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# NCAR TELEMETRY AND COMMAND SYSTEM

W. Jack Snider
NCAR-National Scientific Balloon Facility

## ABSTRACT

Increasingly complex balloon-borne scientific experiments have established a need for sophisticated telemetry and command systems. The National Scientific Balloon Facility (NSBF) has met this need by providing a Pulse Code Modulation (PCM) Data Encoder, a computerized ground station, and a PCM Command System. A description of these systems is presented in this paper.

## PCM TELEMETRY SYSTEM

The ability to accurately recover and reproduce data from a balloon borne experiment is the most important function of the electronic support systems provided by NSBF to the scientific user. As experiments have become more complex, the requirements for support in this area have become more demanding. Greater flexibility in number of inputs, sampling format, bit rate, parity and real-time monitoring capability is a necessity for a system which must meet the requirements of a broad range of experiments. The new Pulse-Code Modulation (PCM) data handling system, which is now fully operational, has answered the demands for this capability in a way that is very well received by the scientific community.

The heart of this system is a PCM data encoder, Spacetac 2100 Series. This unit features modular construction, plug-in format and synchronization word storage and programmable system functions; all of which allow the user to select the system configuration to meet his exact needs without requiring a redesign.

The encoder consists of a control unit and expander modules. The control unit contains the electronics necessary to process, assemble, encode and output the multiplexed analog and digital information from the expander modules.

Input select codes are generated in the control unit from information stored in an electrically programmable read only memory (EPROM) in which the telemetry formats are stored. This device is programmed in accordance with the experimenter's requirements to give him a variety of sampling rates for his input data channels. One EPROM set has storage capacity for up to eight formats. The number of formats per EPROM will vary depending on the complexity of the format and the amount of EPROM storage required. The appropriate format for a particular application is selected from the EPROM by hard-wiring or applying logic levels to pins on the programming connector.

Each analog expander unit (multiplexer) is capable of multiplexing sixteen single ended inputs or eight differential inputs or any combination of single ended and differential inputs. These expander units are interconnected to the control unit subassemblies with printed circuit bus cards which are automatically adapted to any system configuration. A maximum of eight analog multiplexers, providing 128 inputs may be utilized at one time. Each analog channel will accept signals between -5 and + 10 volts without degrading the analog to digital conversion accuracy or resolution.

In addition to the analog inputs, up to eight digital multiplexers with capability for four ten-bit inputs each may be included in the system build-up. These units are interfaced into the control unit in the same manner as described above for the analog expanders. High input impedance (100K ohms) and a wide input signal range (-50 to +50 volts) allows the use of discrete bits for ON/OFF status monitoring of analog signals as well as for digital data. When used in this manner, each digital multiplexer is capable of multiplexing forty discrete event sources into the data stream. These forty inputs are selected as four groups of ten bits each. Associated with the selection of each ten-bit byte is a synchronization signal which rises at least twenty micro-seconds before and falls at least one microsecond after the actual sampling of the ten-bit channel. This signal allows additional data source control.

For frame synchronization a twenty-bit word is stored in a second EPROM set and selected according to the program in the format storage. This word may be expanded up to a maximum of forty bits if required. Subframe synchronization is accomplished by either inverting the frame sync word at the subframe rate or by use of a frame counter.

Programmable functions in addition to format selection include bit rate (1280 bps to 81920 bps with internal oscillator or up to 256K bps with external oscillator), word length (6 to 10 bits), output code (any IRIG code), and parity (odd, even, 1/0 detect, or none). Plug-in pre-mod filters meeting all IRIG specifications are available with frequencies compatible with the standard bit rates. The encoder output drives a subcarrier oscillator which is part of the FM/FM telemetry system. The outputs of all subcarrier oscillators are mixed and used to modulate an L-Band telemetry transmitter for relay to ground receiving stations.

A subcarrier discriminator is used in the receiving station to strip the PCM signal from the frequency multiplex. The data is then processed and recorded using EMR 2700 Series decommutation equipment and a Digital Equipment Corporation PDP-11/20 computer system. The decommutation equipment includes a signal conditioner, frame and subframe synchronizers, binary and decimal displays, and digital to analog converters (DAC's).

After locking onto the incoming signal and establishing synchronization, the frame and subframe synchronizers output parallel data and timing pulses to the PDP-11 computer and to the displays and DAC's for real time monitoring.

The computer system consists of a PDP-11/20 processor featuring 16-bit parallel logic, 24K memory, an extended arithmetic element for hardware multiply and divide, a 64K fixed head disk, a 1.2 million word floating head disk cartridge system, a high speed paper tape reader-punch, and two 7-track, industry compatible magnetic tape units. The telemetry data is processed by the computer for logging on magnetic tape and for real-time display of critical flight parameters on the teletype.

A down-range receiving station is available for use when the flight trajectory extends beyond the range of coverage from Palestine. This station consists of essentially the same equipment outlined above with the exception of the computer. A manual version of the PCM decommutation equipment is available for real-time monitoring and conditioning of the signal for analog recording. The analog tapes are played through the computerized station after the flight to generate the digital tapes. This procedure gives the experimenter a complete set of industry compatible tapes covering his data for the entire flight. These tapes can easily be read into a larger computer for data reduction.

## PCM COMMAND SYSTEM

The second most important function of NSBF electronic support is to provide remote control of the experimenter's payload. With the ability to modify his equipment during a flight, the experimenter can monitor his data in real time and then update the system as necessary. In addition to the scientific requirements, command capability is also necessary for such balloon control functions as the release of ballast or helium and termination of the flight.

To meet these requirements, the NSBF has acquired a Pulse Code Modulation (PCM) command system. The system, developed by United Technology Laboratories, consists of an encoder and a decoder, both of which utilize "Data Communicator" ® Modules manufactured by Larse Corporation. The module in the encoder, known as the "SEN" ® unit accepts sixteen bits of data input and provides time-division multiplexing, encoding and frequency-shift-keying for modulation of the command transmitter. In the decoder, the "REDE" ® unit decodes the data and presents it in its original state as sixteen bits of output.

The SEN unit performs several functions which greatly increase the reliability of this system. These include a special coding of the sixteen data bits and a double transmission of each encoded word. The code consists of a thirty-four bit word to represent sixteen data bits. The word is made up of eight four-bit elements and two synchronization bits. Each element contains two data bits preceded by a low clock bit and followed by a high clock bit. The output signal is frequency-shift keyed (FSK) for modulation of the transmitter. Each bit is represented by a tone of 1440 Hz for a zero state or 1800 Hz for a one state.

The REDE unit in the decoder performs security checks on the data before it is strobed to the output circuitry. Upon receipt of a command transmission, the REDE unit first performs code element checks to ensure that any errors introduced by the communication link are not interpreted as data. The first 34-bit word is then stored until the second transmission has been received and validated. The two words are then compared for bit-by-bit correlation. Upon completion of this check, the last six bits of the data word are released to the output terminals. These bits, designated as address bits, are then patched back into the REDE unit for decoding. If the address is correct, the remaining ten bits are released and a data strobe pulse is generated, indicating that all data is valid for that decoder.

The command encoder provides the selector switches, control logic and timing circuitry necessary to operate the SEN module and to key the command transmitter. There are three modes of operation which are selected using front panel selector switches. In the COMMAND mode, one of forty-eight open-collector drivers in the decoder unit is activated for control of relays or application of logic levels to digital circuitry. The DATA mode allows the transmission of a sixteen-bit data word as one command. The state of the sixteen bits is established by setting toggle switches on the front panel. The REMOTE mode of operation provides for computer control of command transmission. When this mode is selected, all front panel switches are deactivated and the computer is given control of command, data and address selection.

In any of the three modes of operation, the encoder circuitry interprets the switch settings and presents sixteen bits to the SEN unit for encoding and transmission. Bits ten through fifteen are used for address selection in all modes. A total of sixty-four different addresses are possible. In the command mode, bits zero through seven represent the command number and bits eight and nine indicate the type of transmission. For a sixteen-bit data word transmission, the encoder must make two double-scan transmissions. In the first transmission, bits zero through seven of the command word contain data bits zero thru seven. In the second transmission, these bits contain bits eight through fifteen of the data word. Bits eight and nine of the command word are used to identify the two bytes of the data word. Timing pulses from the SEN unit are used to control the sequence of data word transmissions.

The encoder automatically keys the command transmitter for the required length of time to complete each command.

The command decoder accepts the FSK output from the command receiver, performs decoding and security checks, and presents the sixteen-bit command word to the output circuitry. A data ready pulse from the REDE unit initiates a timed sequence of decoding and command activation.

The output logic interprets bits eight and nine of the command word to determine the mode of operation. If these bits indicate a discrete command, bits zero through five are decoded and used to activate the appropriate open-collector driver. Associated with each command is a twenty-four volt dc output which is turned on by the control circuitry for fifty milliseconds. This voltage is used in conjunction with the driver to activate the command function. A current limit of eighty milliamperes prevents damage to the driver circuitry.

When the data mode of operation is detected, bits zero through seven of the first transmission are loaded into a temporary storage register. When the second transmission is completed, bits eight through fifteen of the data word are loaded into the output register and a data strobe pulse is generated to initiate a parallel dump of the full sixteen bits to the user's circuitry. When used for flight termination, the decoder is assigned an address number which is in the upper thirty-two possible addresses. This is done to prevent accidental termination of a flight. The most significant bit of the address code is protected in the encoder using a switch in series with the address selector switches. In order to transmit a command to a termination decoder, this additional switch must be placed in the "terminate armed" position. A warning light on the encoder gives an indication when either the address selector or the terminate armed switch is set for termination.

## DISCUSSION SUMMARY — PAPER 5.1

Several questions regarding technical details of the system were asked. These and the answers given by the speaker are summarized below:

Q. Does the PCM encoder that you fly go into your FM-FM system?

A. Yes. We still have the FM-FM in addition to the PCM.

Q. Do you put those in the Omega and other subcarriers?

A. Omega occupies Channel 13 band in the FM multiplex. The Rossmont signal is generally put into one of the analog channels of the PCM and in some cases the subcarrier as well.

Q. Have you ever had problems with the PDP-11 that caused flights to fail and, if so, is it possible that a back-up PDP-11 will be bought?

A. There do not appear to have been failures during flights which caused loss of data.

Q. What is the power consumption on the encoder full blown?

A. Roughly 120 mils at 28 volts.