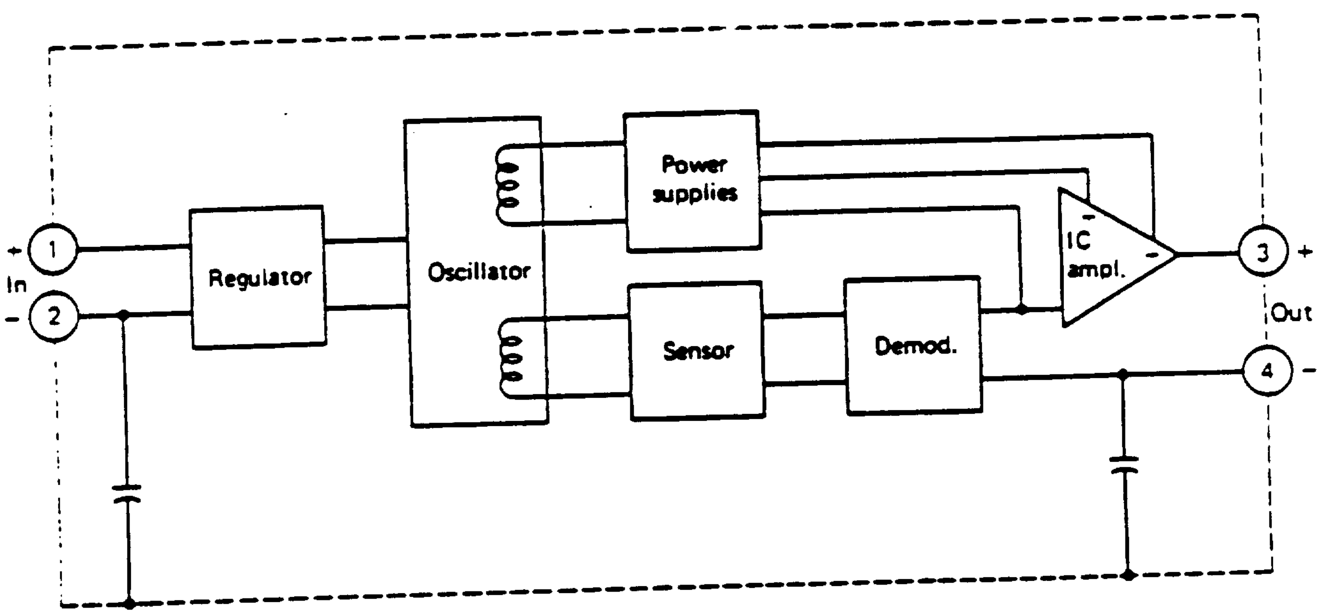
SENSOR DESCRIPTION:

This sensor uses a change in reluctance caused by diaphragm deflection when pressure changes in the system. Inductance bridge reluctive pressure transducers use a magnetically permeable member (such as a diaphragm or Bourdon tube) to increase the inductance of one coil while decreasing the inductance in the second coil. The coils are connected in a bridge circuit so that the increase and decrease in inductance of the two coils are additive in the resulting bridge output voltage. The twisted Bourdon tube sensing element is used for pressure ranges between 0 and 350 kPa. The armature and coil assembly designed for this transducer model increases the range from 0 to 35 MPa. C-shaped and U-shaped Bourdon tubes have been used for pressure ranges having an upper limit of 1.5 MPa, and single or multiple capsules are used for pressure ranges with upper limits of about 3.5 MPa.

REFERENCE:

Harry N. Norton, "Sensor and Analyzer Handbook", Prentice Hall, Inc., 1982.
Donald G. Fink & Donald Christiansen, "Electronics Engineers' Handbook, 3rd Edition", McGraw-Hill, 1989.





G.6 Reluctive Pressure Transducer

SENSOR NAME : **Resistive Pressure Transducer**

SENSOR INFORMATION

SUBSYSTEM: WRM	TECHNOLOGY: All	
SENSOR TYPE: PRESS	OPERATION: Electrical Resistance Change	
ACCURACY: ± 0.10 %	<u>Operational Environment</u>	POWER: --- W*
MIN. RANGE: 0 Psi	TEMP. RANGE: ---	WEIGHT: --- LB*
MAX. RANGE: 20000Psi	PRESS. RANGE: ---	VOLUME: --- FT^3*

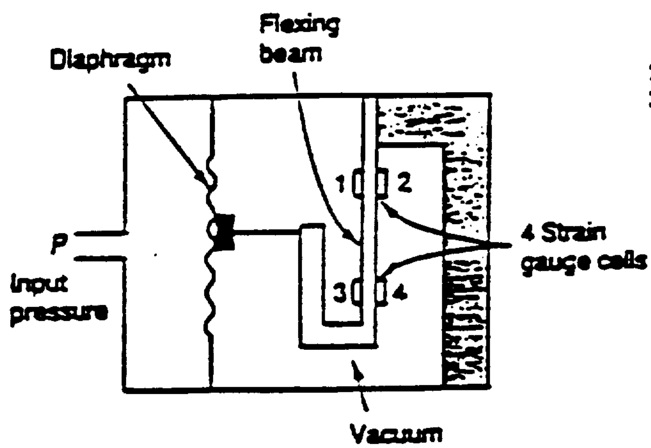
* Design specific information, to be determined.

SENSOR DESCRIPTION:

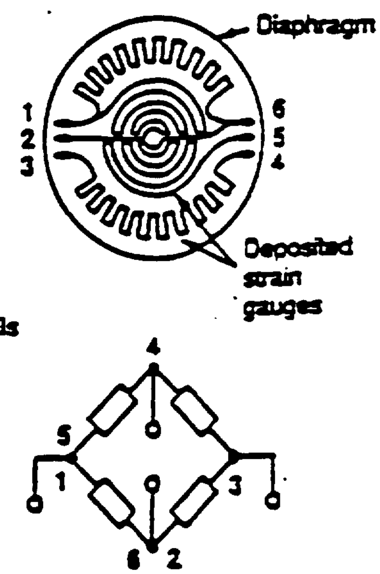
A number of different designs have been developed that measure the resistance changes in certain conductive materials at different pressures. Carbon powder has been used in some designs (the earliest microphones were based on this material and principle). Stacked carbon disks have also been used, with a diaphragm or bellows as a force summing member. Carbon undergoes a decrease of resistivity when pressurized. The only material that is used in commercially available sensors, however, is manganin, a copper alloy. Manganin gages are probably the most suitable sensors for very high pressures up to about 1400 MPa.

REFERENCE:

Harry N. Norton, "Sensor and Analyzer Handbook", Prentice Hall, Inc., 1982.
Alan S. Morris, "Principles of Measurement and Instrumentation", Prentice Hall, 1988.



(a) Flexing beam/strain gauge



(b) Rosette strain gauge and bridge configuration

G.7 Resistive Pressure Transducer

SENSOR NAME : **Servo-Type Pressure Transducer**

SENSOR INFORMATION

SUBSYSTEM: WRM	TECHNOLOGY: All	
SENSOR TYPE: PRESS	OPERATION: Servo Type	
ACCURACY: ± 0.20 %	<u>Operational Environment</u>	POWER: --- W*
MIN. RANGE: 0 Psi	TEMP. RANGE: ---	WEIGHT: --- LB*
MAX. RANGE: 30Psi	PRESS. RANGE: ---	VOLUME: --- FT^3*

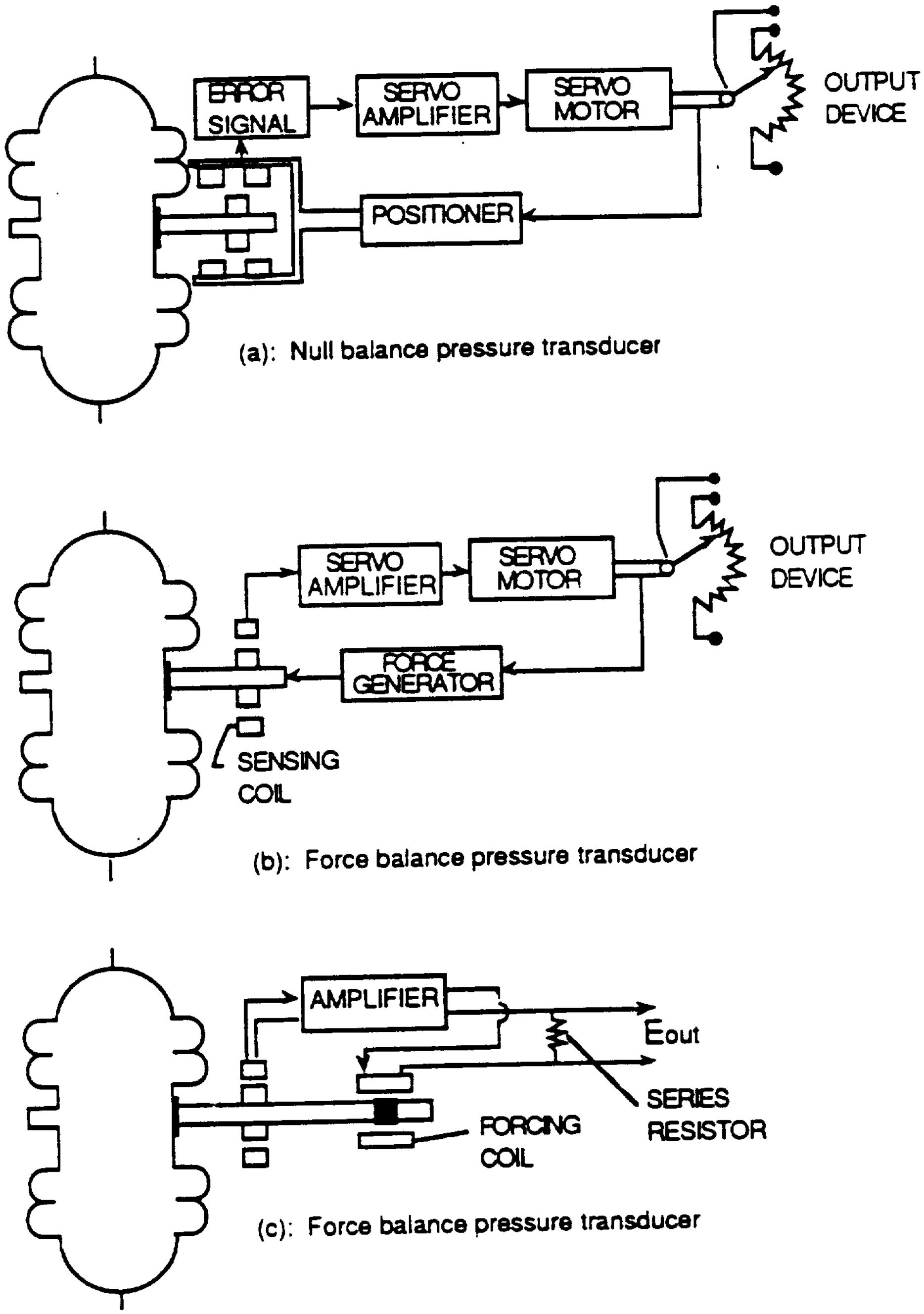
* Design specific information, to be determined.

SENSOR DESCRIPTION:

Servo-type pressure transducers incorporate a closed servo loop. These designs are generally more complex than other transducer types but provide very good accuracy. In general, these transducer consist of a sensing element (capsule or bellows) which deflects in response to applied pressure, a transduction element which detects the beginning of displacement and produces an error signal, and an amplifier which amplifies the signal to a servo motor or other device that drives the system to a new position.

REFERENCE:

Harry N. Norton, "Sensor and Analyzer Handbook", Prentice Hall, Inc., 1982.
George C. Barney, "Intelligent Instrumentation", Prentice Hall, 1988.
Donald G. Fink & Donald Christiansen, "Electronics Engineers' Handbook, 3rd Edition", McGraw-Hill, 1989.



(a): Null balance pressure transducer

(b): Force balance pressure transducer

(c): Force balance pressure transducer

G.8 Servo Type Pressure Transducer

SENSOR NAME : **Strain Gage Pressure Transduce**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: All	
SENSOR TYPE: PRESS		OPERATION: Electrical Resistance Change	
ACCURACY: ± 1.00 %	Operational Environment	POWER:	--- W*
MIN. RANGE: 0 Psi	TEMP. RANGE: -20°C to 80°C	WEIGHT:	--- LB*
MAX. RANGE: 50000Psi	PRESS. RANGE: ---	VOLUME:	--- FT^3*

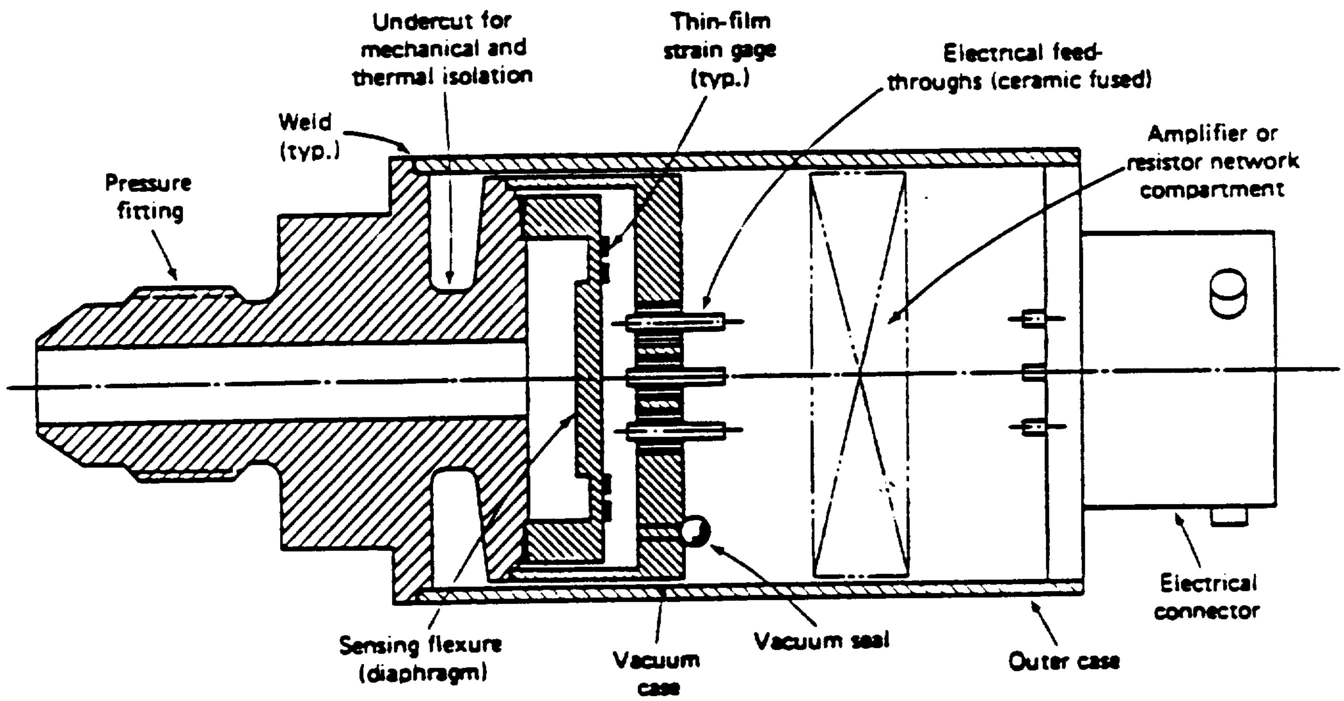
* Design specific information, to be determined.

SENSOR DESCRIPTION:

When a wire or other electrical conductor is stretched elastically, its length is increased and its diameter is decreased. Both of these dimensional changes result in an increase in the electrical resistance of the conductor. Strain gage transducers convert a pressure change into a change in resistance due to strain, usually in a Wheatstone bridge. Change of electrical resistance in materials when mechanically deformed is the property used in the resistance-type strain gages. Photolithographic techniques allow the production of very small sensors, as small as 0.75 mm diameter. Integrally diffused semiconductor gages (diffused directly into a silicon diaphragm) have been developed and produced for a wide variety of pressure ranges between 25 KPa and 200 MPa.

REFERENCE:

"Strain Gage & Piezoresistive Pressure Transducers", Measurements & Control, April 1989.
R. H. Perry, D. W. Green, and J. O. Maloney, "Perry's Chemical Engineers' Handbook", McGraw - Hill Book Company, 6th Edition, 1984.
Donald G. Fink & Donald Christiansen, "Electronics Engineers' Handbook, 3rd Edition", McGraw-Hill, 1989.
Ernest O. Doebelin, "Measurement Systems Application and Design", McGraw-Hill, 1983.



G.9 Strain Gauge Absolute Pressure Transducer

SENSOR NAME : **Vibrating Element Pressure Traducer**

SENSOR INFORMATION

SUBSYSTEM: WRM		TECHNOLOGY: All
SENSOR TYPE: PRESS		OPERATION: Resonant Frequency
ACCURACY: ± 0.20 %	<u>Operational Environment</u>	POWER: --- W*
MIN. RANGE: 0 Psi	TEMP. RANGE: ---	WEIGHT: --- LB*
MAX. RANGE: ---Psi	PRESS. RANGE: ---	VOLUME: --- FT^3*

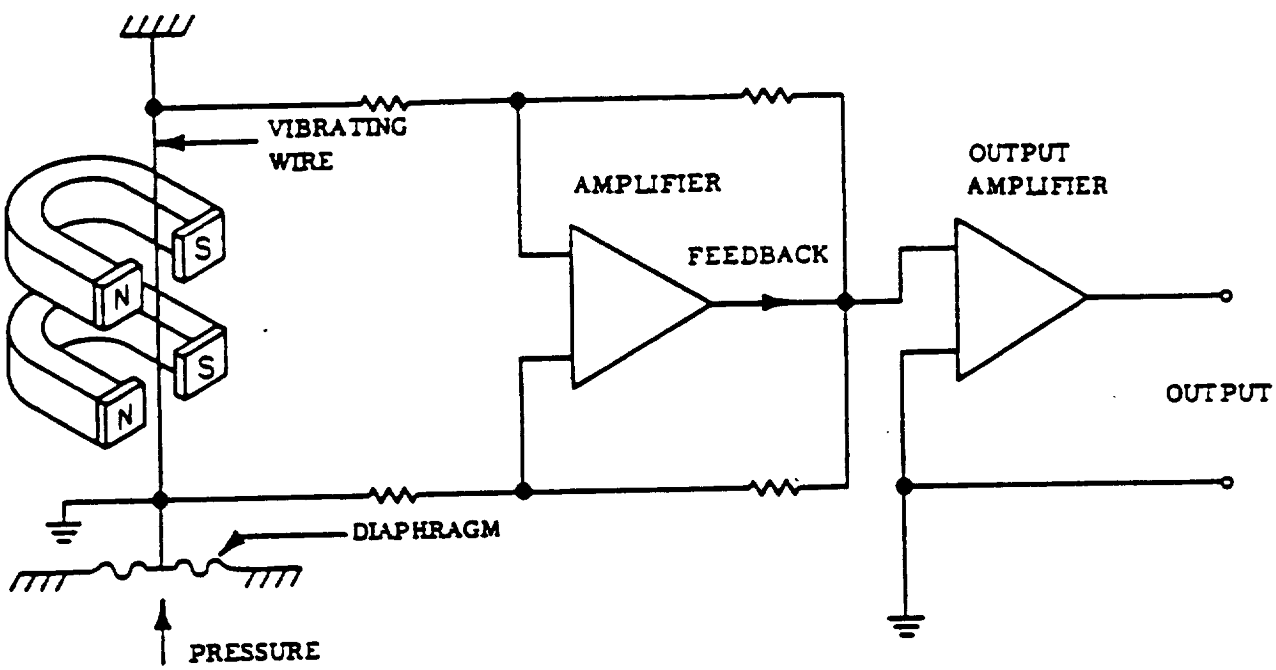
* Design specific information, to be determined.

SENSOR DESCRIPTION:

Pressure transducers which use the change in the resonant frequency of vibrating mechanical members due to pressure changes are capable of providing extremely good repeatability. They also produce a frequency output or frequency - modulated output (frequency deviation from a center frequency) which lends itself to digitization without conversion error. Such devices are highly accurate, and they are particularly insensitive to ambient condition changes.

REFERENCE:

Harry N. Norton, "Sensor and Analyzer Handbook", Prentice Hall, Inc., 1984.
Donald G. Fink & Donald Christiansen, "Electronics Engineers' Handbook, 3rd Edition", McGraw-Hill, 1989.
Alan S. Morris, "Principles of Measurement and Instrumentation", Prentice Hall, 1988.



G.10 Vibration Wire Pressure Transducer

SENSOR NAME : **Electro-Optic Pressure Transducer**

SENSOR INFORMATION

SUBSYSTEM: All		TECHNOLOGY: All
SENSOR TYPE: PRESS		OPERATION: Bourdon Tubes & Diaphragm
ACCURACY: ± 0.10 %	<u>Operational Environment</u>	POWER: --- W*
MIN. RANGE: 5 Psi	TEMP. RANGE: ---	WEIGHT: --- LB*
MAX. RANGE: 60000Psi	PRESS. RANGE: ---	VOLUME: --- FT^3*

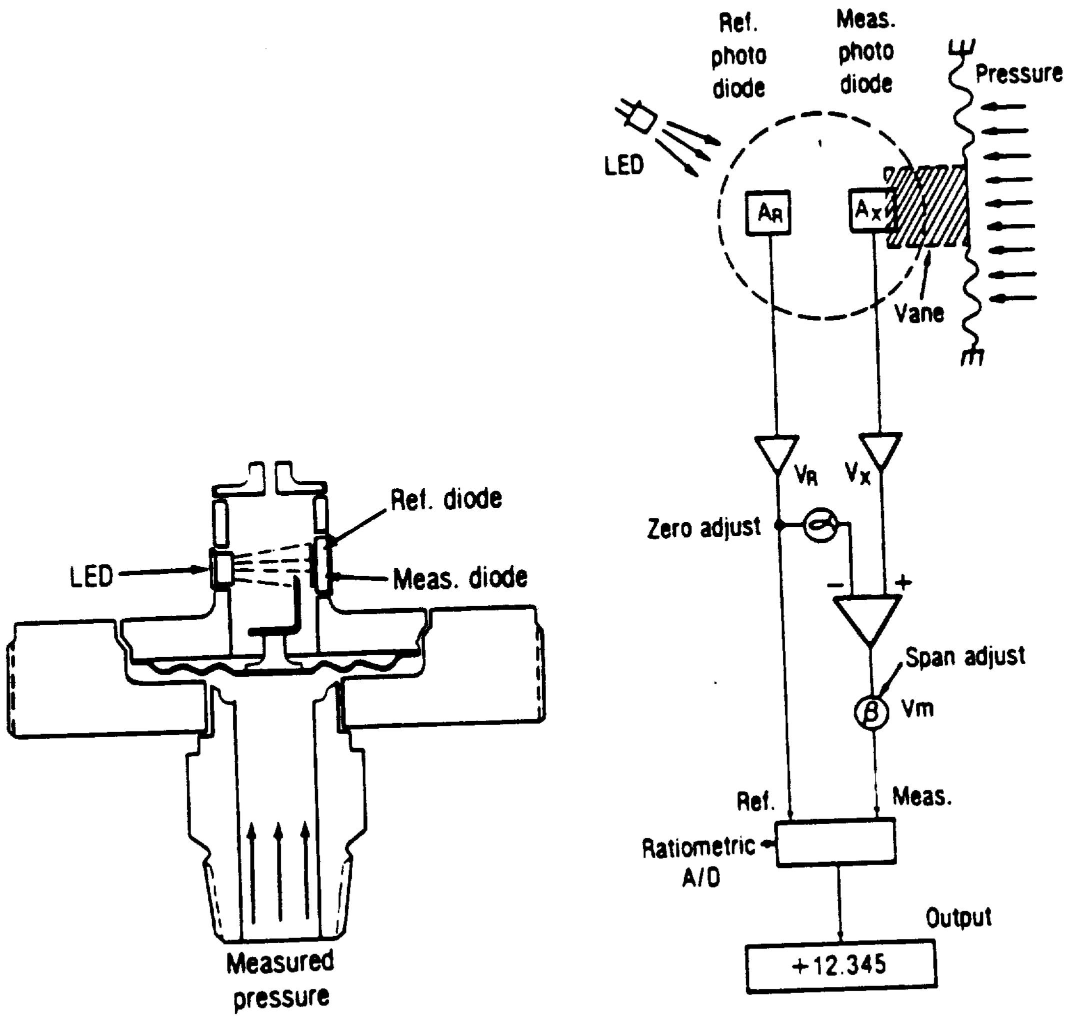
* Design specific information, to be determined.

SENSOR DESCRIPTION:

Electro-optical pressure transducers are diaphragm or helical Bourdon-tube devices which use an optical method of displacement measurement. Figure G.11 shows a sensor utilizing an infrared LED and two photodiodes to optically measure displacement of the pressure-sensitive elstic element. The reference and measurement photodiodes are on the same chip and thus are equally affected by temperature changes. Changes in LED output due to temperature or age also cancel, since both diodes that share the same illumination and ratiometric integrating analog/digital converter is employed to obtain a digital output sensitive to only diode-illuminated areas Ar and Ax and pot settings alpha and ß. Any nonlinearities are linerized in the analog/digital converter using a look-up table resident in a pair of PROMs (programmable read-only memory). A programmable electronic unit is used to tailor each unit to achieve overall linearity. An automatic-zero feature in the analog/digital converter minimizes thermal zero shifts.

REFERENCE:

Alan S. Morris, "Principles of Measurement and Instrumentation", Prentice Hall, 1988.
Ernest O. Doebelin, "Measurement Systems Application and Design", McGraw-Hill, 1983.



G.11 (Intelligent) Electro-Optic Pressure Transducer

SENSOR NAME : **Piezoresistive Pressure Transducer**

SENSOR INFORMATION

SUBSYSTEM: WRM			TECHNOLOGY: All		
SENSOR TYPE: PRESS			OPERATION: Semiconductor Diaphragm		
ACCURACY: ± --- %		Operational Environment		POWER:	--- W*
MIN. RANGE:	0 Psi	TEMP. RANGE: ---		WEIGHT:	--- LB*
MAX. RANGE:	50000Psi	PRESS. RANGE: ---		VOLUME:	--- FT^3*

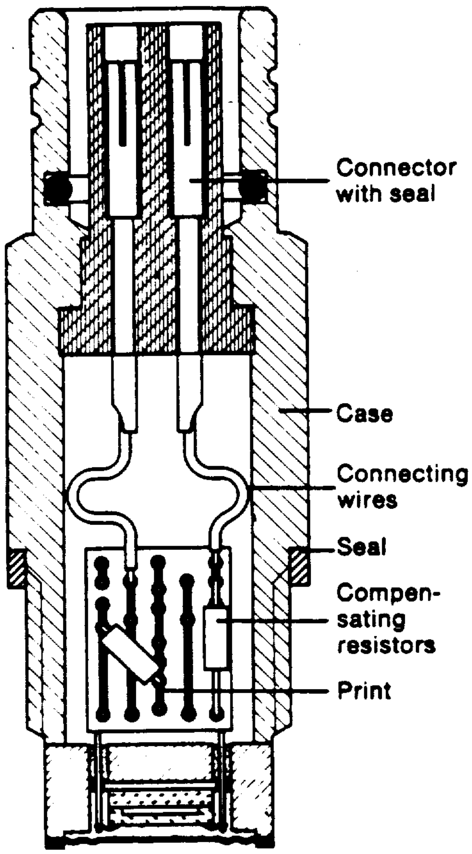
* Design specific information, to be determined.

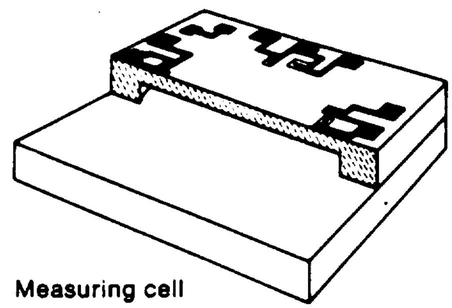
SENSOR DESCRIPTION:

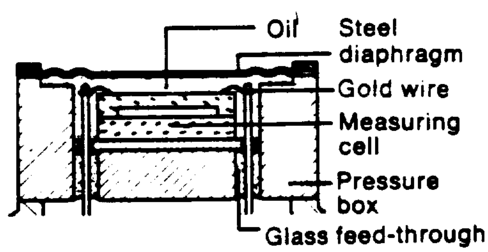
Piezoresistance of a semiconductor can be described as the change in resistance that is caused by an applied strain of the diaphragm. Thus, solid state resistors can be used as pressure sensors, much like strain gages, but with several important differences and advantages. The high sensitivity, or gage factor, is approximatly 100 times that of wire strain gages. Piezoresistors are diffused into a homogeneous single crystaline silicon medium. The difused resistors are thus integrated into the silicon force sensing member. The sensing element consists of four nearly identical piezoresistors buried in the surface of a thin circular silicon diaphragm. A pressure causes the thin diaphragm to bend, inducing a stress or strain in the diaphragm and also in the buried resistors. The resistor values change depending on the amount of strain they undergo. Hence, a change in pressure is converted to a change in resistance.

REFERENCE:

Ernest O. Doebelin, "Measurement Systems Application and Design", McGraw-Hill, 1983.
"The OMEGA Pressure, Strain, and Force Handbook", Vol. 27, Copyright 1989.
H. R. Winteler and G. H. Gautschi, "Piezoresistive Pressure Transducers", Kistler Instruments, Amherst, N. Y., 1979.
R. M. Whittier, "Basic Advantages of the Anisotropic Etched Transverse Gage Pressure Transducer", Prod. Dev. News, Vol. 16, No. 3, Endevco Corp., San Juan Capistrano, CA, 1980.
"Pressure Transducer Handbook", National Semiconductor Corp., Santa Clara, CA, 1977





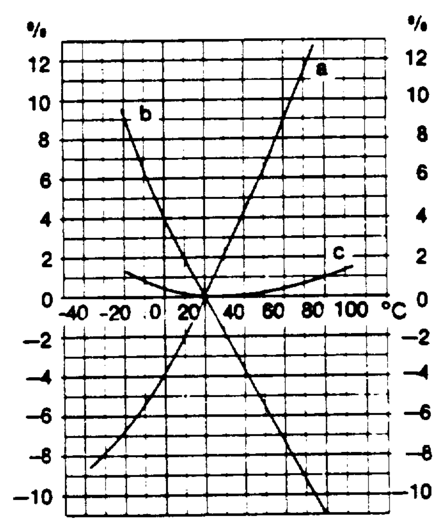


Current excitation
The pressure transducers are excited by constant current. The voltage rise due to the increase in resistance with temperature compensates for the decrease of the gage factor with temperature. The graph shows the typical relative changes of the resistance R, the gage factor G and the output voltage U_{out} in function of temperature.

a) $\frac{\Delta R}{R}$

b) $\frac{\Delta G}{G} = \frac{\Delta U_{out}}{U_{out}}$ with constant voltage excitation

c) $\frac{\Delta U_{out}}{U_{out}}$ with constant current excitation



G.12 Piezoresistive (Semiconductor Strain Gage) Pressure Transducer

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Appendix H

Temperature Sensors

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Temperature Sensors Reference Summary

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Temperature Sensors Reference Summary

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5. Thermistor	1,2,3,4
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7. Thermopile	1,2
8. Radiation Pyrometer	1,2,5,6,7
9. Fiber Optic Thermometer	8,9,10

References

1. Alan S. Morris, "Principles of Measurement and Instrumentation", Prentice Hall, 1988.
2. Ernest O. Doebelin, "Measurement Systems Application and Design", McGraw-Hill, 1983.
3. "The OMEGA complete Temperature Measurement Handbook and Encyclopedia", Vol. 27, Copyright 1989.
4. Donald G. Fink & Donald Christiansen, "Electronics Engineers' Handbook, 3rd Edition", McGraw-Hill, 1989.
5. Harry N. Norton, "Sensor and Analyzer Handbook", Prentice Hall, Inc., 1982.
6. James R. Leigh, "Temperature Measurement & Control", Peter Peregrinus Ltd., London, United Kingdom, 1988.
7. B. E. Noltingk, "Instrument Technology: Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.
8. T. Giallorenzi, J. Bucaro, A. Dandridge, J. Cole, "Optical Fiber Sensors Challenge the Competition," IEEE Spectrum, September 1986.
9. T. Giallorenzi, J. Bucaro, A. Dandridge, G. Sigel, J. Cole, "Optical Fiber Sensor Technology," IEEE Journal of Quantum Electonics, April 1982.
10. K. Kyuma, S. Tai, T. Sauada, M.Nunoshita, "Fiber Optical Heterodyne Interometer for Vibration Measurements in Biological Systems," IEEE Journal of Quantum Electonics, April 1982.

Temperature Sensors

Instruments for measuring temperature can be divided into five separate classes according to the physical principle on which they operate. These principle are:

1. Thermal Expansion
2. Thermoelectric Effect
3. Resistance Change
4. Resonant Frequency
5. Radiative Heat Emission

SENSOR NAME : **Bimetallic Thermometer**

SENSOR INFORMATION

SUBSYSTEM: All	TECHNOLOGY: All	
SENSOR TYPE: TEMP	OPERATION: Thermal Expansion	
ACCURACY: ± 0.50 %	<u>Operational Environment</u>	POWER: 0.00 W*
MIN. RANGE: -75 °C	TEMP. RANGE: -75 to 1500 °C	WEIGHT: 0.00 LB*
MAX. RANGE: 1500 °C	PRESS. RANGE: ---	VOLUME: 0.00 FT^3*

* Design specific information, to be determined.

SENSOR DESCRIPTION:

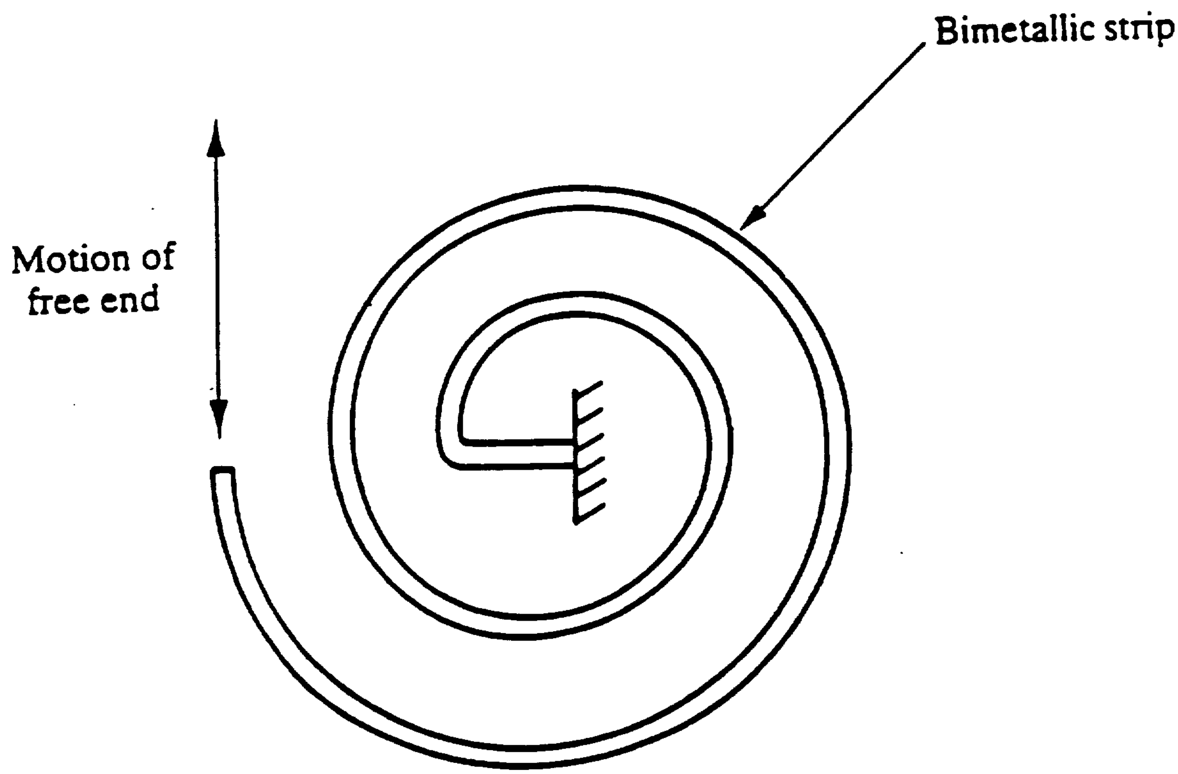
The bimetallic principle is probably more commonly known in connection with its use in thermostats. It is based on the fact that if two strips of different metals are bonded together, any temperature change causes a differential expansion and the bonded strip, if unrestrained, will deflect into a uniform circular arc. The radius of curvature (r) for most practicle cases is determined from the relationship

$r = 2t/[3(\partial a-\partial b)(T1-T2)]$ where: t = total bonded strip thickness, (.0005<t<.125, practicle)
∂a & ∂b = thermal-expansion coefficients, (strips a & b)
T2-T1 = change in temperature

If the magnitude of bending is measured, the bimetallic device becomes a thermometer. The measurement sensitivity is increased further by choosing the pair of materials carefully such that the degree of bending is maximized, with invar and brass being commonly used. In the bimetallic thermostat, the strip is used as a switch in control applications. Accuracy of the order of ±0.5% to ±1% of scale range may be expected in bimetal thermometers of high qualitiy.

REFERENCE:

Alan S. Morris, "Principles of Measurement and Instrumentation", Prentice Hall, 1988.
Ernest O. Doebelin, "Measurement Systems Application and Design", McGraw-Hill, 1983.
"The OMEGA complete Temperature Measurement Handbook and Encyclopedia", Vol. 27, Copyright 1989.



H.1 Bimetallic Thermometer

SENSOR NAME : **Pressure Thermometer**

SENSOR INFORMATION

SUBSYSTEM: All		TECHNOLOGY: All	
SENSOR TYPE: TEMP		OPERATION: Thermal Expansion	
ACCURACY: ± 0.50 %	Operational Environment	POWER:	0.00 W*
MIN. RANGE: -250 °C	TEMP. RANGE: -250 to 2000 °C	WEIGHT:	0.00 LB*
MAX. RANGE: 2000 °C	PRESS. RANGE: ---	VOLUME:	0.00 FT^3*

* Design specific information, to be determined.

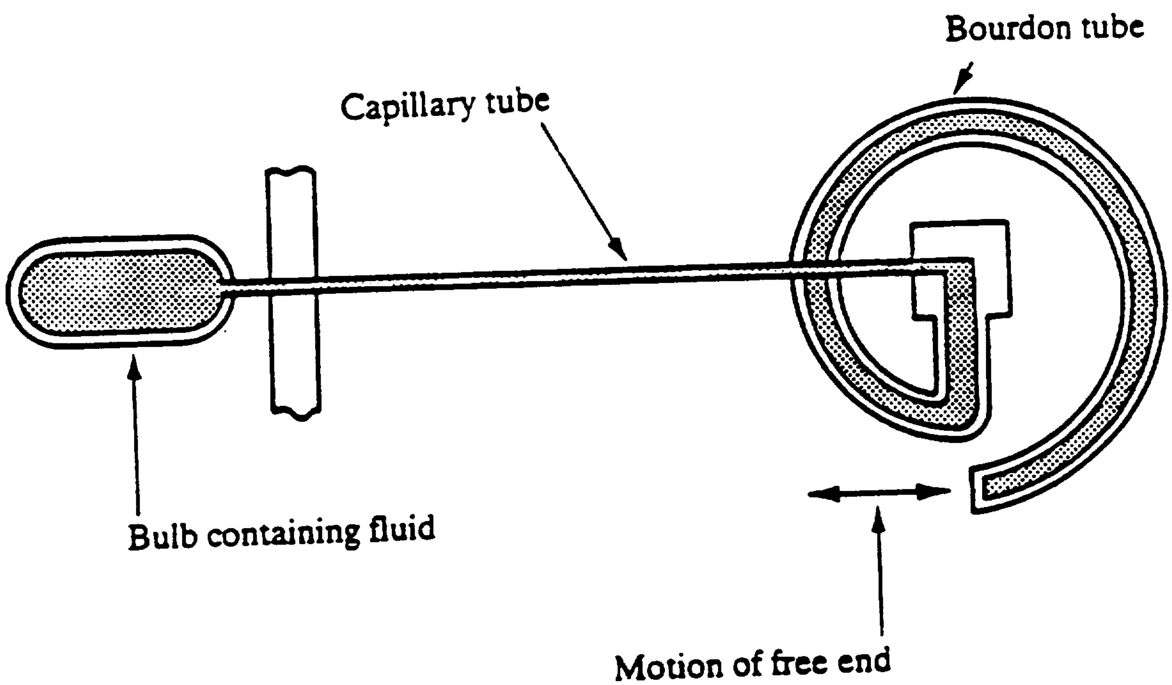
SENSOR DESCRIPTION:

The pressure thermometer measures the variation in pressure of a liquid, gas, or vapor constrained inside a bulb of fixed volume as the temperature changes. Pressure thermometers consist of a sensitive bulb, an interconnecting capillary tube, and a pressure-measuring device such as a Bordon tube, bellows, or diaphragm. When the system is completely filled with a liquid (mercury and xylene are common) under an initial pressure, the compressibility of the liquid is often small enough relative to the pressure gage, $\Delta V/\Delta p$, that the measurement is essentially one of volume change. For gas or vapor systems, the reverse is true, and the basic effect is one of pressure change at constant volume.

Liquid-filled systems cover a linear range of -100 to 400°C with xylene and -40 to 630°C with mercury. Elevation differences between the bulb and pressure sensor different from those at calibration may cause slight errors. Gas-filled systems operate over a linear range of -240 to 650°C. Some gas-filled pressure thermometers cover higher temperature ranges but become nonlinear. Vapor pressure systems operate over a linear range of -40 to 320°C. The accuracy of pressure thermometers under the best conditions is of the order ±0.5% of the scale range.

REFERENCE:

Alan S. Morris, "Principles of Measurement and Instrumentation", Prentice Hall, 1988.
Ernest O. Doebelin, "Measurement Systems Application and Design", McGraw-Hill, 1983.



H.2 Pressure Thermometer

SENSOR NAME : **Quartz Thermometer**

SENSOR INFORMATION

SUBSYSTEM: All

TECHNOLOGY: All

SENSOR TYPE: TEMP

OPERATION: Resonant Frequency Change

ACCURACY:	± 0.10 %	Operational Environment		POWER:	0.00 W*
MIN. RANGE:	-50 °C	TEMP. RANGE:	-50 to 250 °C	WEIGHT:	0.00 LB*
MAX. RANGE:	250 °C	PRESS. RANGE:	---	VOLUME:	0.00 FT^3*

* Design specific information, to be determined.

SENSOR DESCRIPTION:

The quartz thermometer makes use of the principle that the resonant frequency of a material, such as quartz, is a function of temperature, and thus enables temperature changes to be translated into frequency changes. The temperature-sensing element consists of a quartz crystal enclosed within a probe (sheath). The crystal is connected so as to form the resonant element within an electronic oscillator. Measurement of the oscillator frequency therefore allows the measured temperature to be calculated. The quartz thermometer has a very linear output characteristic over the temperature range between -50 to 250°C, with a measurement accuracy of ±0.1% within this range.

REFERENCE:

Alan S. Morris, "Principles of Measurement and Instrumentation", Prentice Hall, 1988.
Donald G. Fink & Donald Christiansen, "Electronics Engineers' Handbook, 3rd Edition", McGraw-Hill, 1989.

Sensor Figure Not Included

SENSOR NAME : **Resistance Thermometer**

SENSOR INFORMATION

SUBSYSTEM: All		TECHNOLOGY: All	
SENSOR TYPE: TEMP		OPERATION: Resistance Change - Metal	
ACCURACY: ± 0.40 %	Operational Environment	POWER:	0.00 W*
MIN. RANGE: -270 °C	TEMP. RANGE: -270 to 1100 °C	WEIGHT:	0.00 LB*
MAX. RANGE: 1100 °C	PRESS. RANGE: ---	VOLUME:	0.00 FT^3*

* Design specific information, to be determined.

SENSOR DESCRIPTION:

The resistance thermometers is a more linear device than thermocouples, but still requires curve-fitting. Resistance thermometers rely on the principle that the resistance of a metal varies with temperature according to the Callendar-Vann Dusen relationship:

$$R = Ro\ (1 + A1*T + A2*T^2 + ... + An*T^n)$$

Platinum, nickel, and copper are the most commonly used and generally require constants A2, A3, and A3, respectively, for a highly accurate representation. Only constants A1 may be used since respectable linearity may be achieved over limited ranges, giving

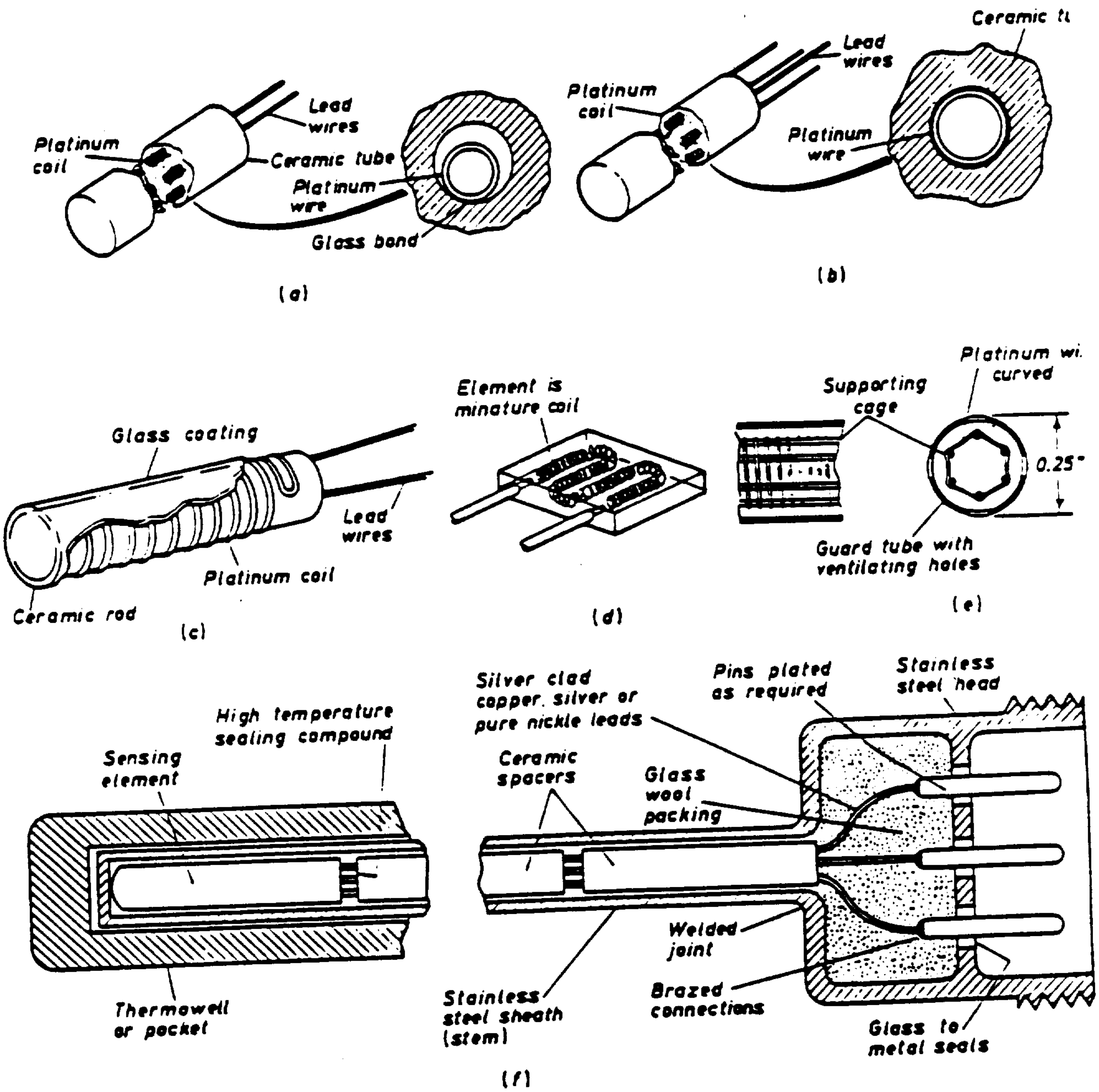
$$R = Ro\ (1 + A1*T).$$

The most commonly used platinum is linear within ±0.4% over the ranges -200 to -75°C and -75 to 150°C, ±0.3% from -18 to 150°C, ±0.25% from -200 to -130°C, ±0.2% from -18 to 95°C, and ±1.2% from 160 to 820°C. The working range of platinum is -270 to 1000°C, copper is -200 to 260°C, nickel -200 to 430°C, tungsten is -270 to 1100°C.

Resistance thermometer elements range in resistance from about 10Ω to as high as 25kΩ. Higher resistance elements are less affected by lead-wire and contact resistance variations, and since they generally produce large voltage signals, spurious thermoelectric emf's due to joining of dissimilar metals are usually negligible. Since resistance thermometers requires supply current, self-heating can appear as a measurement error. This can be addressed by using the minimum current that will give the required resolution or using the largest resistance thermometer that will still good response time.

REFERENCE:

Alan S. Morris, "Principles of Measurement and Instrumentation", Prentice Hall, 1988.
Ernest O. Doebelin, "Measurement Systems Application and Design", McGraw-Hill, 1983.
"The OMEGA complete Temperature Measurement Handbook and Encyclopedia", Vol. 27, Copyright 1989.



H.3 Construction of Resistance Thermometers

SENSOR NAME : **Thermistors**

SENSOR INFORMATION

SUBSYSTEM: All			TECHNOLOGY: All		
SENSOR TYPE: TEMP			OPERATION: Resistance Change - Semiconductor		
ACCURACY:	± 0.20 %	<u>Operational Environment</u>		POWER:	0.00 W*
MIN. RANGE:	-200 °C	TEMP. RANGE:	-200 to 1000 °C	WEIGHT:	0.00 LB*
MAX. RANGE:	1000 °C	PRESS. RANGE:	---	VOLUME:	0.00 FT^3*

* Design specific information, to be determined.

SENSOR DESCRIPTION:

Thermistors are manufactured from semiconductor material prepared from oxides of the iron group of metals, such as chromium, cobalt, iron, manganese, and nickel. The resistance of such materials varies with temperature according to the following expression:

$R = Ro \exp[\beta(1/T - 1/To)]$ where: R = resistance at T, Ro = resistance at To
β = constant, characteristic of material ($\approx$ 4000)
T, To = temperatures (K), typically 298 K

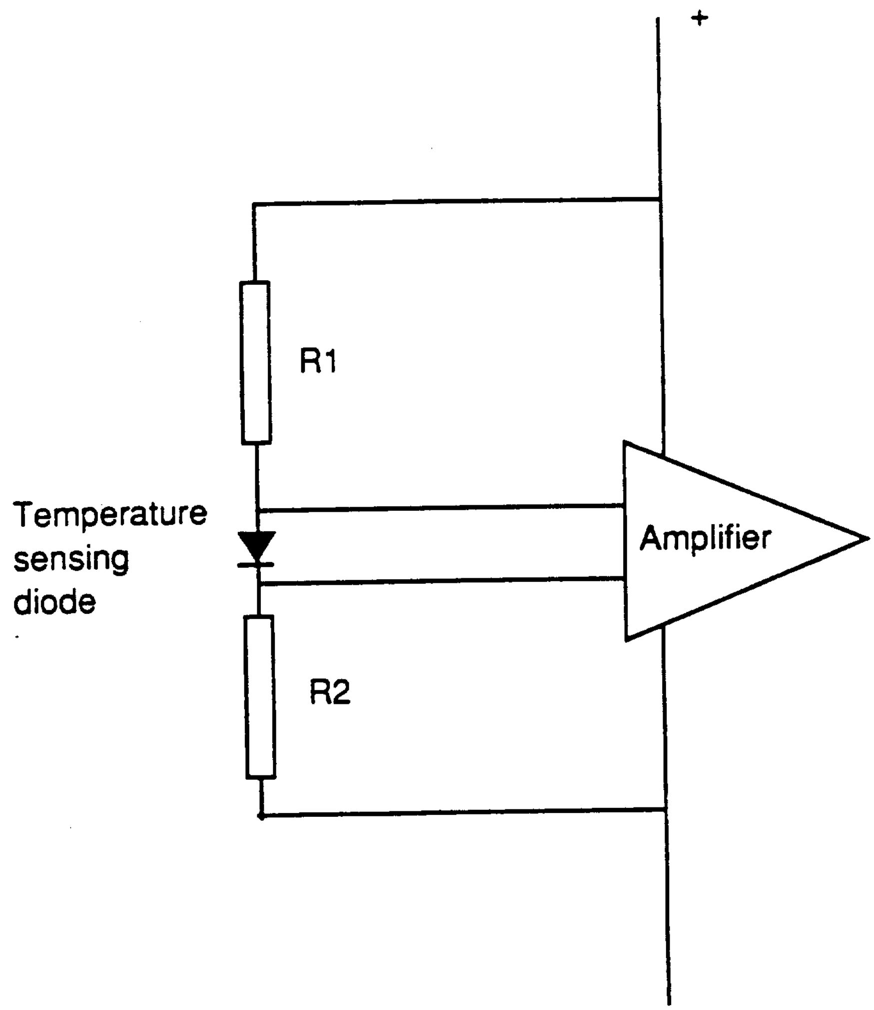
This relationship exhibits a larger negative temperature coefficient (i.e. the resistance decreases as the temperature increases), and so is fundamentally different from the relationship for the resistance thermometer, which shows a positive temperature coefficient. Because of their nonlinear (essentially negative exponential) resistance-vs.- temperature characteristics, they are particularly useful when a large resistance change is needed for a narrow range of temperature. The usable temperature range is from about -200 to 1000°C; however, a single thermistor cannot be used over such a large range. An individual thermistor curve can be very closely approximated through use of the Steinhart-Hart equation:

$1/T = A + B(\ln R) + C(\ln R)^3$ where: A,B,C = curve-fitting constants found by selecting 3 data points on the published data curve and solving 3 simultaneous equations. (accuracy approaches ±.02°C)

The major advantage of thermistors are their relatively low cost, small size, stability, and sensitivity. But because of their small size, the excitation power must be kept low to avoid errors due to self-heating.

REFERENCE:

Alan S. Morris, "Principles of Measurement and Instrumentation", Prentice Hall, 1988.
Ernest O. Doebelin, "Measurement Systems Application and Design", McGraw-Hill, 1983.
Donald G. Fink & Donald Christiansen, "Electronics Engineers' Handbook, 3rd Edition", McGraw-Hill, 1989.
"The OMEGA complete Temperature Measurement Handbook and Encyclopedia", Vol. 27, Copyright 1989.



H.4 Semicondutor Temperature Sensor

SENSOR NAME : **Thermocouple**

SENSOR INFORMATION

SUBSYSTEM: All		TECHNOLOGY: All	
SENSOR TYPE: TEMP		OPERATION: Thermoelectric Effect	
ACCURACY: ± 0.40 %	Operational Environment	POWER:	0.00 W*
MIN. RANGE: -270 °C	TEMP. RANGE: -270 to 2320 °C	WEIGHT:	0.00 LB*
MAX. RANGE: 2320 °C	PRESS. RANGE: ---	VOLUME:	0.00 FT^3*

* Design specific information, to be determined.

SENSOR DESCRIPTION:

Thermoelectric effect instruments rely on the physical principles that, when any two different metals are connected together, an e.m.f., which is a function of the temperature, is generated at the junction between the metals. The general form of this relationship is:

$$e = a1\,T + a2\,T^2 + a3\,T^3 + \dots an\,T^n$$

For certain pairs of materials, the higher powers of the T terms (a2 T,a3 T,...an T) are approximately zero and the e.m.f./temperature relationship is approximately linear according to e = a1 T. Thermocouples are prone to contamination by various metals, protection takes the form of enclosing the thermocouple in a sheath (refer to OMEGA Ref. for compatible working environments). The most common types of thermocouples avalible are listed below.

Type	Temp. Range (°C)	Output, emf (mV)	Accuracy (greatest value)
J (Fe/Cu-Ni)	0 to 750	0 to 42.3	1.1°C or 0.4%
K (Ni-Cr/Ni-Al)	-200 to 1250	-6.0 to 50.6	1.1°C or 0.4%
T (Cu/Cu-Ni)	-200 to 350	-5.6 to 17.8	0.5°C or 0.4%
E (Ni-Cr/Cu-Ni)	-200 to 900	-8.8 to 68.8	1.0°C or 0.4%
R (Pt-13% RH/Pt)	0 to 1450	0 to 16.7	0.6°C or 0.1%
S (Pt-10% RH/Pt)	0 to 1450	0 to 15.0	0.6°C or 0.1%
B (Pt-30% RH/Pt-6% RH)	0 to 1700	0 to 12.4	0.5% over 800°C
N (Ni-Cr-Si/Cu-Ni)	-270 to 1300	-4.3 to 47.5	1.1°C or 0.4%
G (W/W-26% Re)	0 to 2320	0 to 38.6	1.0%
C (W-5% Re/W-26% Re)	0 to 2320	0 to 37.1	1.0%
D (W-3% Re/W-25% Re)	0 to 2320	0 to 39.5	1.0%

REFERENCE:

Alan S. Morris, "Principles of Measurement and Instrumentation", Prentice Hall, 1988.
Ernest O. Doebelin, "Measurement Systems Application and Design", McGraw-Hill, 1983.
Donald G. Fink & Donald Christiansen, "Electronics Engineers' Handbook, 3rd Edition", McGraw-Hill, 1989.
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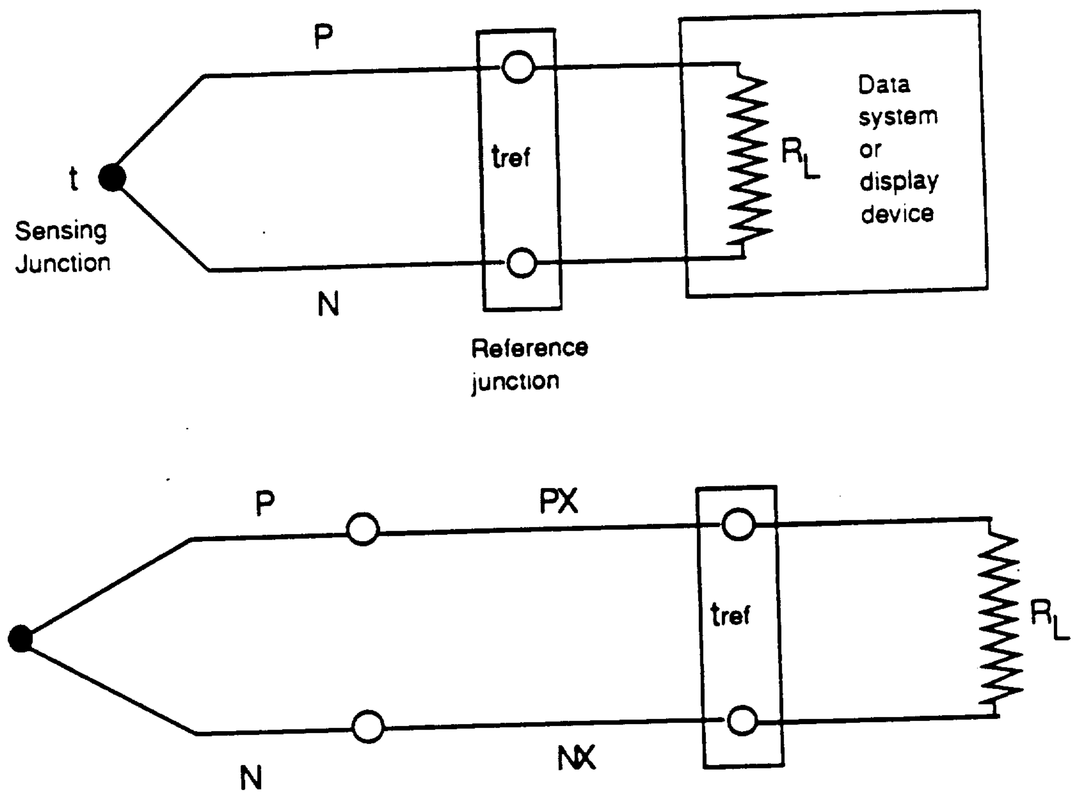


H.5 Basic Thermocouple Wiring Diagram

SENSOR NAME : **Thermopile**

SENSOR INFORMATION

SUBSYSTEM: All		TECHNOLOGY: All	
SENSOR TYPE: TEMP		OPERATION: Thermoelectric Effect	
ACCURACY: ± --- %	Operational Environment	POWER:	0.00 W*
MIN. RANGE: -270 °C	TEMP. RANGE: -270 to 2320 °C	WEIGHT:	0.00 LB*
MAX. RANGE: 2320 °C	PRESS. RANGE: ---	VOLUME:	0.00 FT^3*

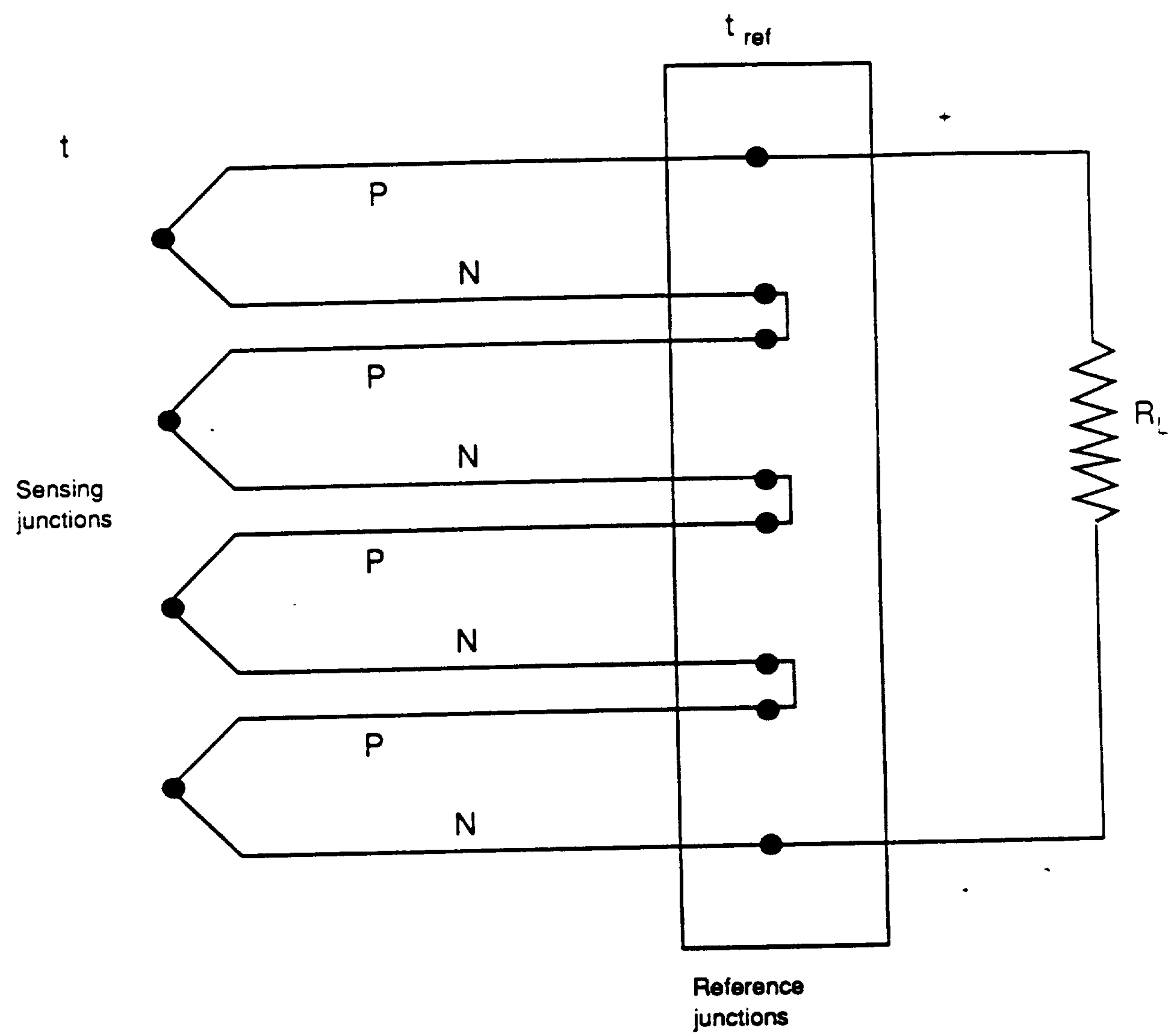
* Design specific information, to be determined.

SENSOR DESCRIPTION:

The thermopile is the name given to a temperature measuring device which consists of several thermocouples connected together in series, such that all measuring junctions are exposed to the temperature being measured and all reference junctions exposed to one reference temperature. By connecting n thermocouples together in series, the measurement sensitivity is increased by a factor of n. A typical chromel-constantan thermopile has 25 couples and produces about 1 mV/°C, giving a measurement resolution of 0.001°C. Because thermopiles consist of thermocouples, their operational requirements and application design considerations are the same, with the exception of temperature measurement sensitivity.

REFERENCE:

Alan S. Morris, "Principles of Measurement and Instrumentation", Prentice Hall, 1988.
Ernest O. Doebelin, "Measurement Systems Application and Design", McGraw-Hill, 1983.



H.6 Basic Thermopile Wiring Diagram

SENSOR NAME : **Radiation Pyrometer**

SENSOR INFORMATION

SUBSYSTEM: All	TECHNOLOGY: All	
SENSOR TYPE: TEMP	OPERATION: Radiative Heat Emission	
ACCURACY: ± 0.05 %	<u>Operational Environment</u>	POWER: 0.00 W*
MIN. RANGE: -50 °C	TEMP. RANGE: ???? °C	WEIGHT: 0.00 LB*
MAX. RANGE: 4000 °C	PRESS. RANGE: ---	VOLUME: 0.00 FT^3*

* Design specific information, to be determined.

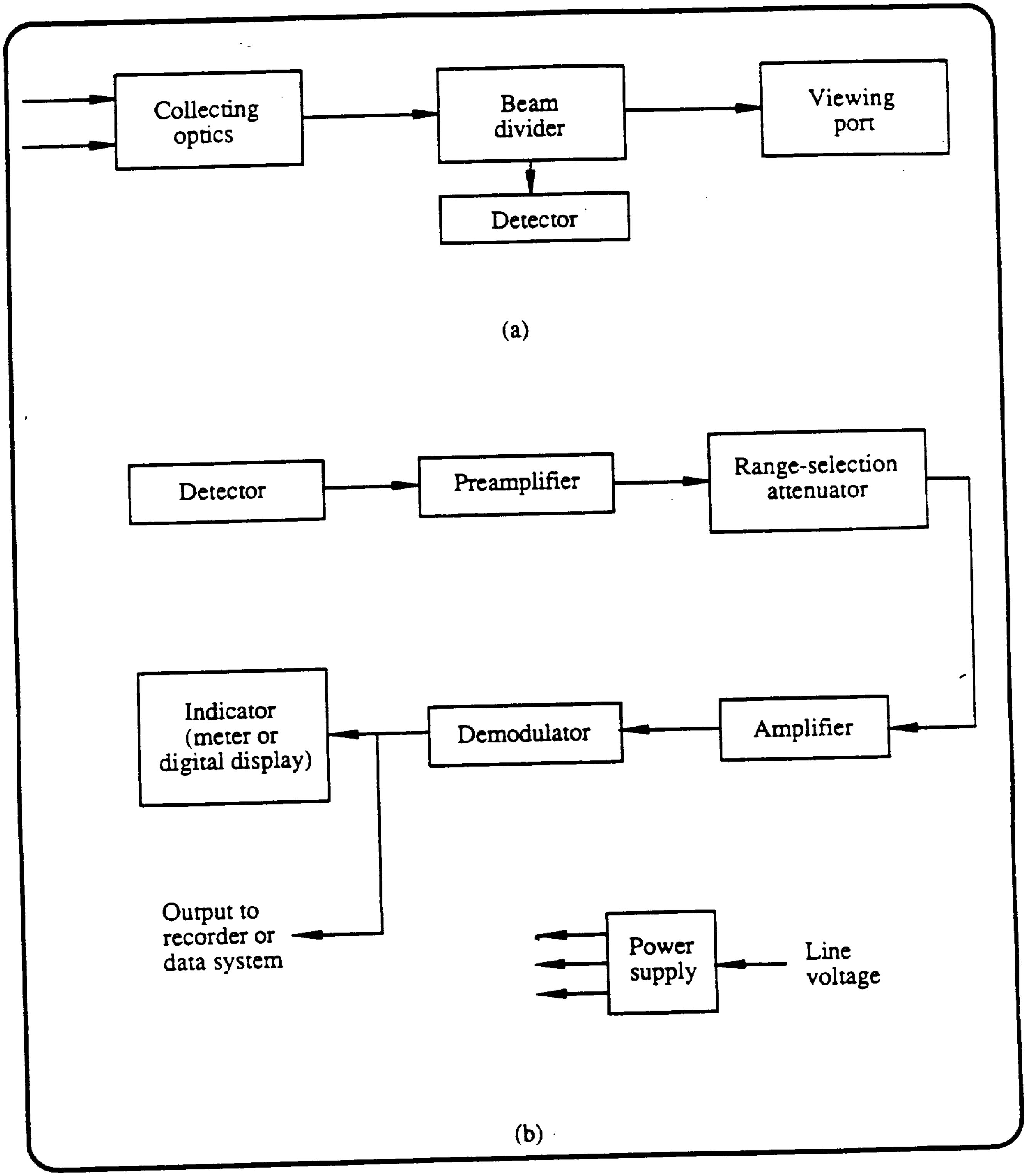
SENSOR DESCRIPTION:

Radiation pyrometers are noncontacting temperature transducers which respond to radiative heat transfer from the measured suface on material. Principle of these meter is described by the Stefan-Boltzman law, that the intensity of radiation emitted by an object is depend on the temperature of the object. This radiation occurs primarily in the infrared portion of the electromagnetic spectrum. Typical radiation pyrometers use optical lens or mirror system which focuses the radiation on a thermoelectric or resistive sensing element (energy detector). The output of the sensing element can be coorrelated to the temperature of the measured suface. Radiation pyrometers are used primarily for high-temperature measurements up to about 4000°C, but have also been found useful for noncontacting measurements in the medium temperature range down to about -50°C.

The radiation detectors used in radiation pyrometers is either a thermal detector, which measures the temperature rise in a black body at the focal point of the optical system, or a photon detector. Thermopiles, resistance thermometers, and thermistors are all used as thermal detectors. Photodetectors are usually of the photoconductive or photovoltaic type.
Types of radiation pyrometers:
- Broad-band: measures radiation across the whole frequence spectrum; uses a thermal detector; accuracy of ±0.05% full scale in best instruments and ±0.5% in cheapest; time constants as short as 0.1s for high temp. and as much as 2s for low temp.; temp. range between -20 to 1800°C.
- Chopped broad-band: measures radiation across the whole frequence spectrum with periodic interrupts in the radiation reaching the detector; uses a thermistor; greater accuracy and resolution than that of the broard-band; time constants as short as 0.01s; temp. range between 20 to 1300°C.
- Narrow-band: measures radiation across the a limited frequence band; uses a photodetector; greater accuracy and resolution than that of the broard-band; time constants as short as 10μs; used to accurately measure a limited temperature range.
- Two-color: Splits radiation with two narrow-band filters before detection to reduce error due the emissivity problems; uses a two photodetectors; temp. range between 1500 to 4000°C.

REFERENCE:

Harry N. Norton, "Sensor and Analyzer Handbook", Prentice Hall, Inc., 1982.
James R. Leigh, "Temperature Measurement & Control", Peter Peregrinus Ltd., London, United Kingdom, 1988.
Alan S. Morris, "Principles of Measurement and Instrumentation", Prentice Hall, 1988.
Ernest O. Doebelin, "Measurement Systems Application and Design", McGraw-Hill, 1983.
B. E. Noltingk, "Instrument Technology: Measurement of Temperature and Chemical Composition", Butterworth & Co. Ltd, 1985.



H.7 Typical Pyrometer Diagrams for (a) Optics & (b) Electronics

SENSOR NAME : **Fiber Optic Thermometer**

SENSOR INFORMATION

SUBSYSTEM: All		TECHNOLOGY: All
SENSOR TYPE: TEMP		OPERATION: Frequency Modulation of Light
ACCURACY: ± 0.01 %	<u>Operational Environment</u>	POWER: 0.00 W*
MIN. RANGE: -50 °C	TEMP. RANGE: -50 to 2000 °C	WEIGHT: 0.00 LB*
MAX. RANGE: 2000 °C	PRESS. RANGE: ---	VOLUME: 0.00 FT^3*

* Design specific information, to be determined.

SENSOR DESCRIPTION:

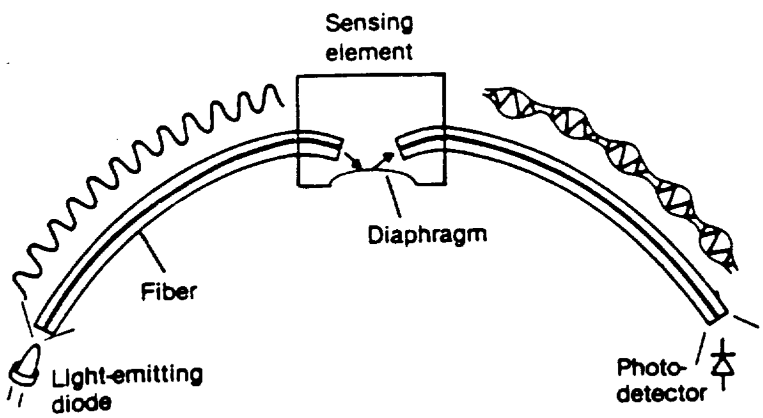
Curremtly, the two variations of fiber-optic thermometers are the external intensity modulated type and the two-fiber phase modulation type. Fiber-optic temperature sensors have been available commercially for many years. The earlier type (external intensity modulated) carries infrared energy radiated into it by a high-temperature process to a detector. It can measure overa range of 300 to 2000°C with an accuracy of ±1°C. More recently, the Luxtron Corp. developed its Fluoroptic thermometer, based on the temperature- dependent fluorescence of materials placed at the end of a fiber-optic probe. Other sensors use temperature- dependent effects in semiconductors, liquid crystals, or refractive polymers. These external modulation sensors are accurate within ±0.2°C in the range of -50 to 150°C.

Experimental temperature sensors of the two-fiber (phase modulation) interferometric class are incredibly sensitive, detecting variations as small as a millionth of a degree. They can also be designed to respond to temperature fluctuations many times higher in frequency than those measurable with other technologies. Currently availible two-fiber phase modulation sensors provide a operational temperature of 0 to 100°C with an accuracy of ±0.001°C.

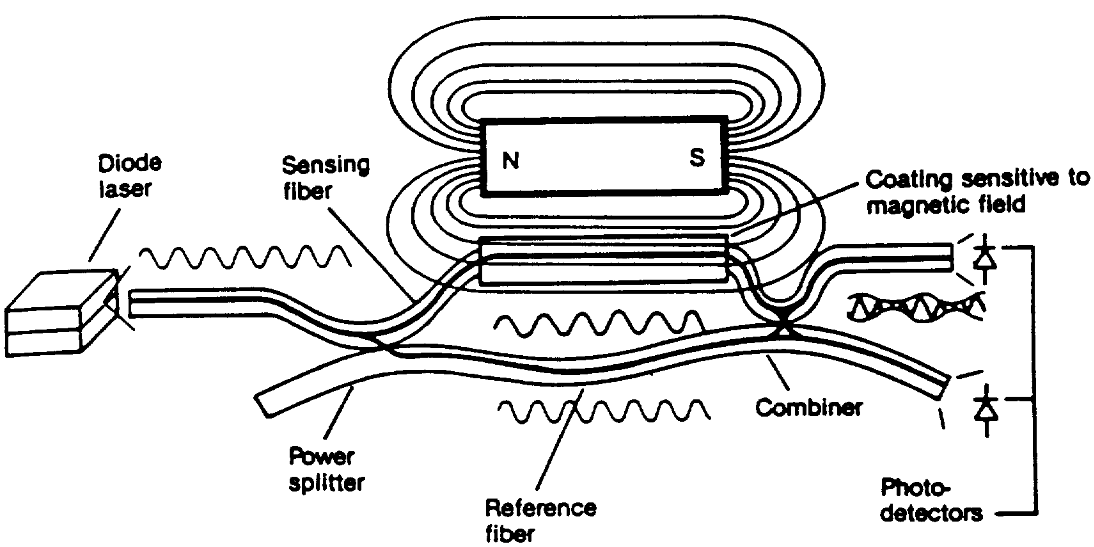
The dielectric properties (immunity to electrical noice), high temperature characteristics, resistance to corrosive gases and liquids, and small size of fiber-optic temperature sensors make them particularly applicable to probing inside operating machines such as transformers and generators, in engine cavities, high voltage divices, and in chemical processing. The extreme sensitivities of these sensors make them attractive for scientific instruments and offer previously unachievable performance.

REFERENCE:

T. Giallorenzi, J. Bucaro, A. Dandridge, J. Cole, "Optical Fiber Sensors Challenge the Competition," IEEE Spectrum, September 1986.
T. Giallorenzi, J. Bucaro, A. Dandridge, G. Sigel, J. Cole, "Optical Fiber Sensor Technology," IEEE Journal of Quantum Electonics, April 1982.
K. Kyuma, S. Tai, T. Sauada, M.Nunoshita, "Fiber Optical Heterodyne Interometer for Vibration Measurements in Biological Systems," IEEE Journal of Quantum Electonics, April 1982.



External intensity modulation



Two-fiber phase modulation

H.8 Fiber Optic Methods for Measuring Temperature