Design and Development of Up-Link Environmental Monitor

Prepared for

UNITED STATES DEPARTMENT OF THE INTERIOR
BUREAU OF MINES

by

Collins Commercial Telecommunications Division
Circuit Switching Systems Operation
Cedar Rapids, Iowa 52406

Rockwell International

FINAL REPORT

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This report describes an operational communications system which provides remote intra-terrestrial wireless transmission of environmental information. Design and modification specifications of requisite equipment are included along with a detailed description of system operation.

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FOREWORD

This report was prepared by Rockwell International, Collins Commercial Telecommunications Division, Circuit Switching Systems Operation, Cedar Rapids, Iowa 52406, under USBM Contract Number H0357146. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of PM&SRC with Mr. Harry Dobroski acting as the Technical Project Officer. Mrs. Pearl A. Shapert was the contract administrator for the Bureau of Mines.

This report is a summary of the work recently completed as part of this contract during the period June 27, 1975 to July 27, 1976.

This report was submitted by the authors on September , 1976.

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LIST OF ILLUSTRATIONS

This report summarizes development effort by Collins Radio Group of Rockwell International in the successful completion of United States Bureau of Mines Contract No. H0357146. The completed program involved equipment design, manufacture, modification, test, and delivery for the USBM test mine at Bruceton, Pennsylvania.

Collins has previously developed a multi-channel, private-line mine telephone system that operates via a single coaxial cable. This system provides environmental monitoring, remote control and through-the-earth paging capabilities in addition to the normal voice telephone functions. A system of this type was obtained by the Bureau of Mines under Contract No. S0346089, and this contract, H0357146, directed the design of new equipment and the modification of existing equipment to augment the monitoring capabilities of the original system. The expanded capabilities included the following items.

1) Development of an expandable monitor information display system with provision for improved operator detection of displayed hazardous conditions.
2) Development of a method of through-the-earth transmission of environmental monitor information, which permits information to be obtained, even in the event of an interruption in the system interconnecting cable.
3) Modification of circuitry to extend battery-powered operating time.
4) Addition of a temperature sensor in the environmental monitor.

This report contains information detailing the design and operational considerations along with the specifications of the new equipment. The amended

system operation is outlined, including the nature and effect of the modifications to the original equipment.

The purpose of the Uplink Environmental program is to prepare and deliver equipment that permits surface determination of underground environmental conditions. This equipment is to be installed in the U. S. Bureau of Mines test mine near Bruceton, Pennsylvania.

The equipment prepared under this program, when operated in conjunction with a Collins Mine Communications and Monitoring System, provides redundant transmission of environmental data. Under normal conditions all underground telephone sets are connected to a surface system center by a coaxial cable, and an environmental monitoring device is connected to each of these telephones. The levels of carbon monoxide, methane and air flow present at the monitoring device are displayed on the face of the telephone and are transferred over the coaxial cable and displayed at the system center.

The environmental data is also available (even in the event of a broken coaxial cable) through an alternative system. When a surface "enabling" signal is transmitted, the environmental information is transmitted directly through the overburden, back to the surface, where it can be monitored by a narrow-band receiver. The following section describes the specific hardware implementation of these objectives.

3.1 EQUIPMENT DESIGN

Two units were designed to fulfill the requirements of this program. The units are the Uplink Actuator Receiver and the Monitor Display. The operational requirements, design considerations and test procedures for these devices are described in the following paragraphs.

3.1.1 UPLINK ACTUATOR RECEIVER

3.1.1.1 OPERATIONAL REQUIREMENTS

The Uplink Actuator Receiver developed for the remote monitor system provides two basic functions to facilitate system operation. The receiver section selectively monitors received signals to detect a "triggering signal", while the digital circuitry provides several control functions including enabling and disabling monitor and phone circuits to conserve power during emergency operating conditions, encoding the status of the monitor sensors, and keying a ULF transmitter in the telephone to transmit the monitor information. The complete operation of the Uplink Actuator Receiver and the Remote Monitoring System is explained in the "System Operation" section of the Wireless Remote Access Underground Monitor Status Uplink Relay System Instruction Manual, included as an appendix to this report.

3.1.1.2 DESIGN CONSIDERATIONS

The receiver is designed to operate in both active and inactive mines. Initial studies (such as the Research and Development Contract for Coal Mine Communication System USBM No. H0232056) have shown that the optimum frequency for a 300 meter through-the-earth signal transmission in an active mine with an overburden conductivity of .01 mho/meter is in the region of 1 KHz to 7 KHz. Because some mines may have greater conductivities which would attenuate the higher frequencies, 990 Hz was chosen as the triggering

3.1.1.2 (Cont'd)

signal transmission frequency. Nine-hundred ninety Hertz is also exactly midway between 60 Hz powerline harmonics, allowing maximum signal isolation from mine noise.

The input sensitivity of the receiver was chosen to be 10 microvolts, which corresponds approximately to a 25 microampere/meter magnetic field. This field could be theoretically produced by a magnetic moment of 6675 amp-turn-meter^2 at 990 Hz assuming an overburden of 300 meters with conductivity of 0.01 mho per meter. For operation of the receiver in an active mine, the ambient noise fields may be much greater than 25 microampere/meter. The receiver was designed for over 70 dB of dynamic range which may be adjusted on location, depending on the electrical noise present at that site. In order to simplify the adjustment procedures, a red LED inside the chassis lights when the receiver detects a signal exceeding its threshold. Since strong noise signals may be present, the gain of the receiver may be reduced by an internal gain adjustment so that the receiver does not respond to mine noise (the LED is not being lit when a "triggering signal" is not present). Reduction of the receiver sensitivity must be compensated by increased power in the surface transmitting loop.

Other design considerations included the need for minimal power consumption (the circuitry requires about 12 MA @ 28 V) and adequate rejection of out-of-band signals. The receiver has a high-Q band pass filter, which provides in excess of 20 dB of rejection to signals at 960 Hz and 1020 Hz. In addition, the receiver must operate beyond the threshold of the temperature sensor included in this program. The receiver was designed to operate from -10 to +50^{o}C.

3.1.1.2 (Cont'd)

The "activation pulse" is a transmitted signal which indicates that the disabled circuits in the wireless monitor system have been activated. A two-minute delay follows to permit the reactivated sensors in the underground monitor to stablize and generate accurate environmental data.

The presence of the key pulses permits acknowledgement of the data transmission, even if all of the data pulses are missing. Pulses and spaces of 430 and 860 milli-seconds were chosen because they were clearly discernable, not readily confused with the 100 msec emergency location pulse (which may be generated independently by the ULF transmitters) and they were easily derived from the 1140 Hz oscillator, which has minimal interference with the receiver circuitry.

Transmission of the same data word three times permits verification of the content of the received message.

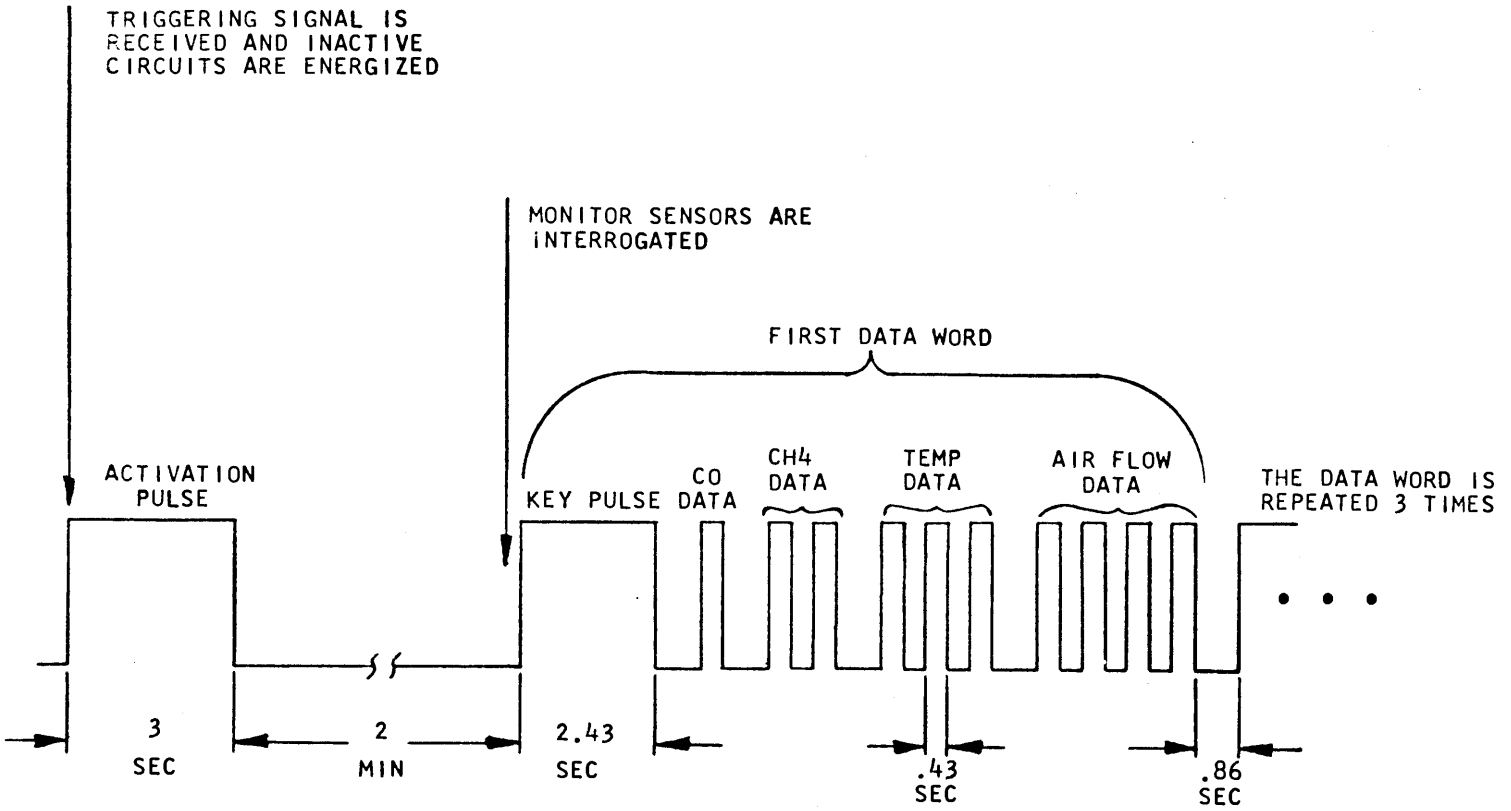
3.1.1.3 Operation

Diagrams of the receiver are shown as Figures 3-2 and 3-3. Incoming signals are amplified by the FET input and variable gain stages. Out-of-band signals are rejected by the 990 Hz bandpass filter, which has a 4 Hz 3dB bandwidth. The signals are then full-wave rectified and integrated. If the signal strength exceeds a pre-set threshhold, the "triggering signal" line goes high, and the triggering signal timer starts timing the signal duration. If the signal lasts over twelve seconds, the disabled circuitry is re-activated, the "activation pulse" is keyed, and the "warm-up" timer begins timing. After approximately two minutes, this "warm-up timer" starts the transmit counter and the data word generator which examines the status of the environmental monitor inputs and generates the data word. Clock pulses trigger the data word bits to sequentially key the transmitter and transmit the monitor information.

3.1.1.2 (Cont'd)

The digital control section of the uplink actuator was designed to minimize interference with the receiver section, provide for the reliable operation of the sensors (by allowing adequate warm-up time) and to generate a coherent monitor data word that could be clearly deciphered by mine personnel with a minimum of training.

The dataword format is shown in Figure 3-1.

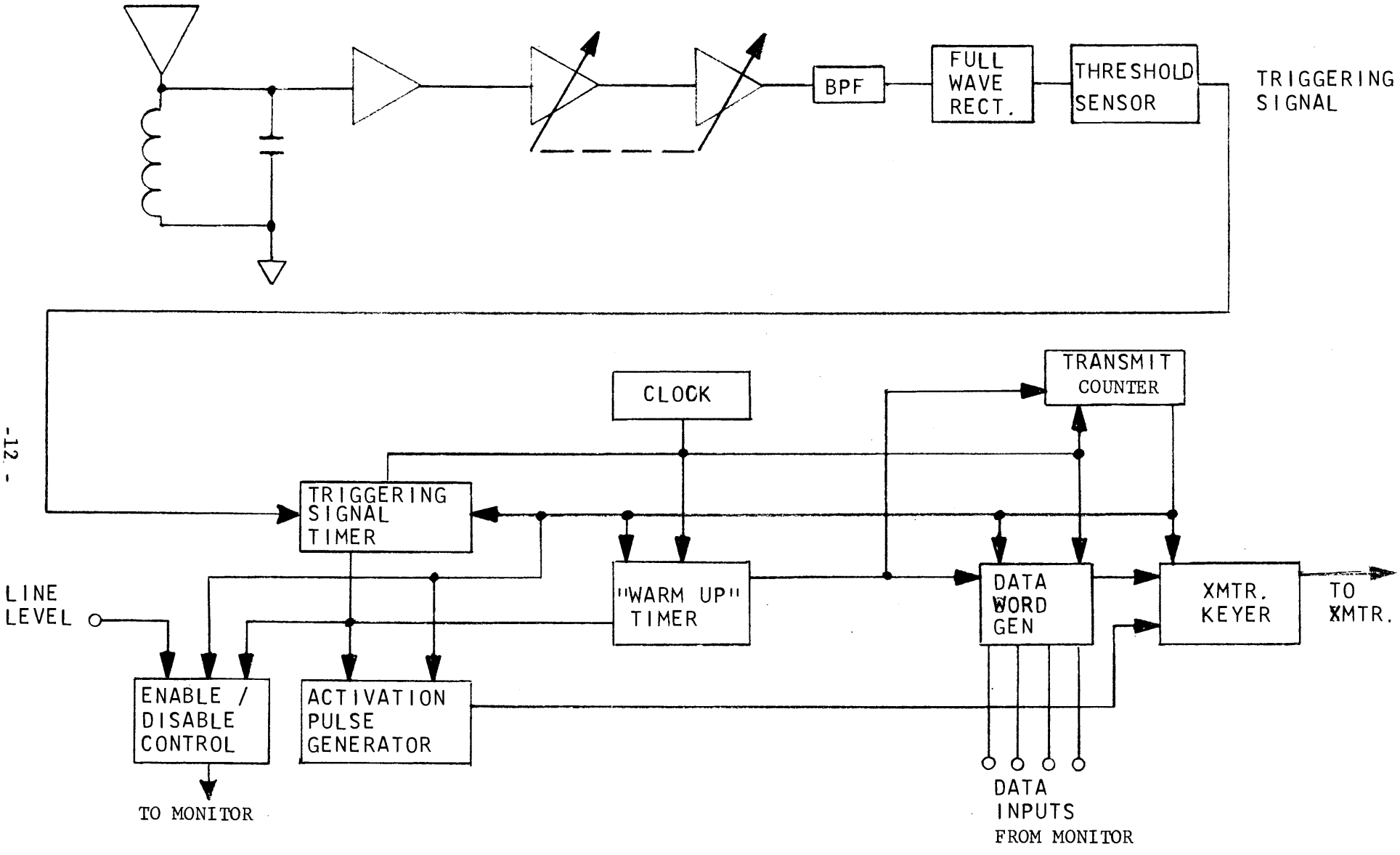


ALL DATA PULSES ARE .43 SEC
ALL SPACES ARE .86 SEC = .3

THE OMISSION OF DATA PULSES CORRESPONDING TO (A) MONITOR SENSOR(S) INDICATES AN ENVIRONMENTAL ABNORMALITY IS DETECTED

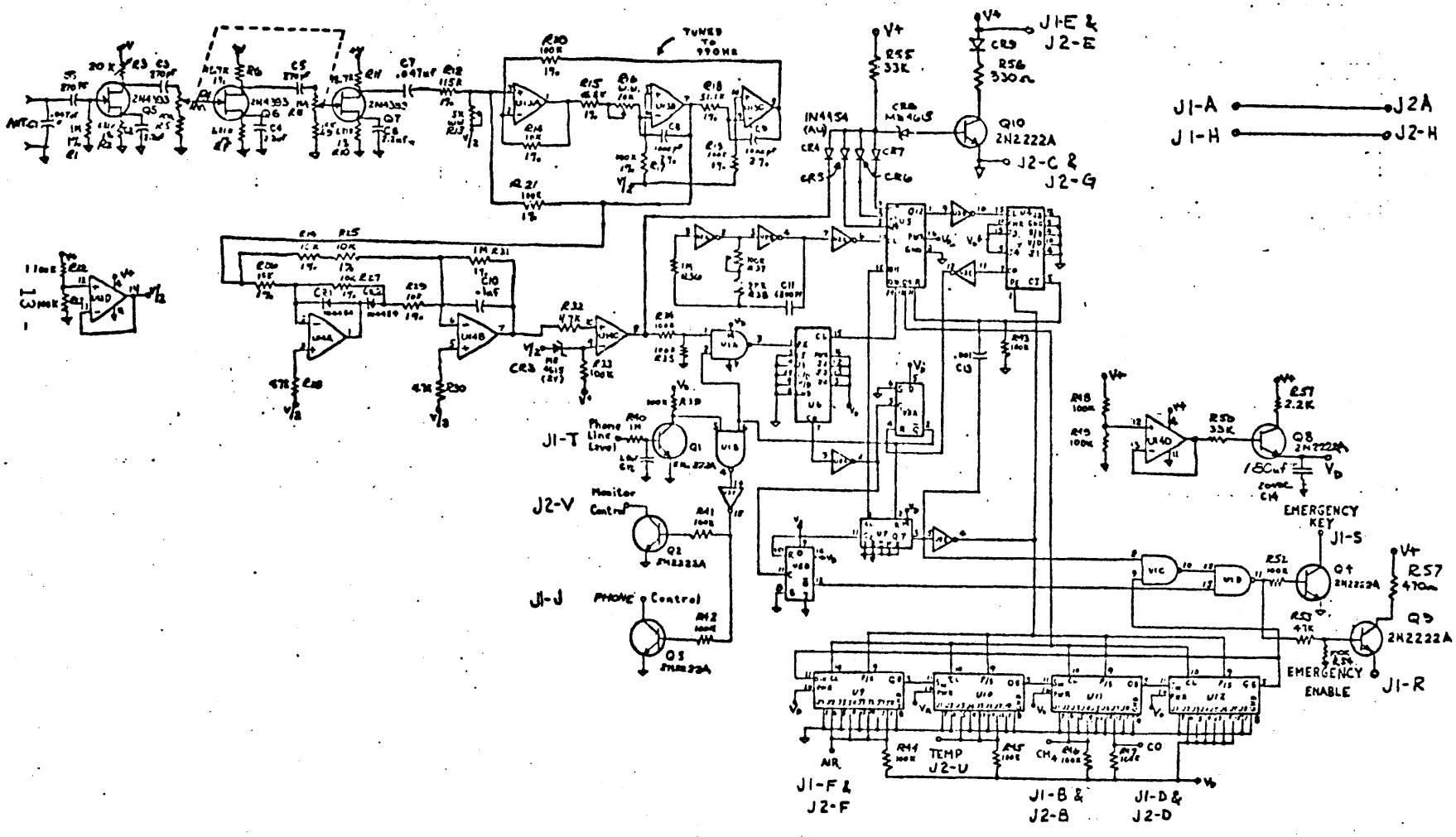
UPLINK DATA TRANSMISSION MESSAGE FORMAT

FIGURE 3-1



UPLINK ACTUATOR RECEIVER BLOCK DIAGRAM

FIGURE 3-2



BRUCETON UPLINK ACTUATOR FIGURE 3-3

3.1.1.3 (Cont'd)

When the transmit counter counts that all of the data bits have been transmitted, it resets all stages and enables the acknowledgement of another "triggering signal". When the ENABLE/DISABLE control is reset, if the line voltage is low, it will disable the monitor and phone function as described in the instruction manual.

3.1.1.4 Specifications

The Uplink Actuator Receiver was designed, built and tested to meet the following specifications:

Receiver Sensitivity	10 μV at 990 Hz $\pm$ 1 Hz
Receiver Selectivity	20dB rejection at 960 and 1020 Hz
Gain Control	70dB Range
Receiver Quiescent/Current Drain	15 ma Max., 12 ma typical
Operating Voltage	22 to 28 Volts

3.1.2 Monitor Display

3.1.2.1 Operational Requirements

The Monitor Display portion of the remote monitor system provides a visual readout of the data received from the various underground phones. The data received at the underground phone from the Environmental Monitor is encoded and transmitted to the System Center. The data is processed and retransmitted from the System Center to the Monitor Display. The Monitor Display decodes the incoming data and provides a visual display of any alarm condition detected by an Environmental Monitor. In the event that any one of the points being monitored is sending an alarm, a common alarm lamp can be lighted and an audible alarm sounded. Contacts are available for the remote indication of this common alarm condition.

3.1.2.2 Design Considerations

The Monitor Display system must be capable of reconfiguration to match any given mine size and must present a readout with a very high confidence factor; i.e., the probability that the correct status is displayed at any given time must be very high. To these ends the system processor is assigned a data routing function, sending information in 8-bit blocks to display panels. These panels are sized such that each displays one 8-bit block of information. A given system can contain from one to 250 panels, thus permitting the display of up to 2000 data points. Redundant transmission of the data is used to ensure error-free display, with multiple comparisons made prior to changing the displayed information.

The processor in the system center configures monitor data into the form accepted by the display panels. Data messages from individual phones (containing monitor information) are read and the monitor data is extracted and transmitted to the monitor display. The monitor panels retrieve data from the system coaxial cable via a set of cable interface cards identical to those used in a phone. This card set receives and stores the data message from the system center.

Before a message containing a change in monitor information is displayed on the individual monitor readout panel, the message must be verified. The verification process requires that after a message is received and acknowledged by the cable interface cards, a second identical message must be received and acknowledged. Only after this second message is received is the new data presented to the individual readout panels.

Logic level control signals are sent from the cable interface to the parallel-wired readout panels via a multi-wire interconnecting cable. Eight address

lines, eight data lines, a load line, a fault line, a test line and a timer control line are among the wires in the cable.

All the above-mentioned lines except the timer control are connected at each individual monitor panel. The address, data, load and test lines serve as inputs. The eight address lines permit up to 250 panels to be connected to the system, while the eight control lines determine the status of the eight indicators on each panel. The load line controls "data loading" to the panels, with a given display "remembered" between load commands. A signal on the test line causes all lamps to be turned on.

The fault line in the multi-wire cable interconnects all the monitor panels and the alarm panel. It is used as a "collection point", so that any of the individual alarm points can cause an indication on the alarm panel. Each indicator on a monitor panel is associated with a pin that can be strapped to provide a fault output and in a given installation any or all of these straps may be installed. When the strap is installed at a given position a fault signal will be sent whenever the indicator associated with that position is lighted.

The final panel in the Monitor Display is used as a common indicating point for all alarms. It contains a visual, an audible, and a remote alarm indicator. Since momentary individual alarms can occur that do not necessarily require that an alert be sounded, the alarm panel display is delayed from the displays presented on the individual monitor panels. A signal must be present on the fault line for a preset number of counts of the timer control line before the general alarms will be activated. The lamp test button for all the displays is also located in the alarm panel.

3.1.2.3 Operations

The entire Monitor Display is unlit if there are no alarm conditions. If any alarm or alarms are set at an Environmental Monitor, a corresponding lamp will be lighted on the monitor display. If the alarm remains on for the predetermined time interval the common alarm will be lighted and sounded. Space is provided on each individual panel indicator so the meaning of a given alarm can be written in. Once set, a given lamp will stay lighted until turned off by a message from the System Center, so if an Environmental Monitor is disconnected while in an alarm state the alarm indication on its monitor panel will remain set.

The lamps in the display may be tested by setting the lamp test switch. The lamp test is also a test of all connections to the parallel cable.

3.2 EQUIPMENT MODIFICATION

3.2.1 Underground Telephone

Two sections of the Underground Telephone have been modified to enable it to be used in the Uplink Environmental Monitor. These modifications affect the ULF transmitter and the main power/battery power reporting circuits.

In a normal Underground Telephone a front-panel switch is used to activate a ULF emergency locator transmitter. The keying circuitry for this transmitter was revised so it could be enabled by either the front-panel switch or by the Uplink Actuator Receiver. The receiver sends encoded environmental data to the surface via the ULF transmitter so that conditions underground can be determined.

The Underground Telephone normally monitors the dc level on the system coaxial cable, sending a signal to the surface whenever the phone and any associated devices (such as the environmental monitor) are relying solely on the phone's

3.2.1 (Cont'd)

internal battery power. The phone was modified so that if there is no line power, this signal is also sent to the Uplink Actuator Receiver. The receiver then commands the Environmental Monitor to shut down non-critical circuits It also forces the "safe" green light of the local phone display to the off condition. These actions reduce energy consumption to approximately forty percent of normal, and extends the battery powered operating time. A fully charged battery can be expected to power an idle phone in the Uplink Environmental Monitor configuration for approximately 24 hours and still respond to at least one interrogation.

3.2.2 Section Environmental Monitors

The basic Environmental Monitor indicates two separate concentrations of methane (CH_4), one concentration of carbon monoxide (CO) and a flow rate for air speed. The actuation level for each of these displays is adjustable and can be set in the field. For this program, an adjustable trip point for temperature was also added.

A normal monitor is designed to be continuously powered from a '28V DC power source. The modified unit has been redesigned such that power consuming portions of the unit are shut off when the Uplink Actuator Receiver indicates that the underground phone to which it is attached is being operated off battery power. The modification was made in order to conserve energy during emergency conditions.

The temperature monitor addition consists of two forward-biased silicon diodes (located in the sense head of the air speed sensor) and an associated comparator amplifier. The nearly linear characteristic of the forward voltage drop of the diodes as a function of temperature is used to sense temperature variations.

3.2.2 (Cont'd)

The varying voltage produced by temperature changes is fed into one input of the comparator. The other input of the comparator is attached to an adjustable voltage, thus providing for a trip point that can be set at the desired temperature. The set point is within the range of 90^{o} to 150^{o}F.

The modification of the unit that permits power to be partially shut off consists of a relay which delivers power when energized. A block diagram of the modified monitor is shown in Figure 3-4. The relay is energized during normal operation via a signal from the Uplink Actuator Receiver. When the signal from the Environmental Monitor and the relay disconnects the unneeded power lines. When the signal returns the monitor reverts to normal operation. The sensors require a short time to stablize once they are re-energized before they will provide accurate environmental data.

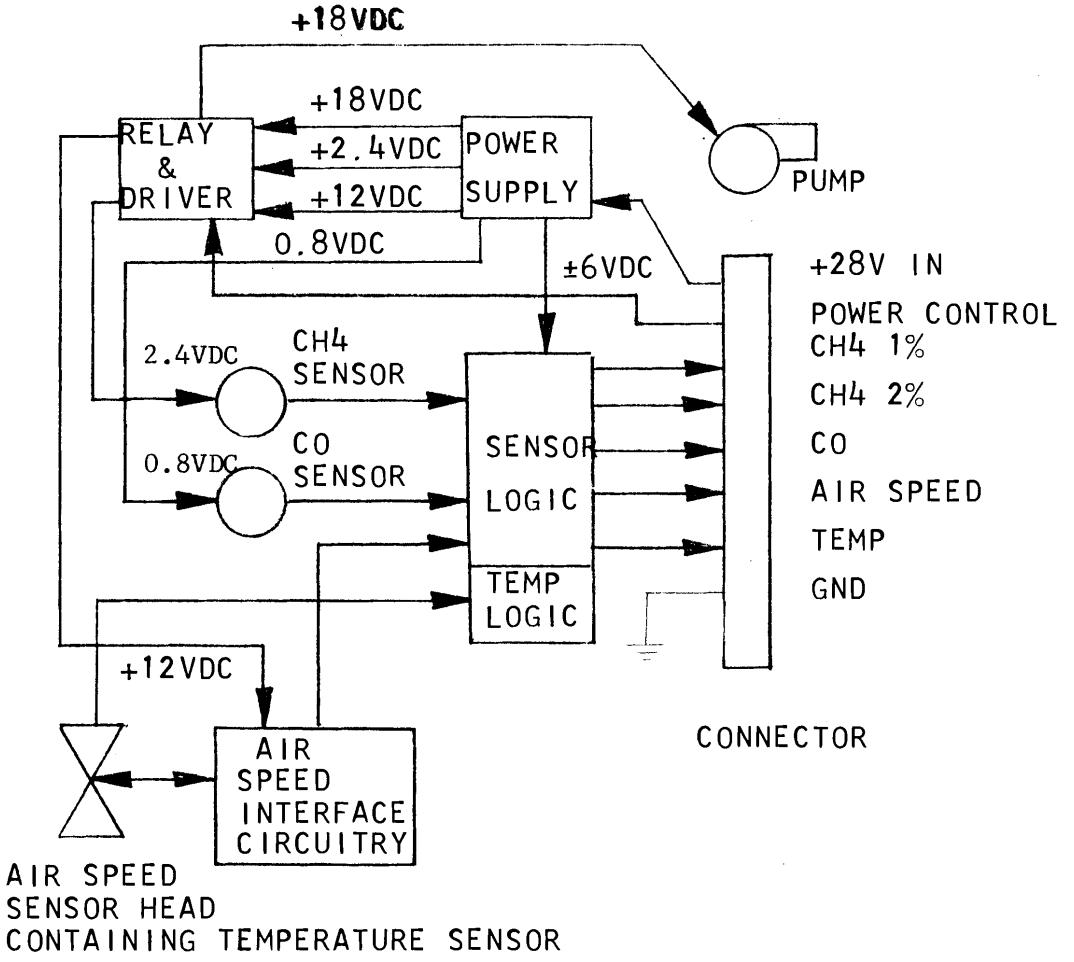


FIGURE 3-4

ENVIRONMENTAL MONITOR WITH TEMPERATURE SENSOR

Collins Radio has expanded and enhanced the capabilities of its mine communication and monitoring system by providing wireless monitor information from underground phones disabled by a broken cable. The battery-powered operating time of the underground phones has been extended by automatically disabling the operation of non-critical circuitry.

An expandable monitor information display system with built-in false alarm protection was developed, along with a means of bussing high priority alarms to a general alarm panel. The new equipment and modifications in no way interfere with the basic functions of the original communication system.

The ease and simplicity with which the basic system was altered to accommodate the expanded functions emphasizes a fundamental advantage of this type of system. Besides providing reliable operation, the multitude of communication channels and the elastic system center software permits the system to grow in complexity without gross redesign or reduction of existing functions.

APPENDIX

WIRELESS REMOTE ACCESS UNDERGROUND MONITOR STATUS UPLINK RELAY SYSTEM

INSTRUCTION MANUAL

PREPARED FOR:

BUREAU OF MINES
U.S. DEPARTMENT OF THE INTERIOR

PREPARED BY:

COLLINS RADIO GROUP
ROCKWELL INTERNATIONAL
CEDAR RAPIDS, IOWA

System Description

The Wireless Remote Access Underground Monitor Status Uplink System (Wireless Monitor System) provides remotely accessed wireless sensor information from an underground monitor via a low-frequency transmitter. The Wireless Monitor System is comprised of a modified 454L-1 Remote Monitoring Unit (monitor), a 59G-1 Uplink Actuator Receiver (receiver actuator) and a modified 960X-1 Underground Communication and Monitoring Unit (underground phone).

The receiver-actuator responds to a "triggering signal" by sampling the status of the monitor sensors, forming the data word (of predetermined format) and keying the emergency transmitter in the underground phone.

The frequency of the data transmission depends on the channel of the emergency transmitter card. Channels 49 (2910 HZ), 50 (2970 HZ) or 51 (3030 HZ) are acceptable for operation in the Wireless Monitor System. These channels may be monitored with any low-frequency narrow-band receiver such as the 515H-1 mancarried waveform receiver or the 515H-2 helicopter-borne waveform receiver.

Operation

The monitor is connected by cable to the receiver-actuator, which is connected by cable to the underground phone. Interconnections between units are made with the provided cable (see Figure 1).

The monitor and the underground phone are preadjusted at the factory and should not require any adjustment upon installation. The receiver-actuator has a single gain control, which varies the sensitivity threshold of the receiver. When the receiver-actuator receives a signal greater than its threshold, a red LED inside the receiver is lit. The gain

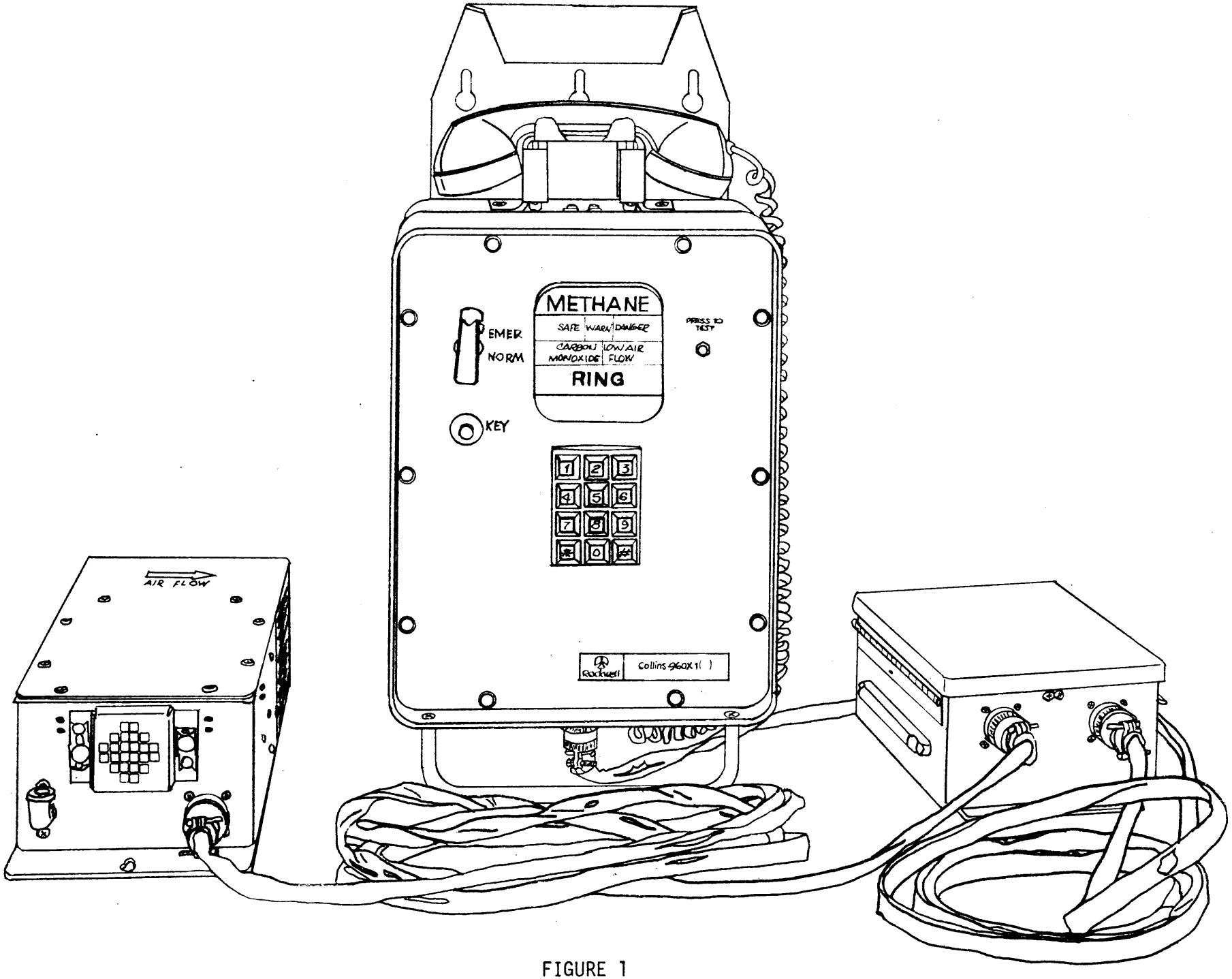


FIGURE 1

WIRELESS MONITOR SYSTEM

control should be adjusted so that the receiver is not responding to the ambient noise at the installation site (the LED is not being lit when a "triggering signal" is not present). The Wireless Monitor System is then ready for operation.

System Operation

Although the monitor and underground phone have been modified to facilitate the Wireless Monitor System operation, the monitor may be connected with one of the provided cables directly to the underground phone. They will then provide the standard MCM-101 monitoring function (50 PPM CO; 1% and 2% Methane; and 100 FPM Air Flow) via the MCM 101 single cable phone network as described in the Collins MCM-101 Mine Communications and Monitor System Operator's Manual.

In the Wireless Monitoring System, as in the standard MCM-101 monitoring system, each of the environmental monitor sensors has a preset threshold. The monitor can therefore indicate two conditions for each sensor. If the environment at the monitor is below the sensor threshold, the monitor indicates a "normal" condition. If the environment has exceeded the thresholds of any of the sensors (i.e., the CO concentration is greater than 50 PPM or the methane concentration is greater than 2% or the air flow is less than 100 feet per minute or the temperature is higher than $50^{o}C$), then the monitor indicates an "abnormal condition" for each affected sensor.

When the receiver-actuator is connected between the monitor and the underground phone (See Figure 2) the Wireless Monitor System is activated and two modes of operation are possible.

If the underground phone is receiving adequate line voltage (not operating on its 24V batteries), the system is in its normal mode of operation

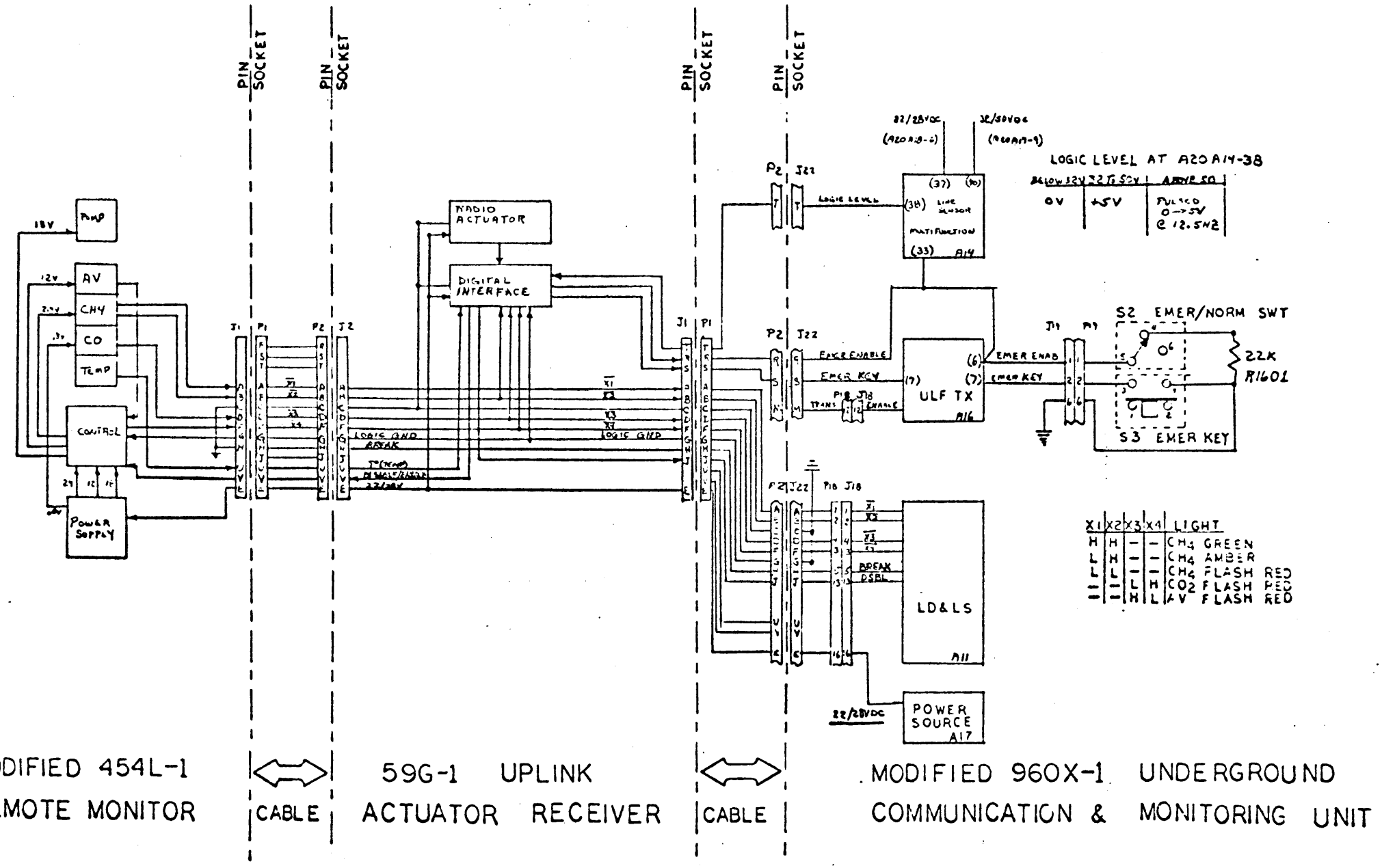


FIGURE 2
WIRELESS MONITOR SYSTEM INTERCONNECTION DIAGRAM

and the monitor and underground phone will provide the standard MCM-101 monitor information through the phone network. If the receiver-actuator receives a "triggering signal" of at least 12 seconds duration, it will send an "activation" pulse via the emergency transmitter in the underground phone. The receiver actuator will wait approximately two minutes, then sample the monitor sensors and form a coded data word which indicates the status of the 50 PPM CO, 2% Methane, 100 FPM Air Flow and a 50^{o}C temperature sensor. The data word consists of a key pulse followed by four data sections. Each data section corresponds to one of the four sensors and each is coded by a different number of of pulses: (See Figure 3) one pulse for CO; two pulses for Methane; three pulses for temperature; and four pulses for Air Flow.

The data pulses for each sensor indicating an "abnormal condition" are missing from the data word. If all four groups of data pulses are present in the data word, then all the sensors are below their thresholds and no abnormalities are being detected. As in the standard MCM-101 monitoring system, the sensors indicate only when their thresholds are exceeded and a potentially hazardous environment is detected. No analog data of how much the environment is above or below the thresholds is available.

After the receiver-actuator generates the data word it keys the emergency transmitter to transmit the same data word three times in succession. After the completion of the third data word, it immediately awaits the next "triggering signal".

The monitoring operation of the monitor and the underground phone continue (through the MCM-101 system) without interruption.

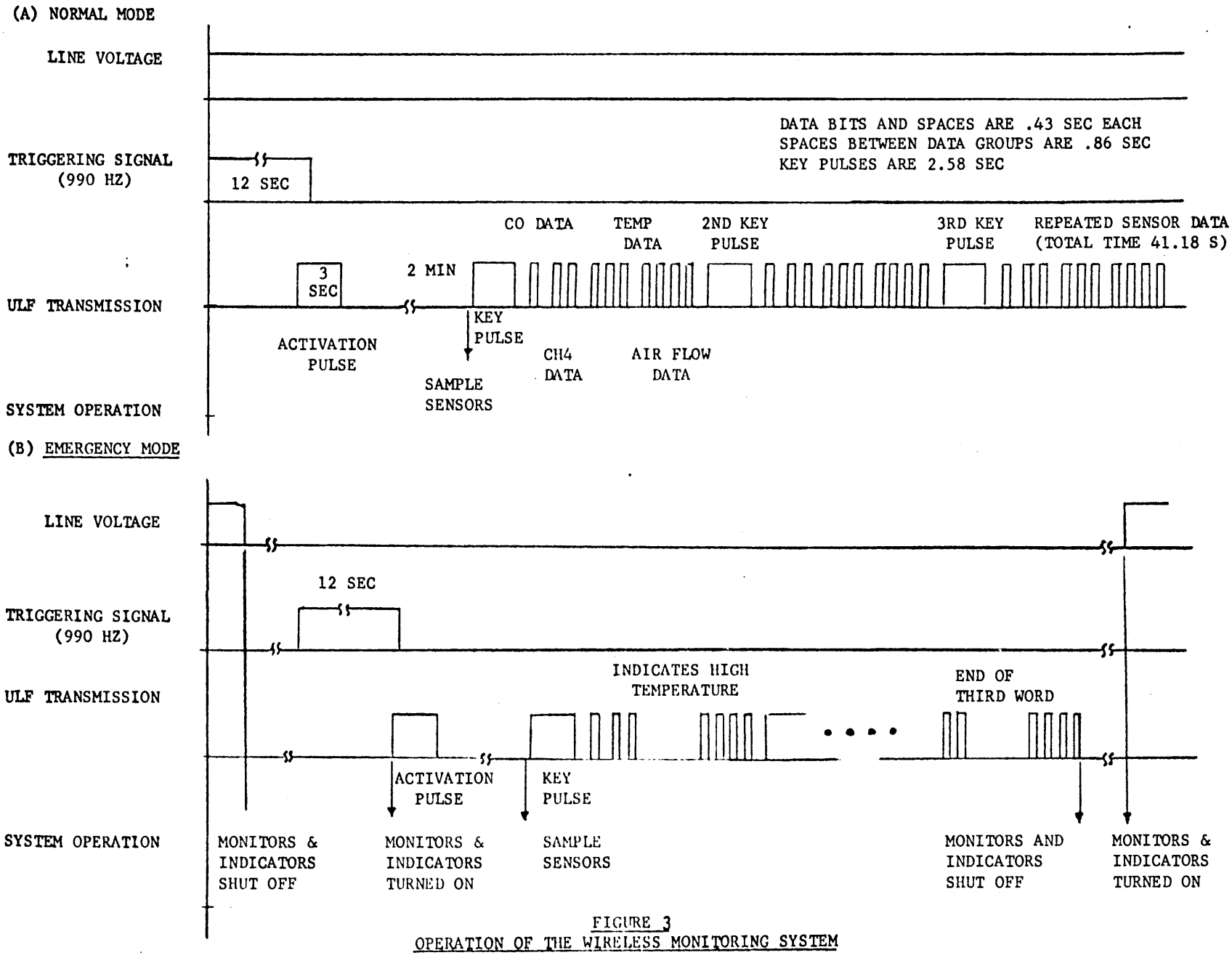


FIGURE 3
OPERATION OF THE WIRELESS MONITORING SYSTEM

If the line voltage to the underground phone becomes too low, the phone reverts to battery operation, and the Wireless Monitor System operates in its Emergency mode.

The receiver-actuator disables power to the monitor indicators in the adjacent underground phone and to most of the circuitry in the monitor (the heater to the CO sensor is left in operation due to the long stabilization time of that sensor).

If the receiver actuator receives a "triggering signal" of at least 12 second duration, it keys an "activation pulse" via the emergency transmitter in the underground phone and reactivates the monitor and indicator circuitry it had previously disabled. After a nominal two minutes (which allows the sensors to stabilize and provide accurate environmental data) the receiver-actuator samples the sensor data, generates the data word (see Figure 3) and keys the emergency transmitter to transmit the data word three times in succession (as in the normal system operation). At the conclusion of the transmission of the third data word, the receiver-actuator disables the monitor and underground phone circuitry as before, and awaits another "triggering signal".

When the line voltage to the underground phone is restored to an adequate level (the phone is not running off of its 24V batteries) the Wireless Monitor System reverts to the previously described normal mode of operation.

Triggering Signal Requirements

The 59G-1 Uplink Actuator Receiver has a high Q active bandpass filter centered at 990 HZ. At 960 and 1020 HZ the filter has a minimum of 20 dB of rejection. The receiver integrates signals passing through

the filter and senses when they reach the receiver threshold (illuminating the LED). Strong out of band signals may also activate the receiver, so the variable gain control (with over 70 dB of dynamic range) has been incorporated in the receiver design. Once the receiver gain has been reduced so that the receiver does not respond to the local ambient noise, reliable operation of the Wireless Monitor System may be obtained by providing a sufficiently strong magnetic field "triggering signal". Adjusted for maximum sensitivity the receiver will respond to a field of about 25uA/m at 990 HZ.

The power required for transmission of a triggering signal will vary greatly from one operating site to another depending on the depth of the receiver, the conductivity of the overburden, the size of the transmitting loop and the noise in the immediate vicinity of the receiver.