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DIGITAL TELEMETRY

FUNCTIONAL DESCRIPTION AND SPECIFICATIONS

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INTRODUCTION

The need for current-data availability has become increasingly important in the past few years. Many users of U.S. Geological Survey data require current information for the efficient operation of their facilities. In the past our transmission of data has been primarily limited to water stage, using the relatively slow, manually operated Telemark, or the equivalent Binary Decimal Transmitter. In some applications this type of telemetry is adequate; in many others a more complex system is required.

Telemetering systems fall into two categories, either analog or digital, with varying degrees of sophistication in each. Digital systems generally offer a more secure, reliable means of transmitting data, and they transmit with a higher degree of accuracy than analog systems. The purpose of this paper is to describe a digital telemetry system designed for transmission of hydrologic data. In addition to having the advantages mentioned above, this system also provides for data reception in a computer-compatible form. Usually, the main disadvantage of a digital telemetry system is its high initial cost. However, because the Geological Survey is already recording data at its sites in BCD (Binary Coded Decimal) form utilizing an ADR (Analog-to-Digital Recorder), a large part of the cost - that required for analog-to-digital conversion - is eliminated. Furthermore, due to the less stringent transmission facility requirements, operating costs generally are lower than comparable analog systems.

FUNCTIONAL DESCRIPTION

As data are recorded, they are stored in a memory bank in BCD form so that the information can be made immediately available for transmission. Recording and storage of data are initiated at preselected timed intervals using a timer contact closure (Figure 1). An Analog-to-Digital Recorder, ADR No. 1, is continually balanced by a water stage sensor and its value is immediately recorded once the initiating signal is received. The same contact closure (Sensor No. 0) also activates a water-quality monitor programmer. The programmer sequences its Sensor No. 1 (in our case, specific conductance) into the system, allows time for a servo-drive to balance ADR No. 2 and calls for the value indicated by the sensor to be recorded. It then sequences sensor No. 2 into the system, balances the ADR and records the value indicated. This procedure is repeated until all active channels, up to a maximum of ten, have been recorded. The programmer then returns to the off position and awaits a new initiating signal from the timer. It should be noted here that the system will also operate with only water stage and ADR No. 1, or with only the water-quality monitor and ADR No. 2.

At the time water stage is recorded on ADR No. 1, a set of electrical contacts within the ADR, representing the recorded value in BCD form is closed. This value is transferred into memory No. 0 through the Telemetry Memory Input Addresser. The value for specific conductance is recorded on ADR No. 2 a few seconds after the recording of water stage on ADR No. 1 due to a time lag in the WQM

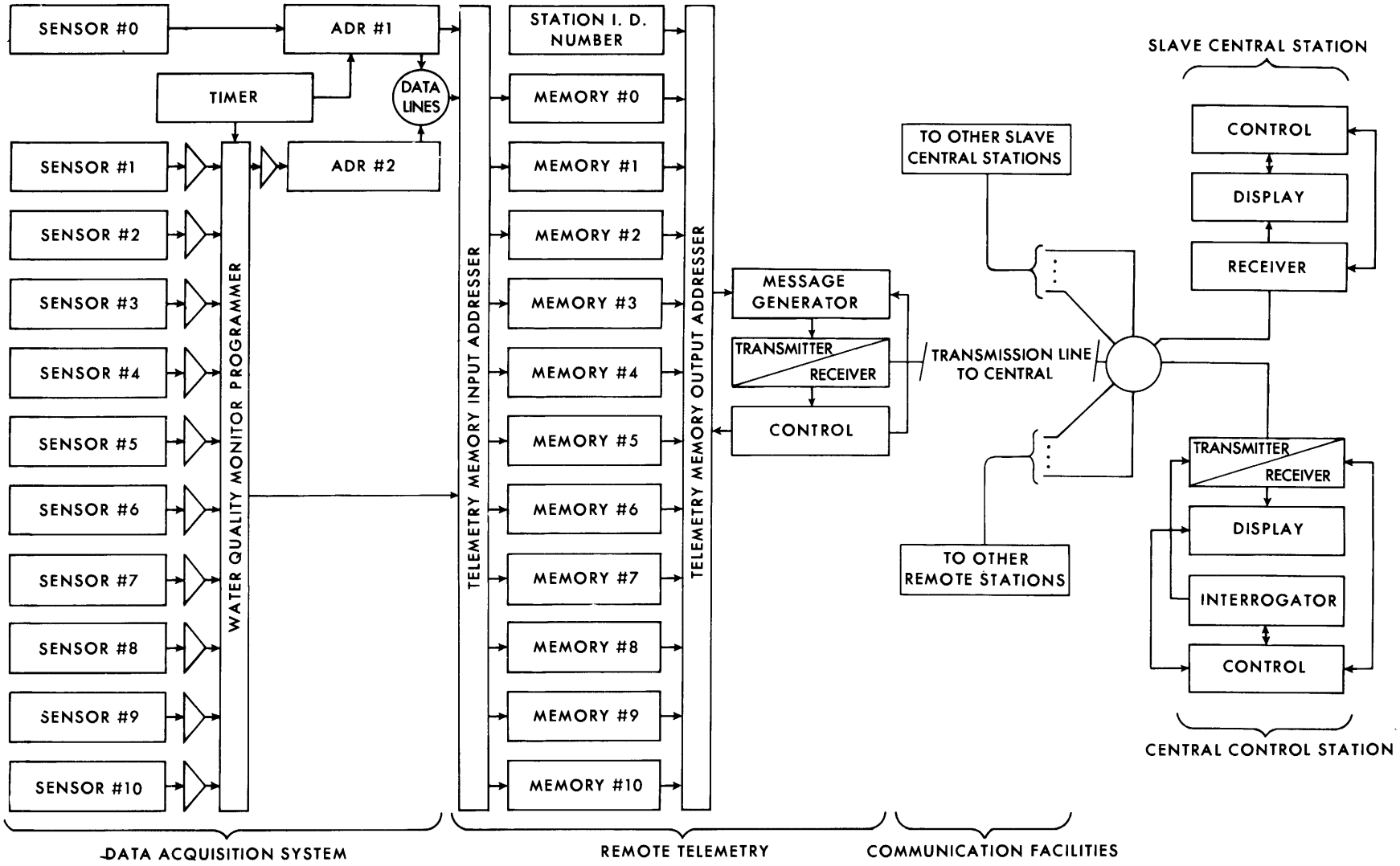

Figure 1 - Telemetry System Functional Block Diagram

(Water Quality Monitor) programmer. Its value, as represented by the set of electrical contacts in ADR No. 2, is transferred to memory No. 1 through the input addresser. The sequence is repeated until all parameters are entered into their appropriate memory modules. The input addresser relies on parameter identifier outputs from the WQM programmer and ADR No. 1 to determine proper memory locations. Upon completion of this cycle, digital data in BCD form are stored in memory and are ready for telemetering on command. These values will remain in memory until new values for the parameters are recorded, at which time the old values are erased and the new ones inserted in their places.

A telemetry network may consist of several remote stations reporting to a central control station. Each remote station may have several parameters. It is therefore necessary to provide both station and parameter identification. This is done by placing fixed identification numbers in each memory module. The first module always contains the station's identification number. The other modules represent data parameters with space for 5 digits of information in each. In the case of water stage the first digit in its module is wired to read 2 and the following four digits represent the value of water stage to the nearest one part in ten thousand. In the other individual parameter modules the first two digits are permanently fixed and represent the parameter identification numbers, ranging from 01 to 19. The last three digits represent the value of the parameter. This arrangement allows for an accuracy of one part in a thousand.

Parameter identification numbers have been assigned as follows:

Water Stage	2
Specific conductance	01
Temperature	02
Dissolved oxygen	03
pH	04
Chloride	05
Turbidity	06

Numbers 07 through 19 have been left uncommitted so that they may be assigned to less frequently used parameters.

Actual transmission of data is initiated by a timer at the central control station. The identification number of the remote station from which data are desired is formed by the interrogator and transmitted to all remote stations. Only the remote station which has this number stored in its station identification memory module responds, transmitting back its station ID number as a series of pulses. This transmission is received at the central station and displayed and/or recorded on a suitable output device, which is in our case a combination teletype page printer and tape punch unit. The Telemetry Memory Output Addresser then advances to the water stage storage module and these data are transmitted to, and recorded at, the central control station. This procedure is repeated until all information from the remote station has been transmitted and recorded. The interrogator then calls for the next remote station to

report and the entire process is repeated. As many as 390 remote stations can be interrogated by a single central control station in this manner. In addition, slave central stations may be operated from the same system; however, they perform no interrogation function and are used only for display and/or storage purposes.

The communication linkage may be leased line (either telegraph or voice grade), radio, microwave, or a combination of these. Rate of transmission is limited by the type of communication linkage used, and the final output device capabilities. System speed is controlled by plug-in modules in the telemetry transmitter and receiver. These are easily exchangeable so that a system's speed may be selected to best suit the situation. Maximum rate over a telegraph grade line is 15 pulses per second; therefore approximately 2 seconds are required to transmit 1 parameter. Maximum rate over a voice grade line is approximately 2300 pulses per second and transmission time is reduced proportionately. Rates over both radio and microwave can be considerably faster. However, when combinations of the different types of linkages are used in a single system, transmission rates cannot be faster than the capabilities of the slowest speed linkage.

Because this is a modular system, a high degree of flexibility is obtained. For example, it is not necessary that a teletypewriter be used for recording data; any other digital recording device can be used. Also, accessories such as digital clocks may be added.

Thus, the system can be adapted to the specific needs of the user. A typical central control station is shown in figure 2, and a typical remote station with associated data acquisition equipment is shown in figure 3.

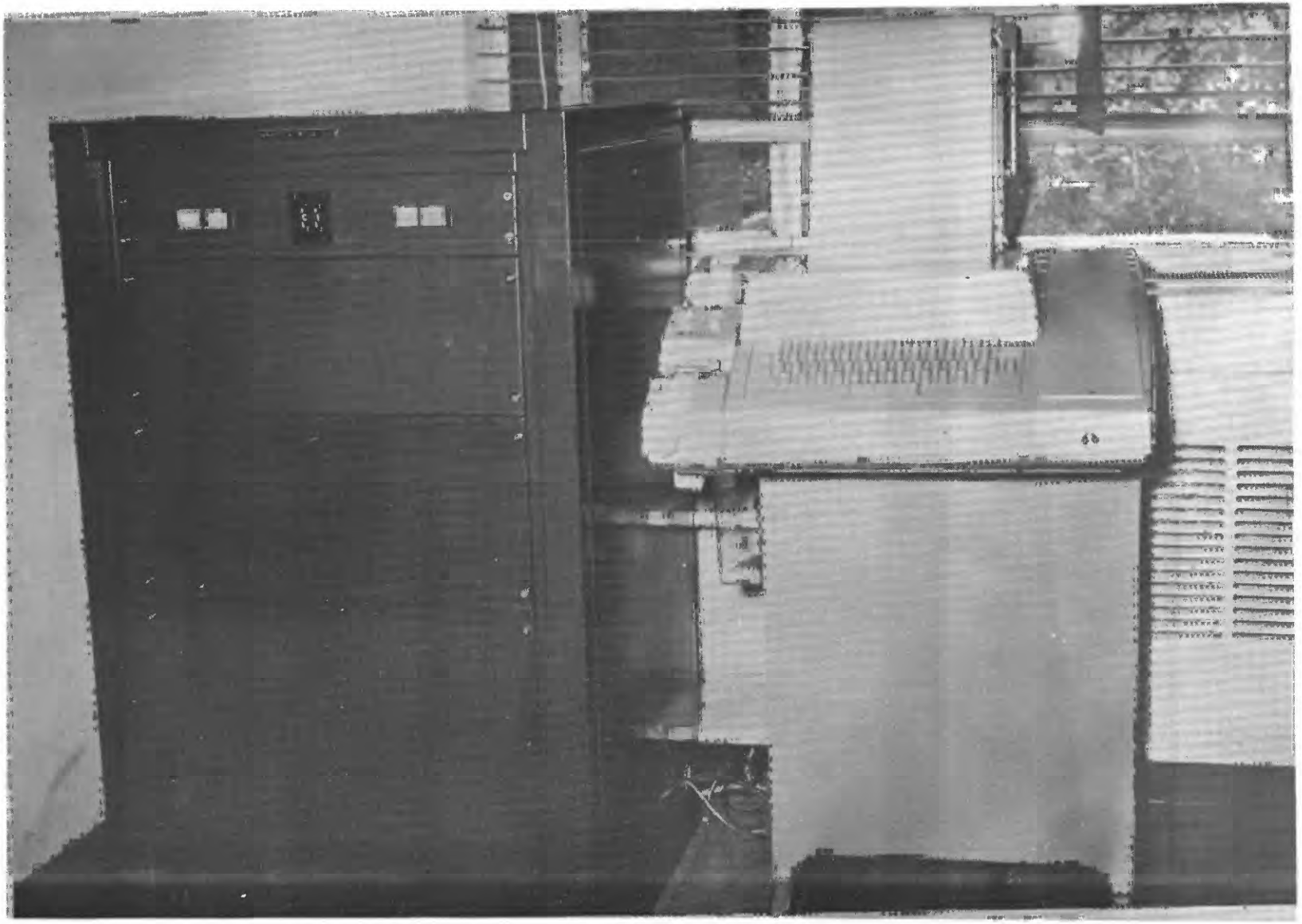

Figure 2. -- Central Control Station

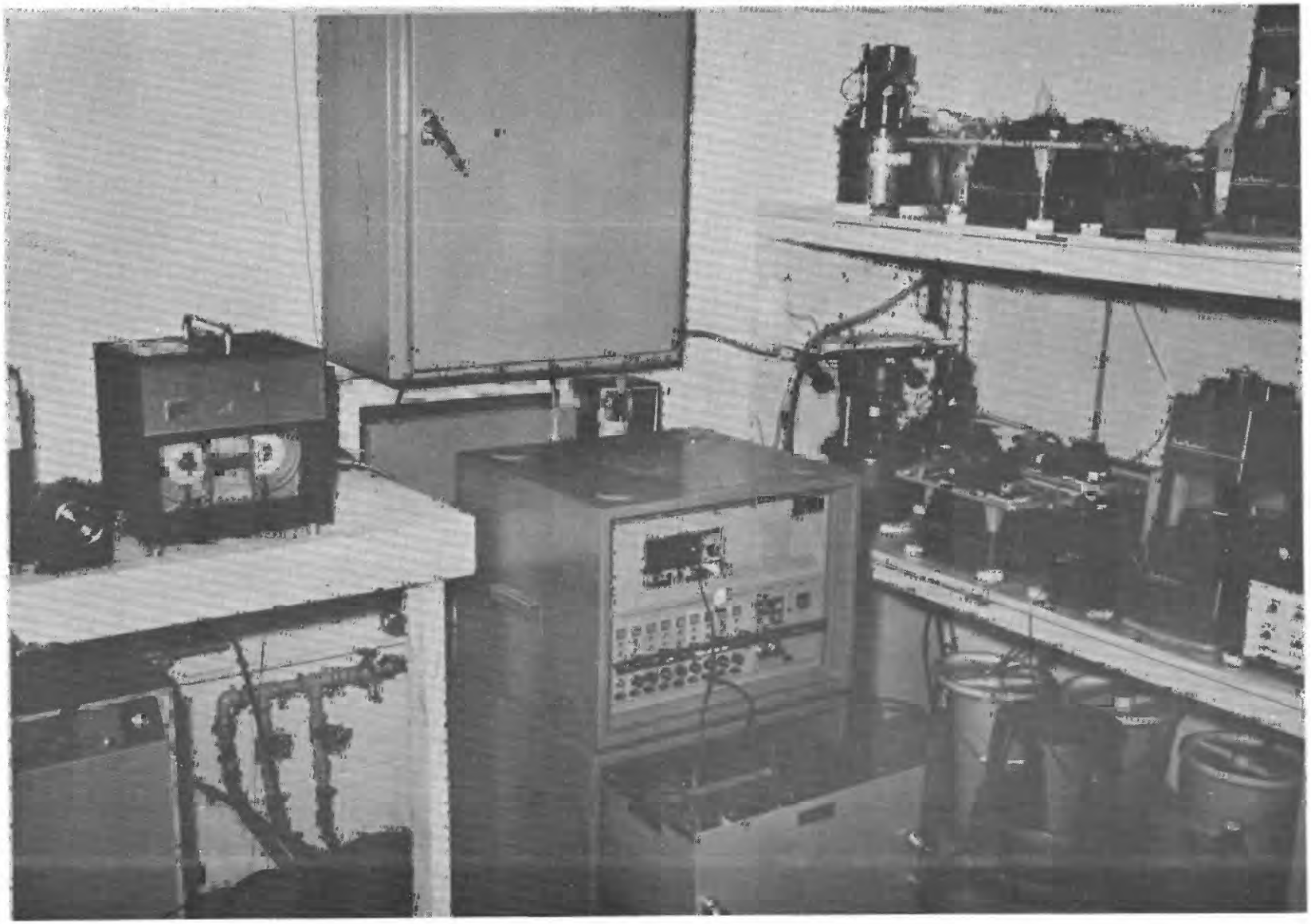

Figure 3. -- A Typical Remote Station with Associated Data Acquisition Equipment

SPECIFICATIONS

1.0 Definition and Scope: This specification describes in various subsections the functional and technical characteristics of the elements and components which make up a variety of digital telemetry systems.

Although the specification is written particularly for systems utilizing a teletype output, there is no intention of limiting a system to only this type of output. The specification of output devices other than teletype shall require a restatement of certain sections contained herein. By the appropriate selection of components from this specification, systems of various degrees of sophistication and magnitude may be assembled.

1.1 General Description: The telemetering systems must be capable of transmitting, periodically or on command, groups of hydrologic data from remotely located measuring stations to a central location. In a basic system a central control station may operate from one to thirty-nine remote stations over a suitable communication channel. Channels may be added, up to a mzximum of ten, to obtain a more complex system with a central control station operating up to 390 remote stations.

Data acquisition systems at the remote stations go through periodic measuring cycles, producing a sequence of sixteen bit, four digit, binary coded decimal (BCD) numbers, on punched tape. There may be up to eleven such numbers in the sequence. At the times of punching, the data are also made available to the remote telemetry stations for storage in prescribed memory modules. Most data variables are significant to only three places and thus require only twelve bits of storage, although at least one variable requires sixteen bits. Data variable-identification prefixes must be provided in the memory modules. Telemetry storage shall be updated with each cycle of the data acquisition system.

Each telemetry remote station will be assigned an identification number. Upon receiving an interrogation message containing this number in a prescribed format, the station must transmit its identification number and all of its stored data variables, prefixed by their identification numbers, according to a prescribed sequence and format. Interrogation during memory update cycles should result in the transmission of a partially updated record. In no case is the stored data to be affected by transmission.

The telemetry central station must control the activity of all remote stations, interrogating them, and receiving and storing and/or displaying their data records. Interrogation must proceed automatically on a prescribed time cycle, sequencing through all remote stations in the system. Any particular remote station's report must also be

available through manual selection, on command. Logging of time for each interrogation cycle must be provided as an optional feature.

Slave central stations must be provided - also as optional equipment - to perform all the functions of a central control station except interrogation and transmission.

2.0 Transmission Code: Transmissions are to utilize a nonreturn-to-Zero, Pulse Duration Modulation (NRZPDM) code. This is a binary code, alternating between two states, mark and space (M, S). Information is derived from the time duration of a pulse as well as its state of mark or space. Pulse durations are based on a unity time duration (T), and are of three types: a SHORT bit of unity duration, a LONG bit of three times unity duration, and a PAUSE bit of six times unity duration. Data logic state "0" is represented by a SHORT bit in the mark or space state (1M or 1S), while data logic state "1" is represented by a LONG bit in the mark or space state (3M or 3S). The unity time duration is defined through the relationship,

$$T = 1/(2F),$$

where F is the frequency in pulses per second that is specified for transmission.

In this system, data is transmitted in an eight bit block form, of which six bits are data and the remaining two are parity and synchronization-pause bits. The data bits are the first six bits in the BLOCK, and are either SHORT or LONG, according to their logic

states. The odd bits are in the MARK state, and the even bits are in the SPACE state. The seventh bit is parity in the MARK state, and is either LONG or SHORT as required to assure an odd number of LONG MARK bits in the BLOCK. The eighth bit is a PAUSE bit in the SPACE state for timing and synchronization. The data BLOCKS are grouped by prefixing a series of them with a special SYNC code consisting of a PAUSE bit in the MARK state followed by a SHORT bit in the SPACE state. Idle line is the SPACE state.

A message takes the form of a SYNC code followed by a string of data BLOCKS.

3.0 Interrogation Message Format: The interrogation message must be generated at the central control station, addressed to a specific remote station, and be responsible for initiating that station's data report. The address must be a six bit BCD number, representing two decimal digits of the form, XY, where Y must range from 0 to 9 in four bit BCD code and X must range from 0 to 3 in two digit BCD code. The format must be a SYNC code followed by two data BLOCKS, each containing the address number of the station being called, as specified above.

4.0 Data Report Message Format: The remote station's data report must be sent as a series of messages, one for the station ID number and one for each of the data variables. The first message must be the station ID number, a five digit decimal representation of the form, 30YXX, 30 identifying it as the ID number, Y identifying the channel (0-9), and XX identifying the station (01-39).

All the decimal numbers in this combination are to be transmitted as four bit BCD codes except the first one, 3, which must be transmitted as a two bit BCD code. This combination requires eighteen bits. The message must take the form of a SYNC code followed by three data BLOCKS.

The second message must be a four place data variable in the decimal form, YXXXX, where XXXX represents the four places of data in four digit BCD form, and Y, ranging from 0 - 3, is an identifier in two bit BCD form. The eighteen bit message must be SYNC code followed by three data BLOCKS. This format is to be used for any additional four-place variables.

The rest of the messages will normally be three place variables in the form, ZYXXX, where XXX represents the three places of data in four bit BCD form, and ZY is one of the combinations 01 to 19 with Y coded in four bit BCD form and Z coded in two bit BCD form. Eighteen bits and three data BLOCKS are required, preceded by a SYNC code for each message. Transmission of a four-place variable, according to the format specified previcusly, must also be allowed in any of these remaining messages.

5.0 Transmission Security: All messages must be generated according to the specific formats stated in sections 2.0, 3.0, and 4.0, and the validity of all information received over the transmission facilities must be subject to the following tests:

a) Input pulses less than twenty percent of unity duration, (T), are to be rejected on the assumption that they constitute spurious line noise.

b) All messages must be preceded by the SYNC code, section 2.0.

c) The parity condition described in section 2.0 must be satisfied.

d) Total pulse count for each data BLOCK must be correct.

e) The presence of the eight bit data BLOCK PAUSE must be tested to at least seventy-five percent of its required time duration, section 2.0.

If any of the above tests fail, the receiver must disregard the information and any that follows, until the beginning of a new message, as indicated by a SYNC CODE.

6.0 Transmission Facilities: The system must be capable of sending and receiving DC (direct current), AM (amplitude modulated) tone, or FM (frequency modulated) tone transmission. Tone transmitter outputs must be adjustable from -40db to +5db and receiver sensitivities must be adjustable down to -40db. Harmonic content must be down at least 42 db from fundamental, with stability of $\pm$ 2Hz or $\pm$ 0.1%, whichever is greater. Impedance levels are to be 600 ohms.

The facilities used may be telegraph or voice grade telephone lines, D.C. pairs, radio link, or microwave, and transmission may range from 15 pulses per second (pps) to 1200 pps.

7.0 Specific Remote Station Functions: The data variables are presented to the telemetering equipment by sixteen parallel contacts arranged in BCD form. In the open state they represent logic "0" and in the closed state, logic "1". All contacts are normally open (logic "0") and assume the coded combination for a period of approximately one half second during the actual punching of the paper tape. The variables are punched in a prescribed sequence on the tape and are

presented by the contacts in the same time sequence. Each of the variables has an associated variable-identifier output. The one identifying the first four-place variable is a set of dry, normally open contacts which close during that variable's recording time. The other ten, representing each of the other ten possible three-(or four) place variables, are outputs with excursions from ground to a positive voltage level during their variable's recording times. The telemetry remote station must provide eleven memory locations for the storage of these variables. The first location must provide sixteen bits of storage for the first four-place variable and the rest must provide twelve or sixteen bits of storage, as required, for each of the other ten variables. Transfer of a data variable to the location indicated by the variable identifier outputs is to occur when at least one of the sixteen data contacts closes. In the case of three-place variables, the units, tens, and hundreds digits are to be stored. Only one level of memory per variable is required, and it is to be updated by each new recording of the variable.

In addition to the storage of data variables, each memory location must provide a means of prefixing the data with a fixed two-digit number represented by six bits in the case of three place storage, and a one-digit number represented by two bits for four-place storage. The formats for these prefixes are described in section 4.0. The five-digit station ID number must also be fixed in storage in the format described in section 4.0. These variable

prefixes and station ID numbers must be available for change by a strapping arrangement. Each memory location must be on a separate plug-in circuit card. System expandability must be possible through addition of memory cards, without wiring changes.

The remote stations must receive transmissions from the central station and perform the security checks required in section 5.0. If the transmissions fail security they are to be disregarded. Valid messages are to be passed on for decoding.

A message decoder, provided with a strapped-in station ID number, must apply a comparison test to the message to determine whether it contains the proper address, as specified in section 3.0. If a positive result is obtained, a read-out cycle shall be initiated.

When instructed by the decoder, a message generator must gain access to the various memory locations and construct and pass on to the transmitting section a series of data report messages according to the formats described in sections 2.0, and 4.0. The station ID and first four-place variable messages must always be sent, followed by any selectable number of the remaining variables. Any scanned memory location which contains no card shall present the number, 00000, for transmission according to the format for the location.

7.1 Data Acquisition System Output Specifications:

Data Contacts - sixteen parallel, normally open dry contacts which assume a BCD code representation of the data for approximately one half to one second during data acquisition. Open contact is logic

"0". Closed contact is logic "1". The contacts are rated at 30ma, up to 24 V. On one side, the contacts are bussed to ground.

Four-Place Variable-Identifier Contact - a normally open, dry contact which closes while the first four-place data variable is being updated. The contact is rated at 30ma up to 24 V.

Three-Place (Or Additional Four-Place) Variable-Identifier Outputs - ten outputs, one associated with each data variable. The outputs are normally in the 0 to +0.5V, 5ma state, and take a +5 V, 1ma state while their associated variables are updating.

Contact bounce and RF noise, due to the presence of several small D.C. motors, are present on all outputs.

8.0 Specific Central Control Station Functions: A timer at the central control station must initiate automatic interrogation cycles. An address encoder must present the BCD representation of the station ID numbers specified in section 3.0 to a message generator in numerical order, starting with station number one.

The message generator, on command from control logic, must form the interrogation message according to the format in section 3.0, using the output of the address encoder as the station ID number. The message generator must then pass the message to the transmitter and to the system.

The remote-station report consists of a series of messages, as specified previously, and as each message arrives at the receiver, it should be passed on to display/storage control, providing it

passes the necessary format and security specifications in sections 4.0 and 5.0. If a violation of this nature is detected, the message is to be disregarded.

The display/storage control must translate the messages and store and/or display them on a page printer, tape deck card punch, or any other suitable specified output device. The display/storage control shall be capable of controlling only one particular specified output device, and for these specifications, this is a teletype unit.

In the present system, the display/storage control unit must control the teletype motor, turning it on only while actually providing display data to the printer, and off the rest of the time. Also, the printer must be held in a mark condition during motor off-time to prevent spurious characters from appearing in the display.

If any station fails to report within one hundred unity time periods (100T), the receiver must cause re-interrogation. If a second failure occurs, the station shall be left out of the record and the interrogation cycle continued. The end of a station's report shall be detectable as at least one hundred unity time periods (100 T) of idle line time, and cause the cycle to be continued. Continuation of the cycle involves incrementing the address encoder to the next station number and interrogating it.

The cycle must continue to a programmed point, at which time the address encoder shall terminate activity. This point must be adjustable from address two to address thirty-nine, inclusive, by a strapping arrangement.

An optional Channel Selector must be available, and provide a full ten channel capability. The Channel Selector must direct the interrogation cycle to channel number one, and utilize the normal end-of-cycle signal to initiate a second cycle, directing it to channel number two, and continue in this manner until a programmed stop is reached. The stop shall be adjustable through strapping to allow interrogation to cease at the end of any selected one of the 10 channel reports.

A manual interrogation capability must also be provided, allowing selection and interrogation of any remote station on command. This station should only be interrogated once, and if no report is received, the procedure should terminate. If a report is received, the normal procedure should be followed in displaying it.

A control panel containing the necessary switches and indicators to select remote stations by identification and channel number and to initiate manual interrogations must be provided. A status indicator shall also be furnished to aid in determining whether manual interrogation may be initiated. The internal logic of the system must protect the normal automatic activities of the station against interruption by manual initiation.

An optional digital clock may be required for time logging the interrogation cycle. Hours and minutes on a 2400 basis must be provided.

8.1 Central Station Teletype Display Format: Each remote station's report consisting of the station ID number followed by its data variables, as described in section 4.0, must be printed in the order received on one line of page printer copy. The items must be separated by a single space. Including the space, each item shall require six characters. Each station's report must be terminated with a single carriage return-line feed combination. The spaces, carriage returns, and line feeds, not being present in the transmitted report, must be supplied in the appropriate positions by the display/storage control section of the central control.

The complete data record of one interrogation cycle must consist of a series of line reports, one for each remote station in order of interrogation. Any variable message that fails to satisfy security or format requirements, or any station failing to report, should be missing from the record. As a means of blocking individual data records, the display/storage control, at the beginning of the interrogation cycle, should generate a single carriage return-line feed combination to the page printer, or, in the case of optional time logging, cause the output of the digital clock to be entered as four digits, followed by a carriage return-line feed combination.

An example of a display of a data cycle of three stations, numbered one to three, with time logging is given. The first station reports no four-place variable, and three three-place ones, numbered from one to three. The second station reports a four-place

and three three-place variables numbered from one to three. The third station reports a four-place and two three-place variables numbered from two to three. The values of the variables are indicated by X's. Two cycles are shown.

0800

30001 00000 01XXX 02XXX 03XXX

30002 2XXXX 01XXX 02XXX 03XXX

30003 2XXXX 02XXX 03XXX

0900

30001 00000 01XXX 02XXX 03XXX

30002 2XXXX 01XXX 02XXX 03XXX

30003 2XXXX 02XXX 03XXX

The same report is next shown without time logging and with station two failing to report in the first cycle and failing security in three-place variable number two in the second report.

30001 00000 01XXX 02XXX 03XXX
30003 2XXXX 02XXX 03XXX

30001 00000 01XXX 02XXX 03XXX
30002 2XXXX 01XXX 03XXX
30003 2XXXX 02XXX 03XXX

9.0 Slave Central Station Functions: Slave central stations shall have no interrogation capability. The storage and/or display of data reports shall be according to the same format specified for a central control station. The unit must be provided with a means of detecting the beginning and end of individual reports from stations. All security tests applied to the data reports in the central control stations are to be similarly applied here.

10.0 Remote Station Assembly: The following sections detail the components required in a complete remote station.

10.1 Remote Station Logic Cards: Plug-in circuit boards shall provide all the controls and procedures necessary to utilize the memory cards, data acquisition system outputs, and line interface unit, and provide a system that meets all the requirements stated in section 7.0. Provisions must be made on the cards to strap in the interrogation ID number, the station's report message ID number, and the point at which memory scanning halts according to the specifications in section 7.0. One set of these cards is needed for a remote station.

10.2 Remote Station Enclosure: The enclosure shall be capable of being gasketed and heated in inclement environments, and be no larger than 24" wide by 24" high by 17" deep. The necessary power supplies, mounting racks, marked card connectors, and hardware to assemble a complete remote station must be provided. The unit shall be fully wired and capable of operating with the insertion of a full complement of cards and appropriate data inputs. The size of memory is to be adjustable by simply removing or adding memory cards as required, and making suitable card strappings. Marked terminal blocks shall be provided for the various data inputs. The enclosure shall contain facilities for mounting and connecting a specified line interface unit. The enclosure shall be provided with tabs for wall mounting.

11.0 Twelve Bit Memory Card: These plug-in circuit cards shall provide twelve bits of memory for three-place data variables. The cards must have facilities for prefixing the data bits with six bit identifiers, utilizing strapping arrangements according to the

specifications given in section 7.0. One card is required for each three-place variable.

12.0 Sixteen Bit Memory Card: These plug-in circuit cards shall provide sixteen bits of memory for four-place data variables. The cards must have facilities for prefixing the data bits with two-bit identifiers, utilizing strapping arrangements according to the specifications given in section 7.0. One card is required for each four-place variable.

13.0 Central Control Station Assembly: The following sections detail the components required in a complete central control station with teletype output.

13.1 Central Station Logic Assembly Cards: These plug-in circuit cards shall provide all the logic functions and procedures necessary to make up the address encoder, message generator, display/storage control, and the central control functions as specified in sections 8.0 and 8.1. The logic for manual interrogation must be included. The system must be capable of operating either with or without the optional digital clock and channel selector. Arrangements for setting the point at which the address encoder halts, somewhere between the count of one and thirty-nine, must be provided, using a strapping procedure. One set of these cards is required at each central control station.

13.2 Cycle Timer: This timer must be capable of initiating the interrogation cycle at the central control station on a periodic time interval from thirty minutes to twelve hours as specified.

13.3 Central Station Enclosure: The enclosure shall be a floor mounted cabinet no larger than 24" wide by 26" deep by 30" high, and contain all the necessary power supplies, mounting racks, marked card connectors, and hardware to assemble a complete remote station consisting of the central station logic cards, the cycle timer, optional equipment, and the line interface units. The enclosure must also contain the control panel with the necessary equipment specified in sections 8.0 and 8.1. The unit should be fully wired and capable of operating with a full complement of cards and the appropriate connections to the page printer and external facilities. Marked terminal blocks must be provided for external connections.

13.4 Digital Clock Option: The clock must present a four-digit (sixteen bit) BCD output representation of the time in hours and minutes for time logging. Interfacing logic needed to use the clock in the system as specified in sections 8.0 and 8.1, is considered as part of the digital clock option.

13.5 Channel Selector Option: These plug-in circuit cards shall provide all the logic functions and procedures necessary for the automatic channel selection procedure described in section 8.0. The cards must provide a means of strapping in the stop position described in section 8.0. Manual interrogation must be possible through the use of a channel selector switch provided on the control panel.

14.0 Display Printer: The display printer shall be a model 33 ASR or model 35 ASR, Teletype Corporation automatic send-receive set, or a suitable equivalent. The unit must be furnished with the motor control facilities specified in section 8.0. Use of the tape punch and tape reader shall be optional.

15.0 D.C. Line Interface: This unit must be able to supply and receive D.C. keying and operate over standard telegraph lines. It must be compatible with the transmitting and receiving inputs and outputs of either the remote or central station. It must meet the transmission facilities specifications in section 6.0.

16.0 Tone Interface (AM or FSK): These units must be capable of operating with the transmitting and receiving outputs and inputs of the remote and central stations, and provide the send-receive capability detailed in section 6.0.

17.0 Slave Central Station Assembly: The following sections detail the components required in a complete slave central station.

17.1 Slave Central Station Logic Assembly Cards: These plug-in cards shall provide all the logic functions and procedures necessary for the proper operation of a slave central station as described in sections 1.0 and 9.0.

17.2 Slave Central Enclosure: The enclosure shall have the same dimensional and functional specifications as the central control station enclosure, with the exception that no control panel is to be provided.

18.0 Construction: All silicon solid-state plug-in printed circuit board construction, with maximum utilization of integrated circuits shall be provided. Components are not to be operated at more than half of their rated values. Commercial equivalent replacements are to be available for all components.

Circuit boards must be glass-epoxy and fitted with pull tabs. Circuit boards and receptacles must have gold plated contact surfaces.

Power supplies shall have short circuit and over voltage protection.

The system, with the exception of output devices, shall require no routine maintenance.

19.0 Power Requirements: The system shall operate from 115 VAC $\pm$ 10%, 60 cps power.

20.0 Environmental Specifications: The system shall operate over a temperature range of 0 to +60°C, and, with the exception of output devices, must be capable of operating over a range of relative humidities which includes the conditions of 90% at 30°C and 40% at 50°C.