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Remote Monitoring of Air Quality in Underground Mines

UNITED STATES DEPARTMENT OF THE INTERIOR

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REMOTE MONITORING OF AIR QUALITY IN UNDERGROUND MINES

by

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ABSTRACT

This report presents several systems for continuously monitoring the quality of air in underground mines that are being developed by the Bureau of Mines. Underground stations measure methane, carbon monoxide and nitrogen dioxide concentrations, air velocity, and air temperature. This information is transmitted over a single telephone pair to central stations located on the surface. The central stations display alarms and the data is selectably displayed on digital panel meters.

INTRODUCTION

Toxic or explosive gases are often present in underground mines. For this reason, regulations have been promulgated requiring frequent tests for gases such as methane, carbon monoxide, and nitrogen dioxide.[2] The methods presently used to comply with these regulations use a variety of handheld or portable instruments that are carried to the places where measurements are to be made. Not only is there danger associated with this method, but it is a discontinuous method which may fail to detect dangerous conditions between measurement periods.

The Bureau of Mines has developed several systems that can be permanently installed in underground mines and will continuously monitor the environmental conditions in the mines. Measurements are transmitted to a central station, usually on the surface, where they can be recorded. Alarm circuits

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[2]U.S. Code of Regulations. Title 30--Mineral Resources; Chapter I--Mining Enforcement and Safety Administration, Department of the Interior; Subchapter O--Coal Mine Health and Safety; Part 57--Mandatory Safety Standards, Surface Coal Mines and Surface Work Areas of Underground Coal Mines. July 1, 1976, pp. 269-307.

_____. Title 30--Mineral Resources; Chapter I--Mining Enforcement and Safety Administration, Department of the Interior; Subchapter O--Coal Mine Health and Safety; Part 75--Mandatory Safety Standards--Underground Coal Mines. July 1, 1976, pp. 339-437.

have been incorporated into these systems to alert mining personnel when any measurement goes out-of-limit and could indicate a potentially dangerous condition.

In assembling these monitoring systems, the Bureau of Mines has attempted to use commercially available sensors and other components, although it has been necessary to supply some custom-made equipment.

This paper describes three mine monitoring systems that were assembled and installed in underground mines. Two of these systems were installed in coal mines and the third was installed in an iron mine. Although these systems have been operated satisfactorily some modifications need to be made to increase the reliability, to increase the accuracy, and for greater operating convenience.

SENSOR SELECTION

The basis for selection of sensors was their ability to measure environmental conditions in an underground mine that affect the health and safety of personnel working underground. The sensors selected measure air velocity, methane concentration, carbon monoxide concentration, temperature, and nitrogen dioxide (table 1).

TABLE 1. - Sensors used in remote stations

Parameter	Sensor	Range	Manufacturer
Air velocity.	J-Tec[1] anemometer, model VA-214.	50 to 3,000 ft/min	J-Tec Associates, Inc. 317 7th Ave., SE Cedar Rapids, Iowa 52401
Methane......	Canary, pellement only.	0 to 5 pct........	Bacharach Instrument Co. 625 Alpha Drive Pittsburgh, Pa. 15238
Carbon monoxide.	Ecolyzer, 2700....	0 to 500 ppm......	Energetics Science Co. 85 Executive Blvd. Elmsford, N.Y. 10523
	Ecolyzer, 3200....	0 to 50 ppm.......	Do.
Temperature..	YSI temperature probe, model 705.	0 to 105 ° F......	Yellow Springs Instrument Co. Yellow Springs, Ohio 45387
Nitrogen dioxide.	Dynascience NO_2 analyzer.	0 to 10 ppm.......	Dynascience Corp. 9100 Independence Ave. Chatsworth, Calif. 91311

[1]Use of specific brands and manufacturers is made for identification only and does not imply endorsement by the Bureau of Mines.

Air Velocity

A measurement of air velocity is important to assure that the mine ventilating system is operating properly. Air velocity measurements made simultaneously at strategic locations throughout a mine can also be a significant aid to ventilation engineers when adjustments are being made to the ventilation system.

Rotating vane anemometers were rejected because of poor service life due to corrosion of the blades and from dirt entering the bearings. Hot wire anemometers were rejected because they are too fragile or because they operate at excessive surface temperatures. Draft sensors, that operate on the vortex shedding principle, were selected.

Air movement is sensed by measuring the rate of vortex formation in the wake of a vortex generating rod. The output of this device is a frequency that is proportional to speed. A frequency-to-voltage converter provides a dc voltage output proportional to speed. These sensors have proved immune to moisture and dust in the mine atmosphere. The range of measurable air velocity is from 50 to 3,000 ft/min with an accuracy of 3 percent. Calibration of these devices should be checked on a monthly basis.

Methane Concentration

Methane concentration is measured to detect potentially explosive atmospheres. Catalytic combustion (pellement) sensors are used in a conventional Wheatstone bridge arrangement. The detector senses methane by the process of oxidation. This sensor measures volume-percent methane from 0 to 5 percent with an accuracy of approximately 5 percent of full scale. Service life of these sensors is not well-defined but appears to be in excess of 6 months. Calibration of these sensors should be done at intervals no greater than 1 month. If the sensor fails to calibrate it should be replaced.

Carbon Monoxide

Carbon monoxide sensors were included both to detect toxic concentrations of the gas for health reasons in working places and to act as fire detectors. Recently developed electrochemical cells for measurement of carbon monoxide were used. These cells detect carbon monoxide by chemically oxidizing the CO to CO_2. The current required for this reaction is proportional to the CO partial pressure. These devices have been used with limited success; the service life is approximately 3 to 4 months. One drawback is the necessity of supplying highly humidified air to the detecting cell, which is done by pumping the sample gas through a water chamber. These sensors should be calibrated weekly. A sensor that cannot be calibrated for full scale is assumed to be defective and should be replaced. New sensors are currently under development.

Air Temperature

Temperature rise above anticipated ambient could be an indication of fire or consistent machine overload. Thermistors with a linearizing resistance network are used to measure air temperature. These sensors have been used with notable success; they have operated for over 1 year without replacement at the Loveridge mine. Calibration should be checked periodically, preferably on a monthly basis. A measurement of the rate-of-change of temperature could be an indicator of fire. This parameter is derived from the air temperature measurement by an electronic circuit. This, in effect, increases the thermal sensitivity of the sensor and allows small but rapid changes in temperature to be noted.

Nitrogen Dioxide

Nitrogen dioxide may be present where diesel equipment is used or following blasting. A Dynascience nitrogen dioxide analyzer is used to measure this parameter. This device uses an electrochemical cell for sensing nitrogen dioxide. Calibration of the analyzer is achieved by a permeation tube located within the unit itself. The unit is calibrated automatically every 24 hours. This device was installed recently and it is under evaluation as to stability, repeatability, and accuracy.

LOVERIDGE MONITORING SYSTEM

The first system developed by the Bureau of Mines to monitor a large area of an underground coal mine was installed in the Loveridge mine of the Mountaineer Coal Co. in Fairview, W. Va. This system consists of five remote stations strategically located in return airways to measure methane and carbon monoxide concentrations, temperature, and air velocity. These data are transmitted to a central station located on the surface over a single telephone pair.

Remote Stations

The remote stations were assembled from some of the commercially available sensors listed in table 1. These sensors were placed in a Fiberglas enclosure along with signal-conditioning amplifiers. This enclosure also contains a digital readout for all sensor values, a six-channel data transmitter, a visual alarm, and an audible alarm.

The transmitter (Sonex model 164-02) consists of a pulse-amplitude-modulation-type commutator that time-multiplexes the analog signal from each sensor. A voltage-controlled oscillator converts the commutated signal to a frequency modulated signal for transmission. A line-matching amplifier provides connection to the data line for transmission. Included in the transmitter is a dual-tone receiver that gates the voltage-controlled oscillator output to the line when a specific tone code is received, thus causing a selected station to transmit data (fig. 1).

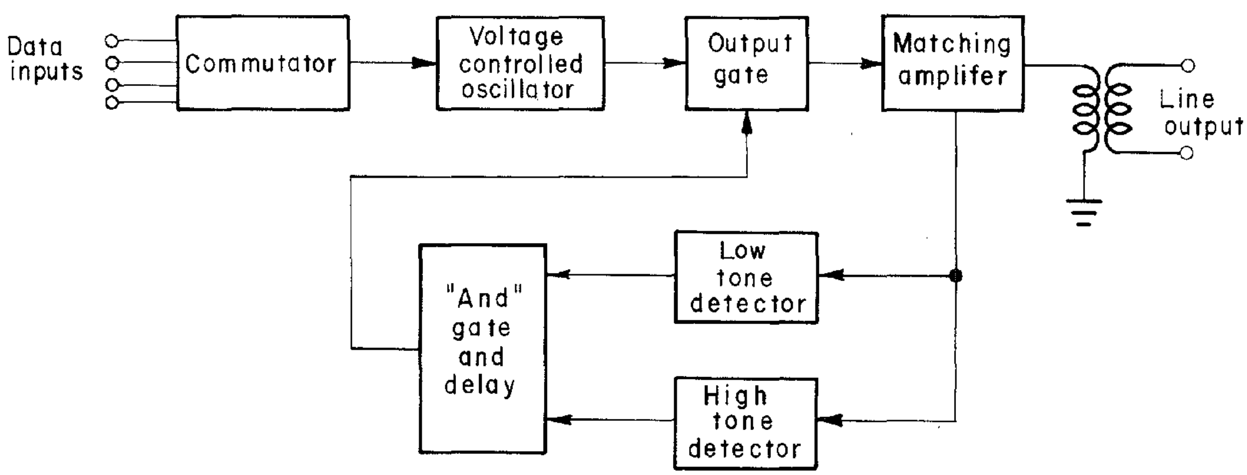

FIGURE 1. - Block diagram of data transmitter, Loveridge system.

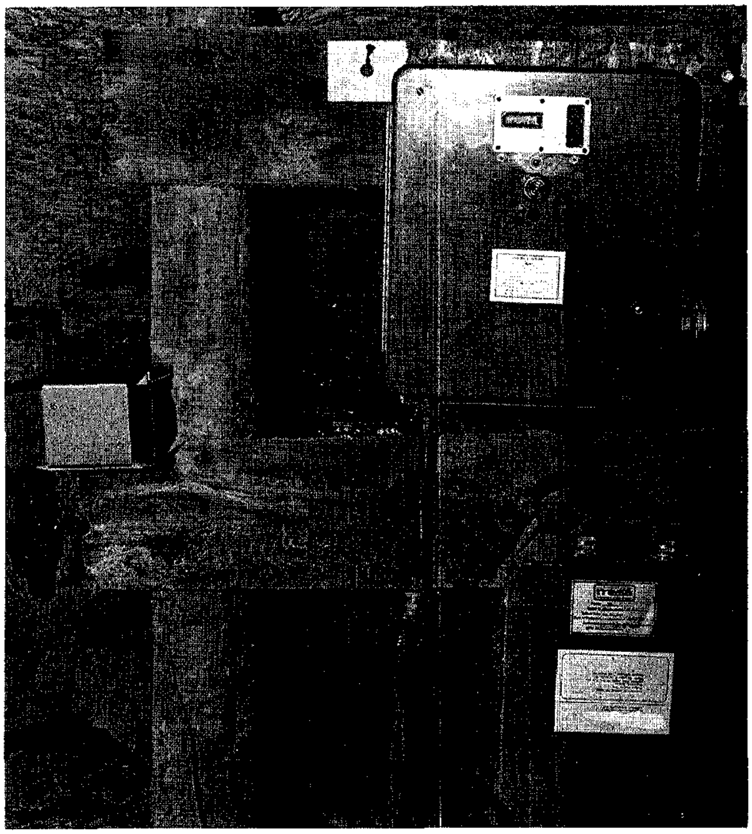

FIGURE 2. - Remote station, Loveridge system.

Included in each remote station is a single audible alarm, a single visual alarm, five individual visual alarms for sensor identification, and comparators for setting alarm levels. The alarm levels are variable throughout the range of the sensors; if any sensor exceeds a preset limit, its comparator will cause the corresponding visual alarm to flash and the master audible and visual alarms will be activated (fig. 2).

The output of each sensor may be observed on a digital panel meter; each reading is held for about 2 seconds and then automatically cycled to the next sensor. Any sensor value may be displayed by depressing a momentary contact switch.

Each remote station is powered from a 300-volt trolley line by a separate power supply (Ocenco, Inc., model PS-175). Each power supply consists of a dc-dc converter, transient suppressor, current- and voltage-limiting circuitry, and standby batteries. The batteries (Globe model GC-680) will operate the remote station for approximately 16 hours in the event of a power failure. Each remote station operates independently of all other stations.

Central Station

The central station consists of a frequency modulated (FM) receiver (Sonex model 156-02), an alarm annunciator panel, a digital display, and a switch matrix for selecting any sensor value for display (fig. 3).

The receiver is tuned to receive a single 14.5-kHz-FM carrier from all five stations. A pulse averaging discriminator removes the time-multiplexed signal from the carrier. A decommutator separates the six data channels from the signal supplied by the discriminator. The receiver also contains a dual-tone transmitter to individually address any one of the remote stations. Part of the tone transmitter is an automatic sequencer that will serially address the stations at a preset rate. Thus, in the automatic mode of operation, the receiver continuously polls each station in sequence for 2.5 seconds. A particular station may be polled by simply turning a station selector switch to

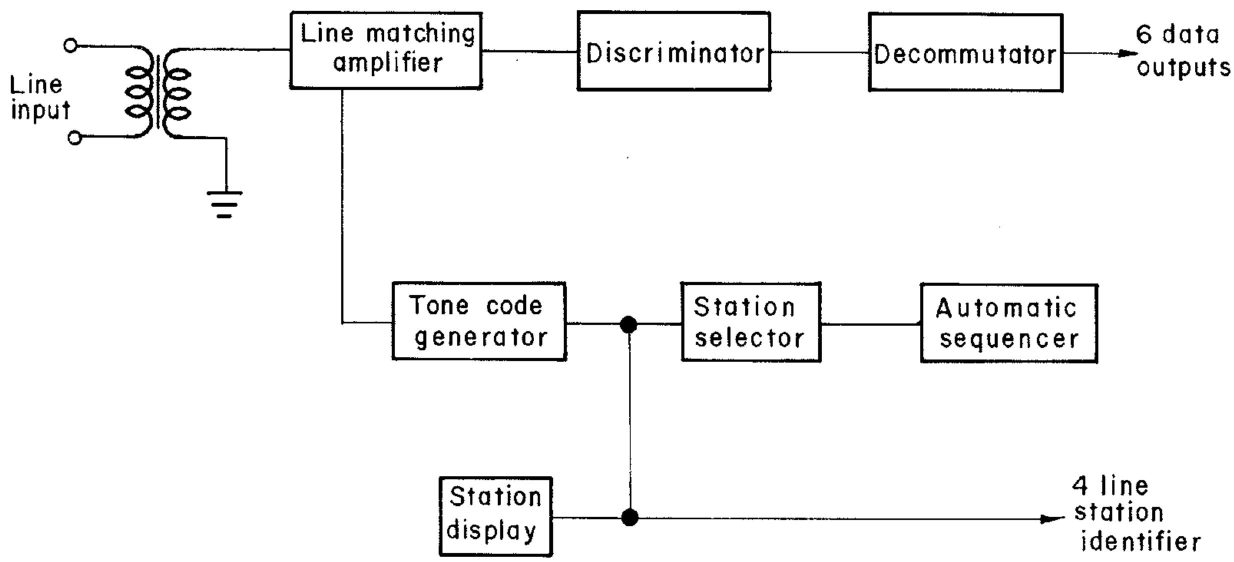

FIGURE 3. - Block diagram of FM receiver, Loveridge system.

that station; the receiver will then poll only that station continuously. A point to remember here is that in the manual mode (observing one station only), data from all other stations are preempted and cannot be displayed.

The alarm annunciator consists of a single master audible alarm, a 5- by 5-element visual matrix for individual sensor alarms, and comparators for setting alarm points. The alarm points are variable throughout the range of the sensors and are independent of the alarm points at the remote stations. Hence, the central station set points can be different from those at the remote sites. This feature was incorporated so that a local warning could be given before conditions lead to an alarm at the central station.

If any sensor value exceeds a preset limit, its respective comparator will light the proper matrix segment; thus indicating which sensor is out-of-limit. The audible alarm will also be activated and will continue to sound until the alarm condition is cleared or the alarm is manually reset.

A digital display, consisting of a digital panel meter, a station select switch, and a sensor select switch, is also provided at the central station. The display is activated by engaging both a station switch and a sensor switch. Any one of the five stations may be selected for data display; however, two stations cannot be displayed simultaneously. Upon selection, sensor data will be displayed in engineering units continuously until a new selection is made (fig. 4).

This monitoring system was not supplied with means for recording data. However, it is interfaced with a computer that was installed at the mine for other purposes. Data are stored on magnetic tapes (digital cassette) by utilizing the computer system and then summarized and tabulated using the output printer of the computer.

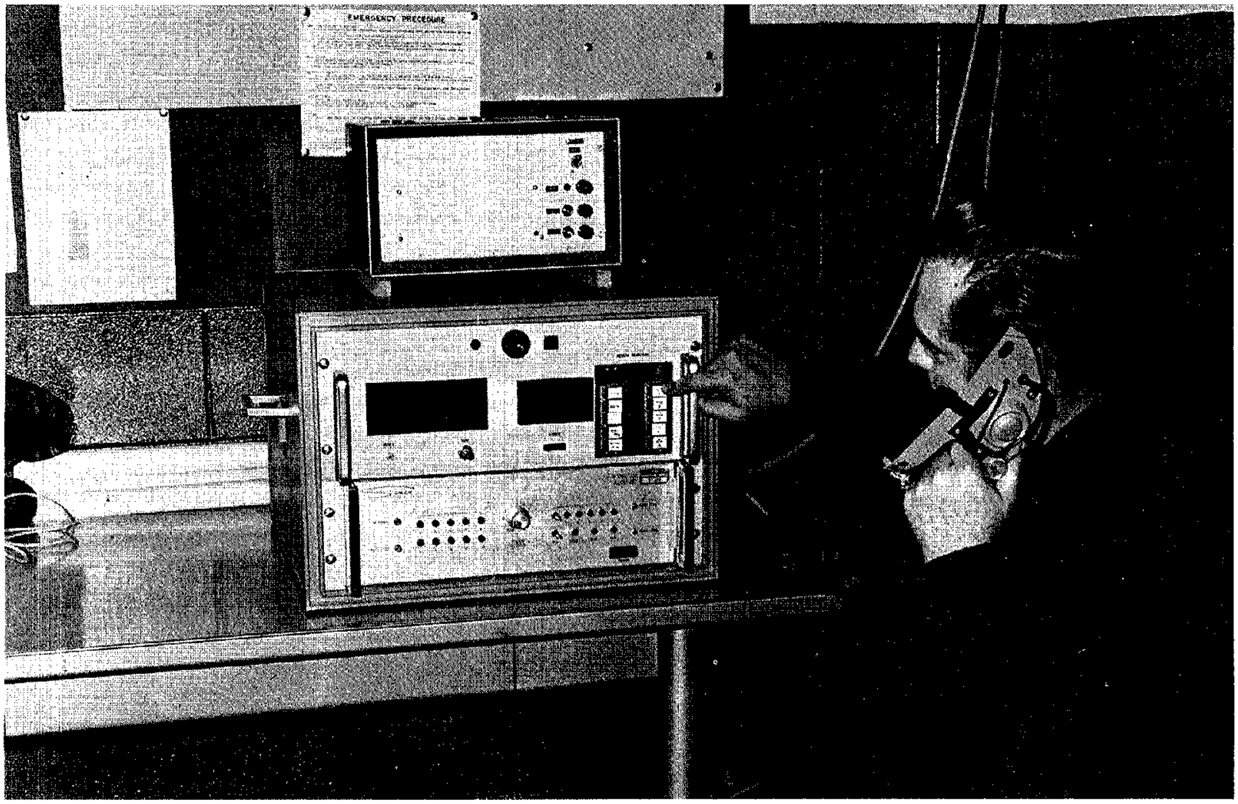

FIGURE 4. - Central station, Loveridge system.

Data from all of the remote sites may be observed at any time. Upon command from the operator, the computer will output data in the following format: date, time of day, and station number; sensor data are averaged over an 8-hour period. These values will be printed along with the low and high values for the period averaged.

GRACE MONITORING SYSTEM

A second monitoring system, developed jointly by the Bureau and RFL Industries, was installed in the Grace mine of Bethlehem Steel Corp. in Morgantown, Pa. This is a multilevel metal mine whose principal product is magnetite (iron ore). This monitoring system consists of five remote stations and monitors carbon monoxide and nitrogen dioxide concentrations, temperature, and air velocity (see table 1).

Remote Stations

The remote sites are located underground on level 6 at strategic points and consists of two parts; a transducer enclosure and a remote station enclosure. The transducer enclosure contains signal conditioning amplifiers for the sequentially collected sensor values. The remote station contains multiplexing circuitry for inputing data, the transmitter and receiver, the receiver filter, and a three-digit display for displaying all sensor values (fig. 5).

The output of each sensor is compared against a preset reference level for alarm conditions, adjustable within the remote unit; all values are continuously and sequentially presented on the remote unit's digital display. Indicating lights parallel the sequential display to designate the specific sensor being displayed. If a sensor value exceeds a preset limit, it causes the applicable channel indicating light to flash. Any alarm condition at the remote station simultaneously initiates an alarm at the central station. All sensor values may be observed sequentially, or any value may be observed continuously by depressing a momentary switch (fig. 6). Each remote station has its own dedicated frequency multiplexed channel. Remote station transmitters use the standard frequency channels from 1,860 to 2,940 Hz, which are standard, and 120 Hz-spacing FSK channels. This system, with a primary power of 110 vac at 60 cycles, is not a polling system, nor was it supplied with standby batteries. Each remote station continuously sends its serialized FSK data stream simultaneously with all other remote stations. Each remote station functions independently and may be operated without the central station.

Central Station

The central station is located on the surface in the mine office and contains FSK transmitters and receivers, control logic, digital displays, visual alarms, and an audible alarm. Station select switches are provided for displaying sensor data from the remote stations (fig. 7).

During normal nonalarm monitoring periods, the central station monitors only the presence of the data carrier from each remote station and ignores actual data being received (standby mode). If a remote station exceeds a preset limit, it automatically turns off its transmitter carrier. This loss of carrier is sensed by the central station, triggering an audible alarm. The lower half of the station select switch assigned to the affected remote station will flash red and the operator engages the switch that is flashing. Engaging this switch causes the affected remote station's transmitter to be turned back on and transmit its serial data to the display logic at the central station. The upper half of the switch that is flashing red will also light in amber to indicate that the remote station's digital data is being displayed (fig. 8).

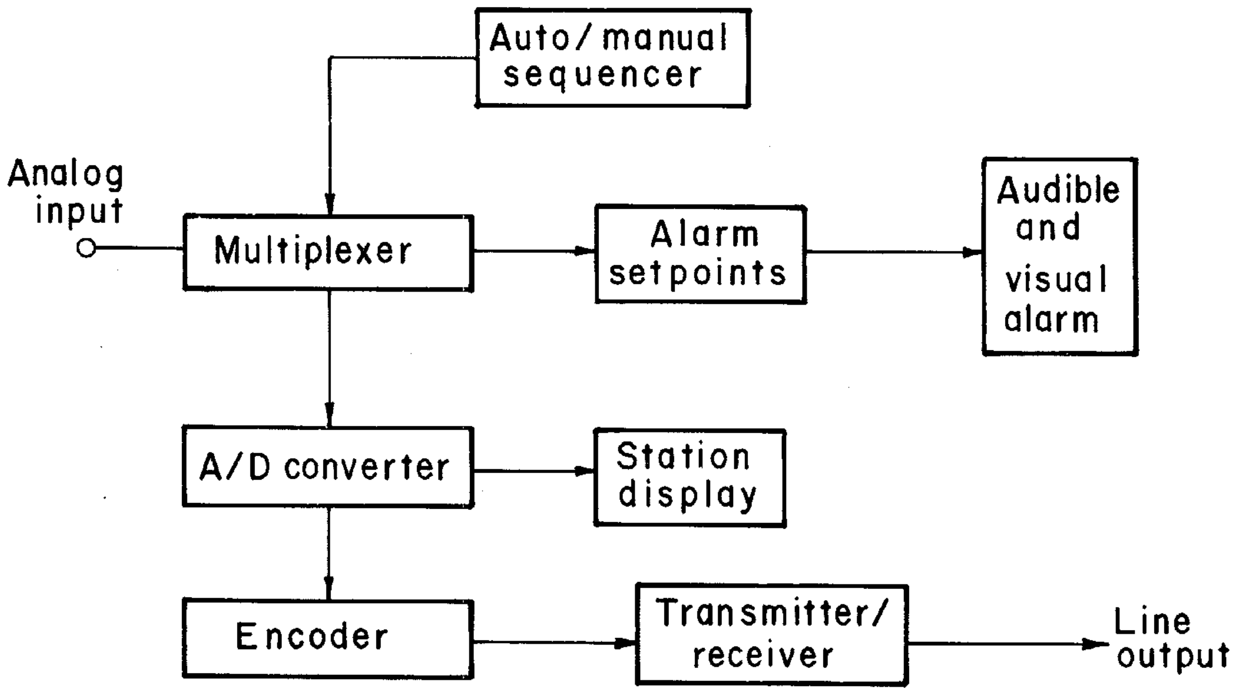

FIGURE 5. - Block diagram of remote station, Grace system.

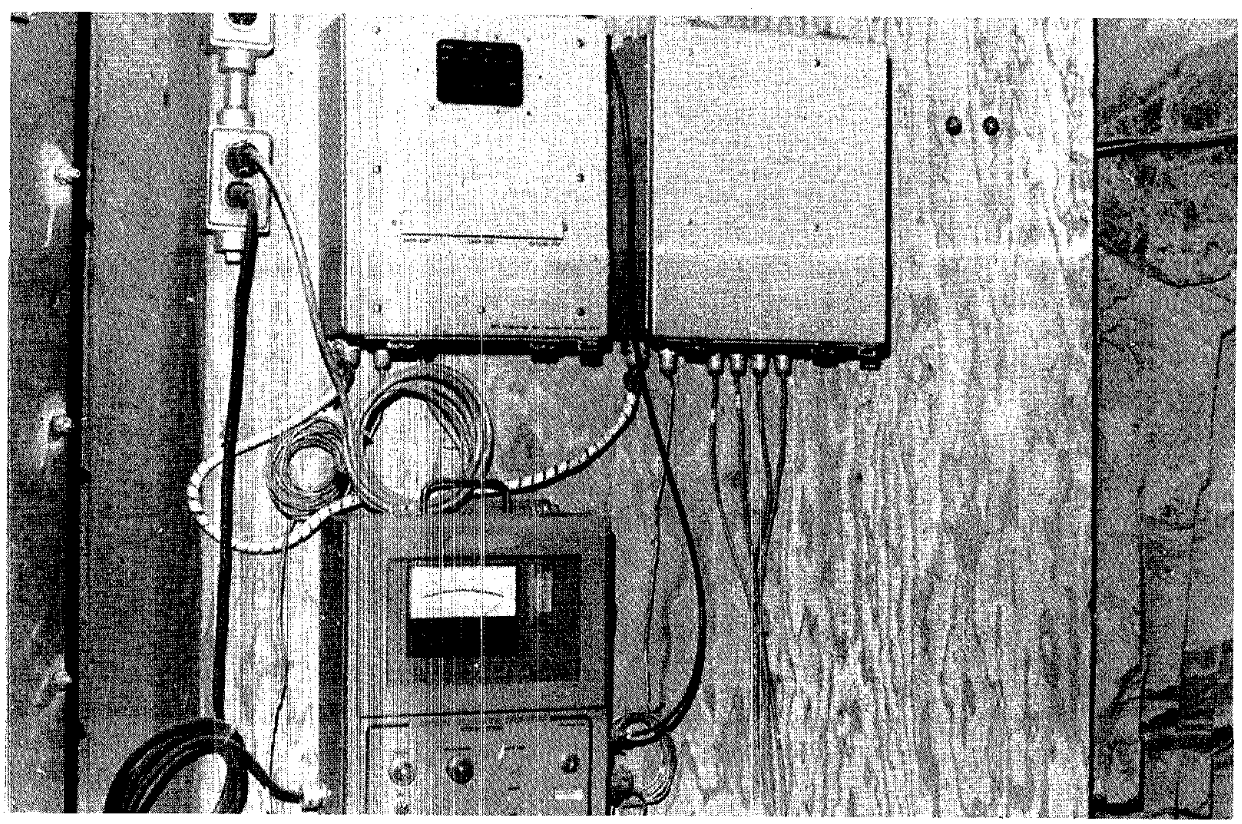

FIGURE 6. - Remote station, Grace system.

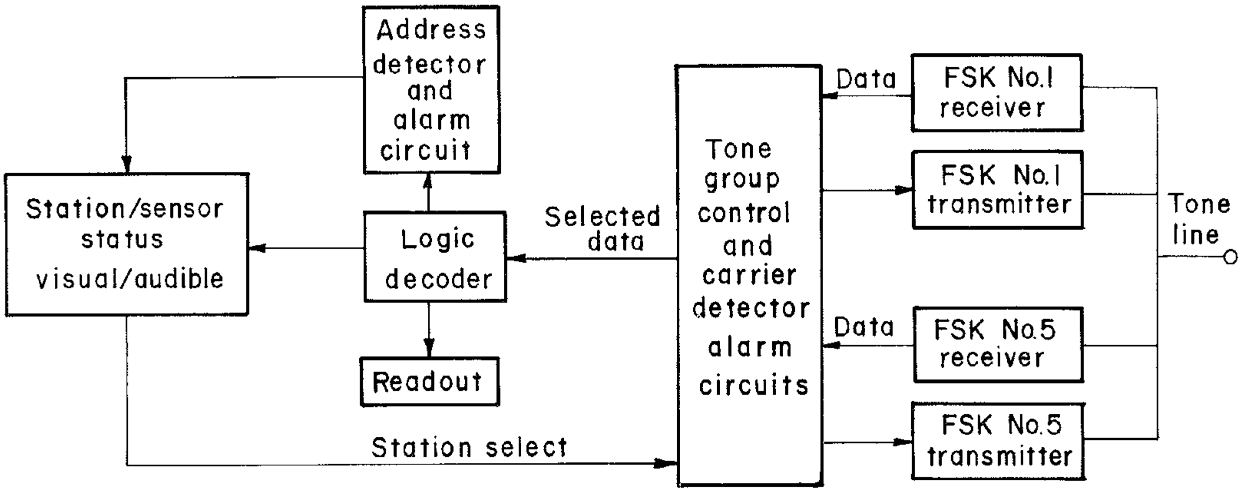

FIGURE 7. - Block diagram of central station, Grace system.

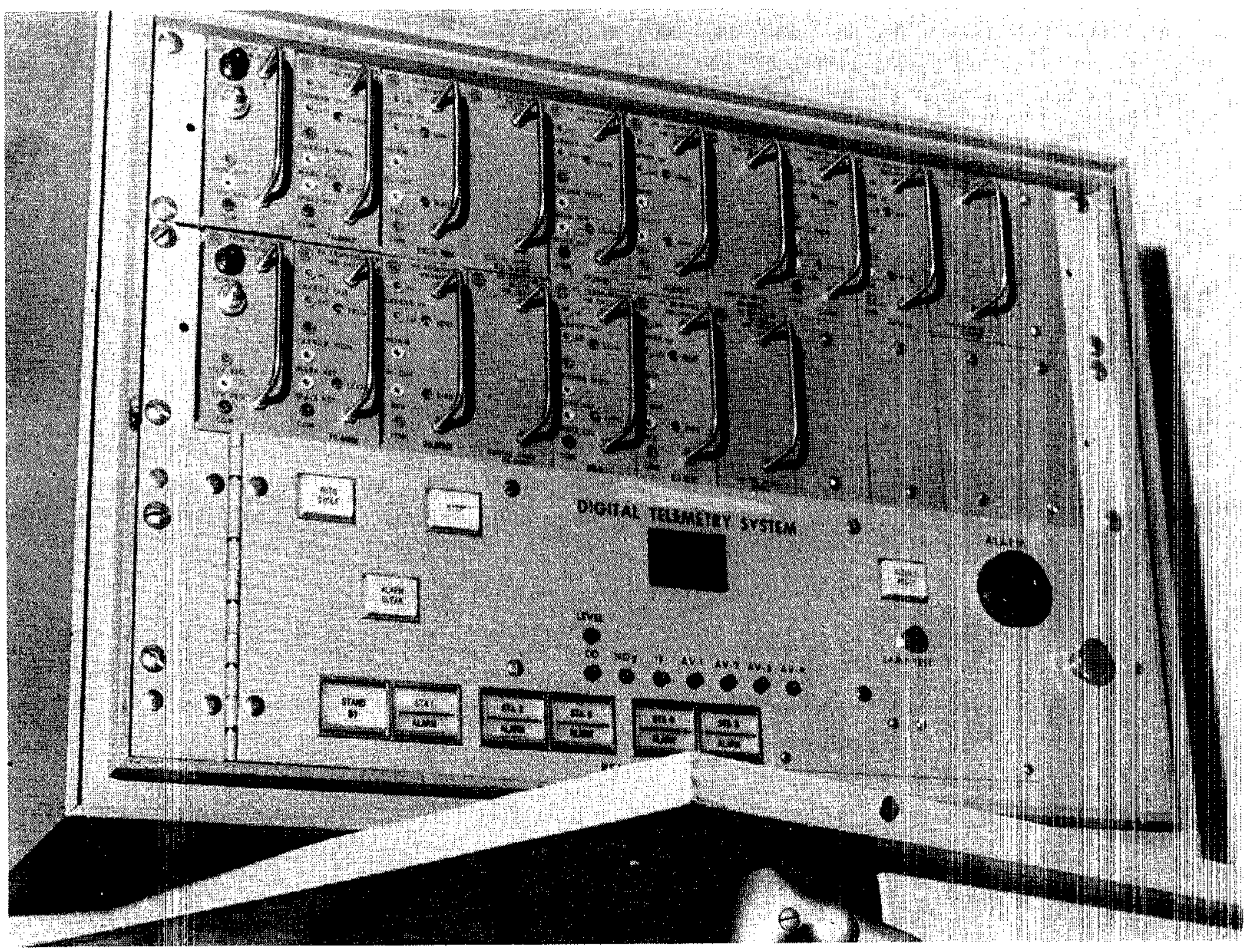

FIGURE 8. - Central station, Grace system.

As in the remote stations, the central station has indicating lights that parallel the sequential display designating the specific sensor value being read. When an alarm value is scanned, the indicating light assigned to the affected channel will flash each time its data is displayed. If the value is not out-of-limit, the light will glow steadily for about 3 seconds and then extinguish; the next light will glow in turn as data is displayed. This sequence is repeated as long as the station select switch is engaged.

A single sensor value may be observed continuously by depressing a manual step switch. Depressing an auto step switch will return the display to the automatic mode of operation. These same functions are provided at the remote stations; however, the central station has the capability of overriding either mode on any remote station.

Another feature of the central station is its alarm clear circuitry. If a sensor value goes into alarm the affected remote station select switch and the affected channel light will flash red. These flashing lights cannot be cleared unless an alarm clear switch is engaged, even though the condition that caused the alarm is corrected. To clear the alarm lights, the alarm clear switch is engaged. After one full scan determines that no sensor value is in alarm condition, the flashing lights will extinguish; thus, a warning is given that an alarm condition did occur, even though conditions may have returned to normal. This system was not supplied with provisions for recording data; however, this capability may be added in the future.

VIRGINIA POCAHONTAS MONITORING SYSTEM

A third monitoring system, simpler than the Loveridge or Grace systems, is installed in the Virginia Pocahontas (VP) No. 4 mine of the Island Creek Coal Co. in Keen Mountain, Va. This system developed in cooperation with the Pittsburgh Technical Support Center of the Mining Enforcement and Safety Administration (MESA) consists of three remote stations located along the belt haulageway and a central station located underground in the dispatcher's office. The primary purpose of this monitoring system is to detect fires or heatings on the beltway; hence, the only sensor used here, an Ecolyzer model 3200 carbon monoxide analyzer (table 1), is to detect carbon monoxide.

Remote Stations

Each remote station (Sonex model 164-03) contains a direct-coupled amplifier, a mixer amplifier, and four voltage-controlled oscillators for inputing four analog signals (fig. 9). Each analog channel operates at a different frequency (frequency division multiplexing). No local readout of data is provided and no local alarms are generated. However, the carbon monoxide sensor, a complete instrument within itself, is equipped with an analog meter for indicating carbon monoxide concentration. An audible and visual alarm is also provided.

The remote stations are powered by Ocenco, Inc.'s model UPS-1212 power supplies. These supplies contain backup batteries that will operate the remote stations for approximately 3 days in the event of a power loss. This system is not a polling system; each remote station transmits its data concurrently with all other remote stations (fig. 10).

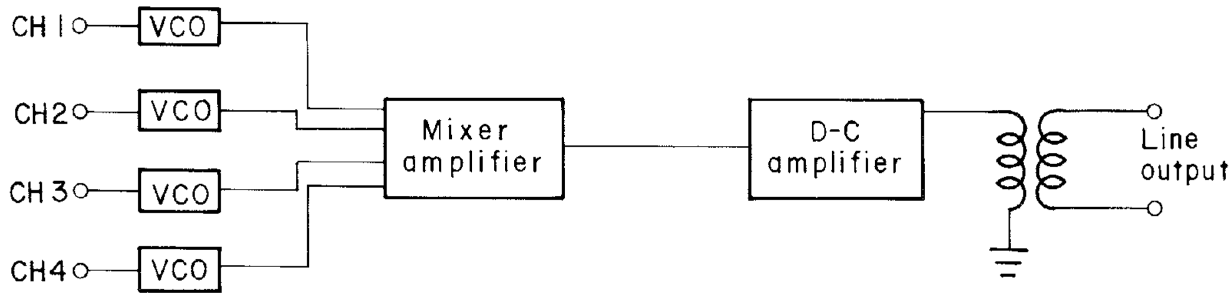

FIGURE 9. - Block diagram of remote station, VP-4 system.

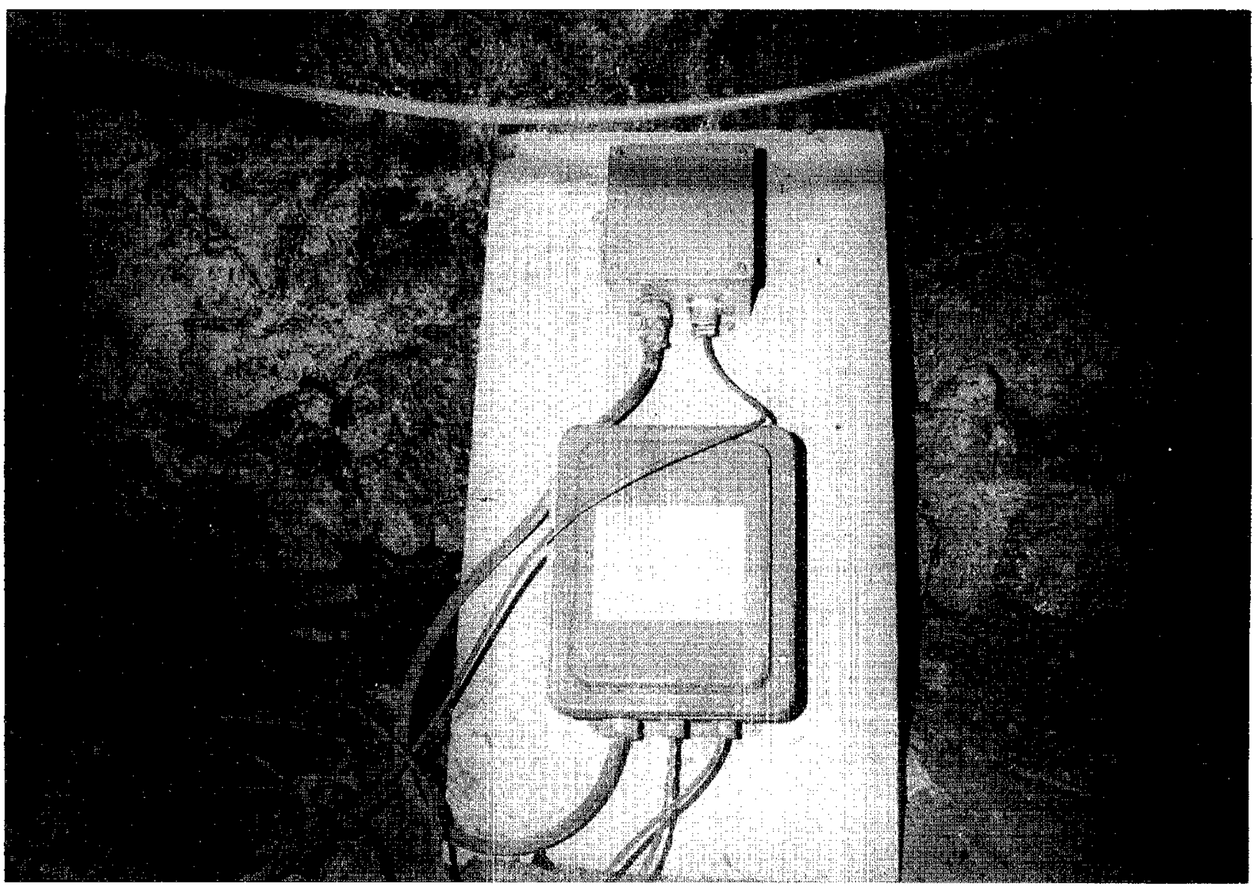

FIGURE 10. - Remote station, VP-4 system.

Central Station

All remote stations are connected by a single telephone pair to the central station which is located underground in the dispatcher's office. The central station consists of a Sonex model 156-03 FM receiver, a Fluke model 2240A datalogger, and strip chart recorders for recording continuous trends (fig. 11).

The receiver consists of 12 FM discriminators for receiving the FM multiplexed signals from the remote stations. The output of the discriminators are connected to the input scanner of the datalogger. Also connected to the discriminator outputs are chart recorders for recording the analog voltages from each sensor.

The datalogger has three selectable scan modes for displaying data; single, continuous, and interval. In the single mode, each sensor value is displayed once; in the continuous mode, values are displayed continuously; and in the interval mode, data is displayed at selectable time intervals that can be varied from 0 to 24 hours. The digital printer operates in the same modes as the data display with one additional feature; in the limit data mode, only values that have exceeded a preset limit will be printed. Following a scan in any mode of operation, the date and time of day will be printed also. The datalogger is equipped with a visual alarm which flashes red when a sensor value is out-of-limit. This alarm will continue to flash until manually reset (fig. 12).

All alarm levels in this system are programable and are made by keyboard entry into the datalogger. In this way, no critical adjustments have to be made at several different remote locations. Thus, the operator can enter or change alarm levels of any sensor without leaving the central station. Perhaps the greatest advantage of this system is that data from all remote stations are available simultaneously.

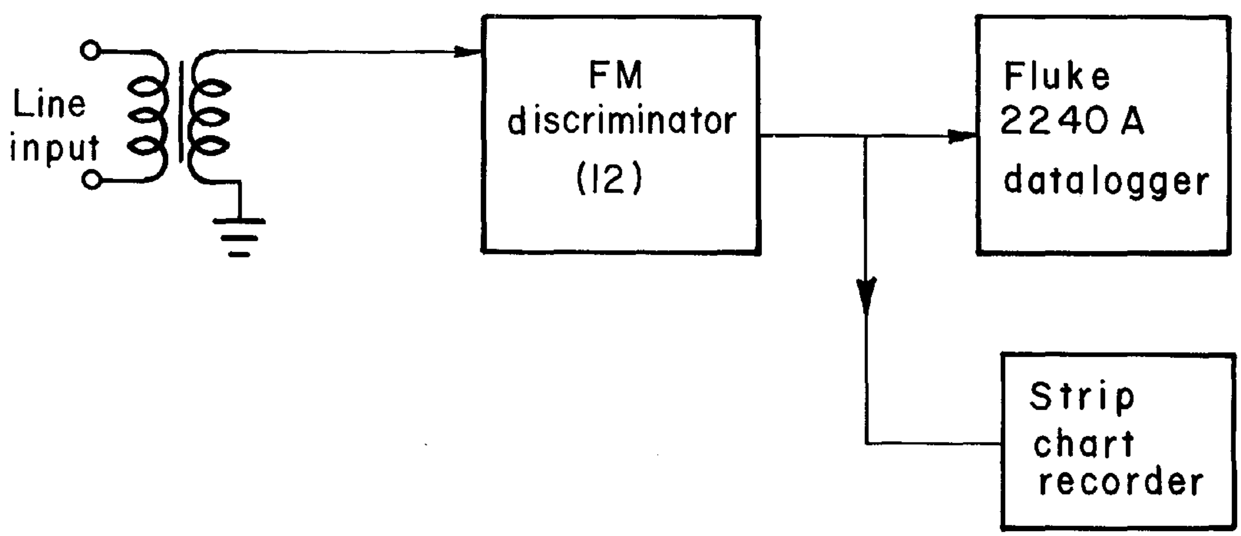

FIGURE 11. - Block diagram of central station, VP-4 system.

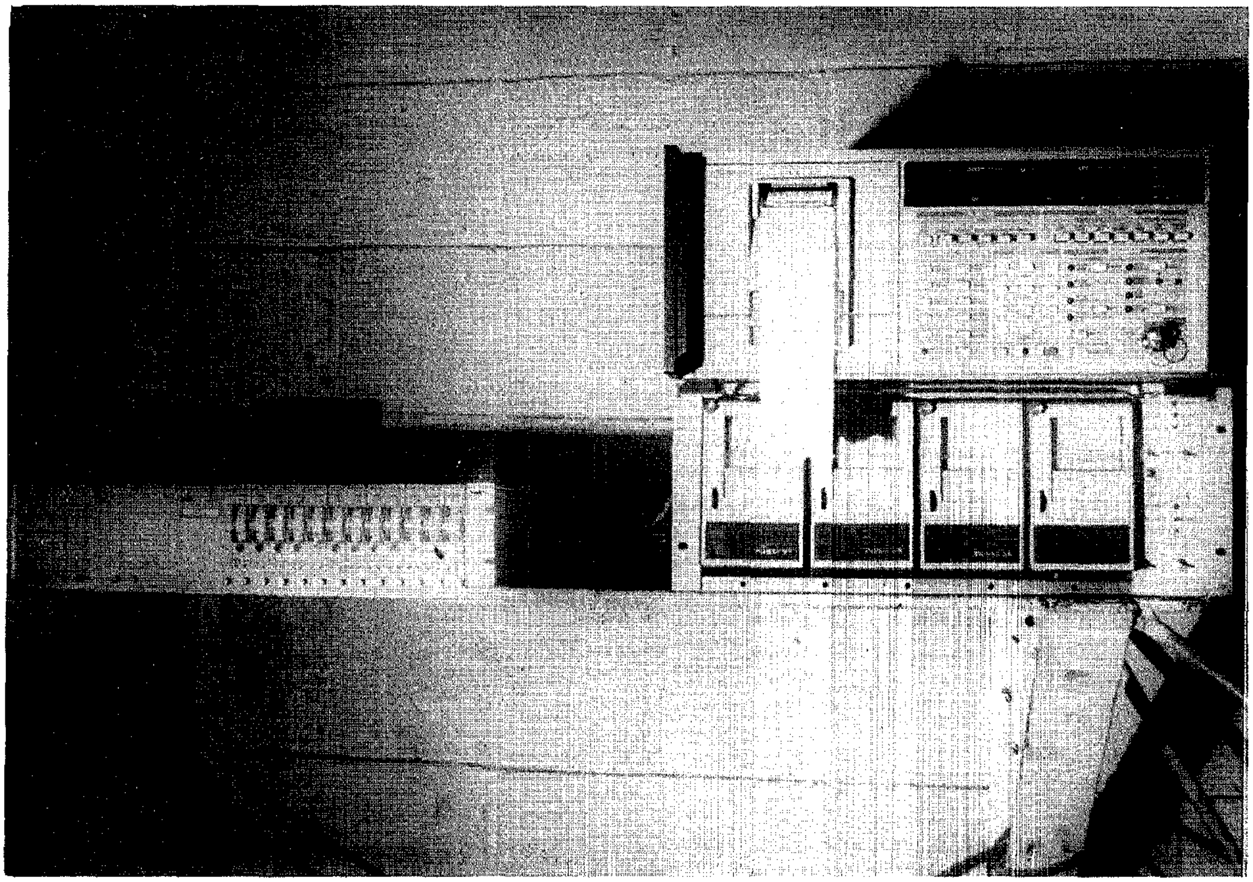

FIGURE 12. - Central station, VP-4 system.

RESULTS AND CONCLUSIONS

The monitoring systems described here are all functional in underground mines. With the development of more reliable sensors, especially for nitrogen dioxide, the utility and accuracy of the monitoring concept will be greatly enhanced. Although these systems are in the experimental stage, they have shown that monitoring health-related parameters is indeed practical. As reliability increases, monitoring systems will increase the safety of persons working underground and, by eliminating routine checking by individuals, will increase production and implement cost savings. Knowing the condition of the mine continuously and immediately, such as methane concentration of air velocity, can provide valuable information in planning the daily activities of mining operations. Both of these measurements are required under the Code of Federal Regulations, parts 75 and 57.[3]

[3]Work cited in footnote 2.

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