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A BURIED TELEMETRY SYSTEM FOR IN-SITU ENERGY EXTRACTION

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ABSTRACT

During an in-situ energy extraction process, a continuous knowledge of the temperature profile through the combustion area is desirable for analysis and control. To provide this data, a telemetry system has been developed that will monitor the thermocouples from beneath the process bed, digitize the data into 12 bit words and store them into memory. Every six hours, the stored data is transmitted laterally through the earth to a receiver outside of the high temperature zone and then sent to the surface by wire where it is stored on magnetic tape and processed and displayed on a ~~T. I.~~ TEXAS INSTRUMENTS Silent 700 terminal.

INTRODUCTION

Beneath portions of several western states lie very large deposits of tarsands, oil shale, and coal which at present are accessible only through conventional extraction methods requiring physical excavation of a deposit area with attendant ecological and safety problems. However, several experimental programs have been undertaken, and more are planned, which seek to remove the energy content from a deposit without excavation. Most of these in-situ energy extraction concepts involve burning the deposit underground which requires temperature data for the control and analysis of the process.

As an example of an in-situ process, consider an underground coal gasification experiment. Air or oxygen is injected down a process well to support a fire which has been ignited in

DISCLAIMER

the coal seam. Extraction of the product gases, mostly N_2, H_2, CO, CO_2, and CH_4 is accomplished through another process well further down the seam. Between the injection and extraction process wells, several instrumentation wells are drilled into the coal seam to determine the extent and position of the reaction zone. Within these wells, strings of thermocouples (TC's) are positioned on a messenger cable throughout the thickness of the seam. To prevent the escape of the product gases from the instrumentation wells, they are filled with grout after the TC's have been positioned. Preferably, the gasification process would first consume the coal in the lower part of the seam creating a void into which the remaining coal would fall, producing a reactor with a large surface area. However, this ideal process geometry has been difficult to achieve, and in practice, the combustion area frequently moves to the center or top of the seam. When this occurs, the hot (>1100° C) reaction zone severs the TC leads to the surface resulting in the loss of temperature data that could compromise the understanding of the process. This problem is overcome by using a second TC string connected to an instrumentation package beneath the seam. The telemetry package samples, digitizes, and stores the TC outputs every hour and then transmits the data every six hours via a low frequency (14,500 kHz) link to a receiver in a vertical shaft outside the high temperature zone. The receiver output is cabled to the surface, demodulated, and sent to a data processor. The use of the dual TC strings guarantees temperature data regardless of where the burn is located in the seam until the time that the seam thickness is consumed. The low frequency propagation through the earth is discussed thoroughly in another report that is available[1] and is also treated in an extensive report on the telemetry system[2]. This paper discusses some of the features of the telemetry system and concludes with some results of a recent coal gasification experiment.

MEASUREMENT TRANSMITTER UNIT

The Measurement Transmitter Unit (MTU) is a totally self-contained unit that provides the timing and control for the entire system. The fielded unit was 146 inches long, 4 inches in diameter, weighed 99 pounds, and was divided into three sections. The first section or upper section is 14 inches long and has all the TC's permanently attached. The middle section, the electronics housing, is an aluminum tube 37 inches long which contains the digital module, the battery module containing six D-cell size lithium batteries connected in series, and the transmitter module. The lower piece, 86 inches long, is a fiber-glass tube in which the transmitting antenna is encapsulated.

The functioning of the MTU can be understood with the use of Figure 1. The "Read-Out Command" line shown on the diagram is used to force an output for system checkout and to initialize the timing sequence. It is cut off and sealed the day before installation, and then the MTU depends upon a crystal-controlled clock to provide timing for the data cycle every hour and for transmission every six hours. The clock and counters are both

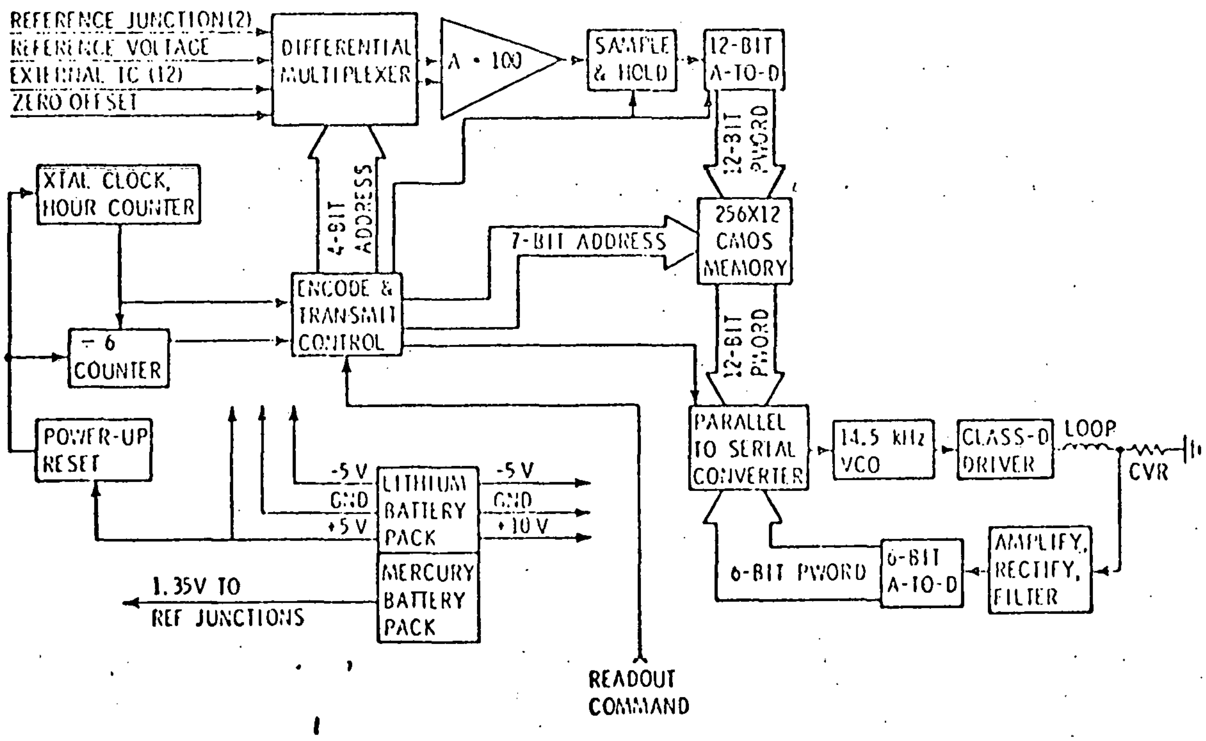

Figure 1. Measurement-Transmitter Unit Diagram

powered-up and reset by making the connection to the battery pack. The time of connection sets the moment of each subsequent hour at which measurements will be taken. When this moment is reached the clock energizes a relay that applies power to the encode electronics whereupon up to 13 TC's, two cold junction compensators, and a reference voltage are successively selected, amplified, converted to a 12-bit digital word, and stored into memory. Only one amplifier is used so that any drift in the amplifier off-set voltage or change in amplifier gain can be detected by the use of the reference voltage. Corrections can then be made to the data by surface software. About 1.5 seconds is required to make the hourly measurement during which time 3.5 mA is drawn from the battery pack. When the system is idling between measurement periods the current drawn is 0.27 mA.

When each sixth data cycle is complete, the transmitting circuit is energized. A frequency of 14225 Hz corresponds to a binary zero and 14775 Hz corresponds to a binary one. Alternate ones and zeros are sent during a three-second stabilization period after which the antenna current is measured, converted to a six bit word, and transmitted preceeded by a sync word. The stored data are then read out in chronological order and transmitted. The bit rate during transmission is 78.5 bits/second and the measured spectrum bandwidth is 800 Hz. The Class-D loop driver provides a DC-to-AC conversion efficiency that decreases from 97% to 90% over the battery life. The current drain during the 19 seconds required for readout and transmission is 300 mA. The total average battery demand each six hours is 505 μAH. Dividing this demand into the battery capacity of 8 AH provides a projected battery life of 660 days. An accelerated operational test of an MTU demonstrated battery capacity for 446 days, so that by either estimate the 180-day requirement is exceeded.

THE RECEIVER

The receiver is divided into two parts, the buried components and the surface components (Figure 2). The buried components are

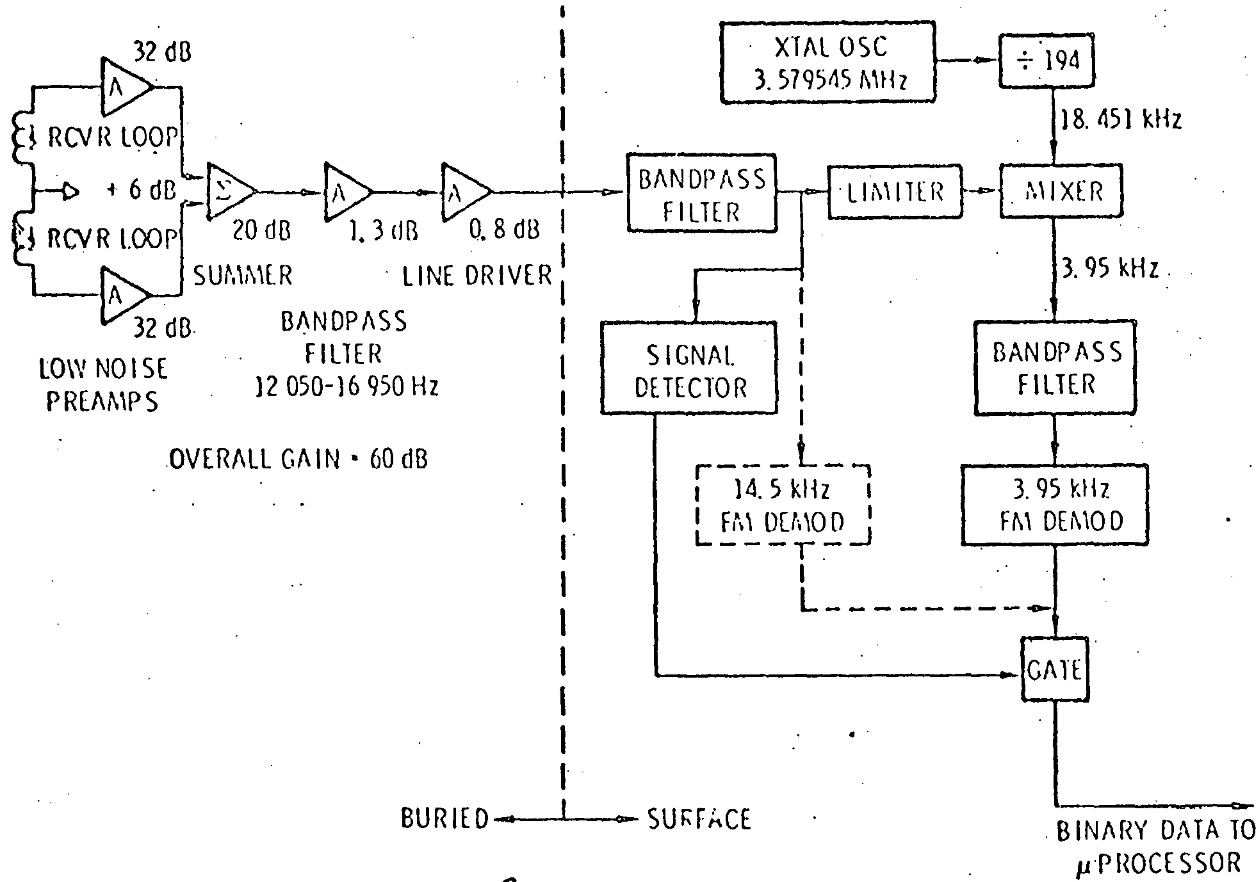

Figure 2. Receiver Diagram

powered from the surface and provide a low-noise amplifier with 60-dB gain and a 3-dB bandwidth of 4900 Hz centered at 14500 Hz. On the surface the signal is down-converted to 3950 Hz and demodulated. The demodulator output to the microprocessor is inhibited by the phase-locked-loop signal detector until a signal is detected. This prevents high level transient noise from energizing the surface data processing equipment. The 14500 Hz demodulator, shown by dashed lines, was used at Hoe Creek because the range was only 10 m instead of the design range of 46 m. The carrier level was thereby increased by 42 dB so that down-conversion and narrow band-filtering were not necessary.

The buried receiver is 64 inches long, 4 inches in diameter, and weighs 44 pounds. The upper 17 inches of the unit is unencapsulated and strengthened with an internal aluminum tube to provide room for the encapsulated preamplifier and a hollow spacer within which the receiver antenna leads are coiled upon assembly. The remainder of the unit contains the receiver antenna. For this fielding, the surface bandpass filters and demodulators were commercial items that were available. In the future, bandpass filters and demodulators designed and built specifically for this use will be incorporated into the system.

THE SURFACE DATA PROCESSOR

Physically this equipment consists of three modules, a data processor, a demodulator chassis, and a Texas Instruments Silent 700 terminal (Figure 3). Both the data processor and the demodulator chassis contain elements of the surface receiver already described. The surface data processor continually looks at the output of the receiver for the string of alternating 1's and 0's that the MTU transmits first. Upon recognition of the alternating pattern, input signals to a buffer memory are turned on and the next 2048 bits of data received are loaded into the buffer memory. The memory is then scanned for a proper sync word. If no sync word is found, data is regarded as noise and is dumped. If the sync word is found, the microprocessor is flagged that data is ready. The microprocessor takes the data from the

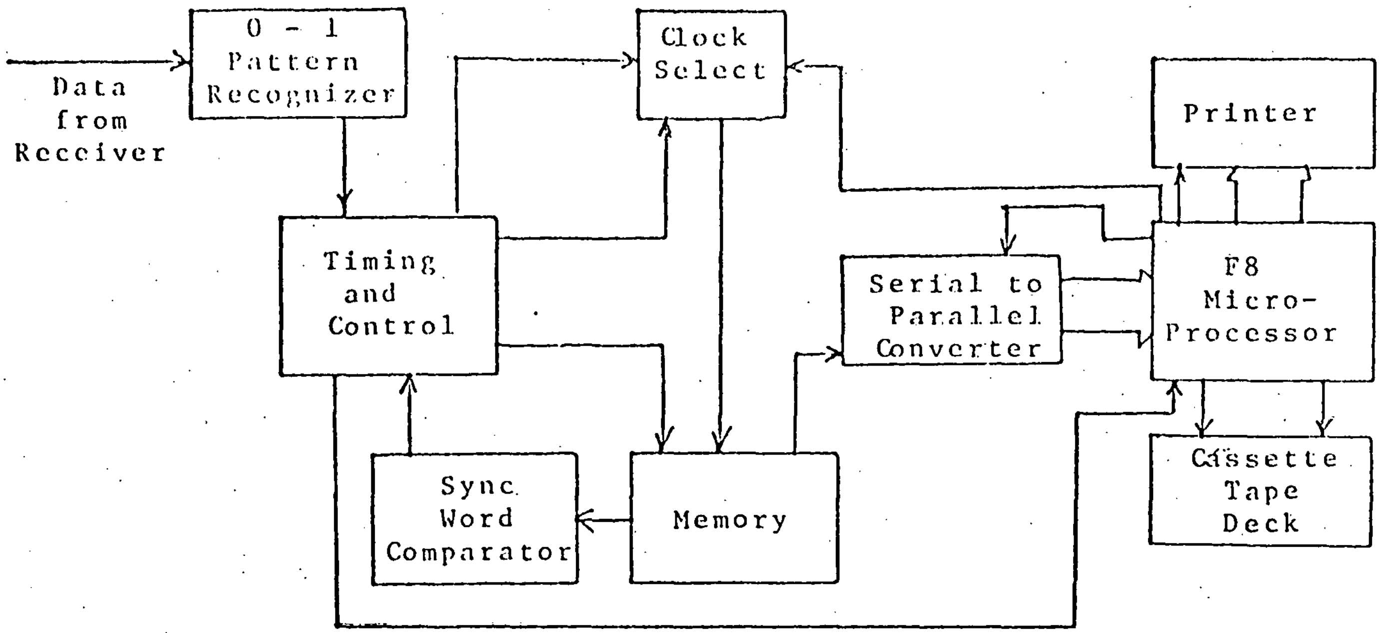

Figure 3: Surface Data Processor Diagram

buffer memory, transfers it to cassette tape for permanent storage, and then processes it into engineering units. The thermocouple data is converted to degrees centigrade and the offset and gain monitors are converted to volts. The converted data is then printed on the TI-700 terminal along with the time of each encode cycle.

HOE CREEK EXPERIENCE

The MTU was located within the Hoe Creek III experiment slightly to the side of the line of process wells and was initiated and sealed at 0.930.00 MDT on July 3, 1979 (Julian Day 184) then temporarily installed at a depth of 25 meters where it hung overnight. The MTU was retrieved the next day, the LLL-thermocouples were attached, and both were emplaced together. Grouting was initiated the next morning and the temperature rise caused by the exothermic reaction of the grout ~~could be~~ was clearly seen ~~which provided a system check~~.

Hoe Creek III was ignited on Day 227 (August 15, 1979) and, after a brief period of reverse combustion along the drilled borehole connecting the process wells, forward gasification was initiated. The arrival of the gasification process was detected first by the thermocouple nearest the coal overburden interface. Shortly after this time the LLL thermocouple string terminating at the surface failed, and the only temperature information below the burn in the Felix 2 seam was from the MTU. Figure 4 shows time histories for the top five thermocouples, and indicates the progressive movement of the gasification process down into the seam. Once having reached approximately 1200° C, the top three thermocouples track one another indicating that these three have probably failed. The slower heating rate seen by the 5.5 m thermocouple, and its failure to reach gasification temperatures, indicate that gasification was no longer active near the MTU well during the later stages of the test.

The Hoe Creek III test ended on Day 282 and the LATRAN surface equipment was removed after the 0933.52 MDT readout on Day 296. The downhole equipment was checked again on March 14, 1980,

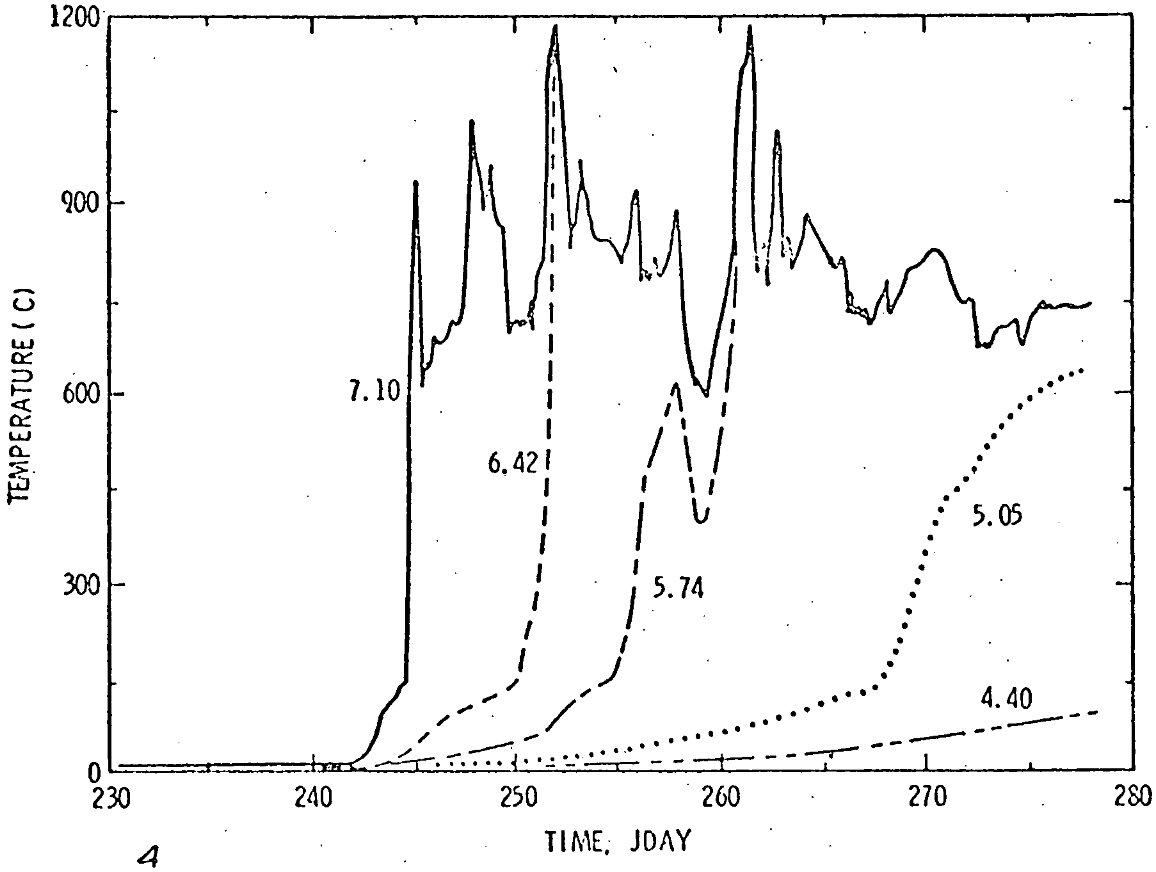

Figure 4. Temperature History of Top Five Thermocouples (Height above Felix 2 seam floor indicated on graph)

and a normal transmission was received at 2036.10 MST. Temperature in the seam varied from 13°C at the bottom to 53° C at the top and the monitored antenna current still had not diminished from its value when the system was initiated 255 days earlier indicating the battery pack was still delivering peak power. All initial design goals were met or exceeded for this experiment, and indications are that the system will still be functioning a year after its emplacement.

REFERENCES

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2. Barnes, D. E. and Caffey, T. W. H., "A Lateral Transmission System for Buried Instrumentation", SAND79-2301, Sandia Laboratories, Albuquerque, NM, April 1980.