A BROADBAND DIGITAL GEOPHYSICAL TELEMETRY SYSTEM

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ABSTRACT

A system has been developed to simultaneously sample and transmit digital data from five remote geophysical data receiver stations to a control station that processes, displays, and stores the data. A microprocessor in each remote station receives commands from the control station over a single telemetry channel. The commands adjust the sensing amplifier's input voltage range (1 microvolt to 2 volts peak-to-peak), the number of samples (128 to 30,000), the sampling rate (256 to 32,768 samples/sec), and the number of signals (1 to 16) to average at the remote stations. A 12 bit analog-to-digital converter samples data with bandwidths of 100 Hz to 10 kHz for time periods selected from 100 seconds to 1 second, respectively. Each remote station begins sampling geophysical signals when it receives a synchronizing pulse relayed from the control station. Digitized geophysical data is transmitted to the control station over broadband (100 kHz bandwidth) UHF telemetry channels using standard asynchronous serial (19.2 kbaud) techniques and hardware dropout detection and recovery. The amount of data (480 kbits) and the maximum time to transmit data (30 secs) dictate using broadband telemetry (even though most geophysical telemetry is less than 10kHz in bandwidth). Header information (transmitted before the data) contains station number, digital sampling parameters, transmission block size, and checksum. This information is used by a computer program (in a PDP-11/23 ([***]) minicomputer) to maintain up to 5 simultaneous Direct Memory Access (DMA) transfers from the remote stations into 5 separate data buffers. Filled buffers are transfered (via an IEEE-488 bus) to an interactive analysis and display system (HP9845C ([***])) for selecting data to be stored on magnetic media for subsequent laboratory analysis.

*** Any use of trade names in this paper is for descriptive purposes only and does not imply endorsement by the U.S. Geological Survey.+++

INTRODUCTION

With a few noteable exceptions (LANDSAT multispectral scanning, seismic and seismological telemetry), telemetry has not been used for geophysical data collection. While biomedical engineers have built small, low-power telemetry systems for mobile data collection and other engineers have developed wide bandwidth and high power telemetry systems for satellites, geophysical data collection has been accomplished primarily without use of telemetry. Usually, geophysical variables (gravity, magnetics, induced polarization (IP), self potential (SP), seismic, and many kinds of electromagnetic field measurements) are collected using handheld analog instruments or hard wired systems.

The data rate needed to collect most geophysical data is low and in most cases does not justify the expediture for telemetry. Typically, only a few values are measured or a single curve is generated for a given geographic location (station). For example, as recently as 1981 Ma Qing-Yun (1) reported developing a compatible “high density” binary code used with multiple-channel digital seismic telemetry for signals having a bandwidth of only 20 Hz. Yamazaki(2) described (in 1980) a system for continuously transmitting apparent resistivity from the Aburatsubo Crustal Movement Observatory (60 km) to the Earthquake Research Institute in Tokyo over a low speed (50 bits/sec) D1 telephone line. Telemetry is in part justified for other scientific instrumentation in order to transfer data with greater bandwidth. For instance, Klein and Davis (3) used (in 1976) a 4 channel hetrodyned biotelemetry system with 10 kHz bandwidth and unknown dynamic range. In 1979 Seeley, et al (4) reported a seven channel multiplexed biotelemetry system which FM modulated a carrier in the commercial FM band (88 to 108 MHz). Because each channel had 150 Hz bandwidth and greater than 46 dR of dynamic range, this system had a transmission rate equivalent to more than (150 * 2 samples/cycle * 8 bits/sample * 7 channels =) 16,800 bits per second. Oceanographic telemetry has also evolved to meet the demand for higher data transfer rates. In 1979 Morgera (5) proposed using parametric acoustics to obtain “high” data rate acoustic telemetry and in 1980 Ryerson (6) demonstrated transmission of 2400 bits per second through 200 meters of water using a high data rate underwater acoustic telemetry system. In 1979 Divis (7) reported transmission of oceanographic data at a bit rate of 32 kHz using airborne telemetry from spar buoys. Recently, some geophysical data measurement requirements have justified the use of telemetry systems. By 1977 Roger, et el (8) developed a multi-channel digital telemetry system for the USGS Digital Seismic (earthquake) Telemetry Network. In 1981 Bisztricsany, et el (9) proposed a similar digital seismological telemetry network in Hungary using a VHF radio telephone system that transmits 3000 bits per sec.

This telemetry system (Figure 1) was developed to simultaneously measure the transient voltage potentials sensed at five remote stations when electricity is injected at some source location in the earth. Measurements of this kind had previously been limited to determining a single value for the steady state DC voltage gradient at each intersection on a 10 meter grid and required as many as 400 measurements for each source location. Computerized modeling programs display the differences (anomalies) between the measured voltage array and the potential field predicted for each source configuration. The sampling rate and number of samples determines if the response measured is the steady state electric field or the transient response, known as the time domain electromagnetic (TDEM) response. According to theory, TDEM signals provide the most information about anomalies, but require wideband (100 kHz) telemetry to transmit enough data in a reasonable period of time. Telemetry also provides command and control functions to automate the calibration, the input gain and filter adjustment, the sampling parameter selection, and the number of signals averaged at the remote stations.

SYSTEM DESCRIPTION

As shown in Figure 1, the “broadband digital geophysical telemetry system” has been designed to collect and transmit TDEM data from as many as 5 remote field stations when commanded by the control station and includes more than just a telemetry link. This system also includes many computers and computer interfaces programmed to maintain the proper data collection sequence for each of the independent remote stations, to relay synchronizing (sync) pulses generated at the source, and to receive, analyze, and store the digitized results. Each remote station can collect up to 30,000 samples (16 bits each) and in order to transmit these 480,000 bits in a reasonable period of time (30 seconds), each telemetry channel must transfer at least 16,000 bits per second. Adding format and signal dropout detection and recovery bits increases the data rate to nearly 19.2 kbaud which was obtained using commercially available “broadband” (100 kHz bandwidth) UHF (412 MHz) telemetry links. A single telemetry channel is used to synchronize the start of sampling at the remote stations with the start of the source signal and to transmit commands from the control station to the remote stations. The control station operator uses an interactive program to select the sampling parameters (gain, anti-alias filter frequency, number of samples per signal, and number of signals stacked per average) for each remote station. Because each remote station can digitize voltages (1 microvolt to 2 volts peak-to-peak) sensed at electrodes, or across fixed resistors or coils of known impedance, this system can measure electric or magnetic fields along any desired axis as well as the source’s current or voltage. As a result, one can measure nearly any broadband geophysical signal that is synchronized to a source and that has a bandwidth of less than 10 kHz.

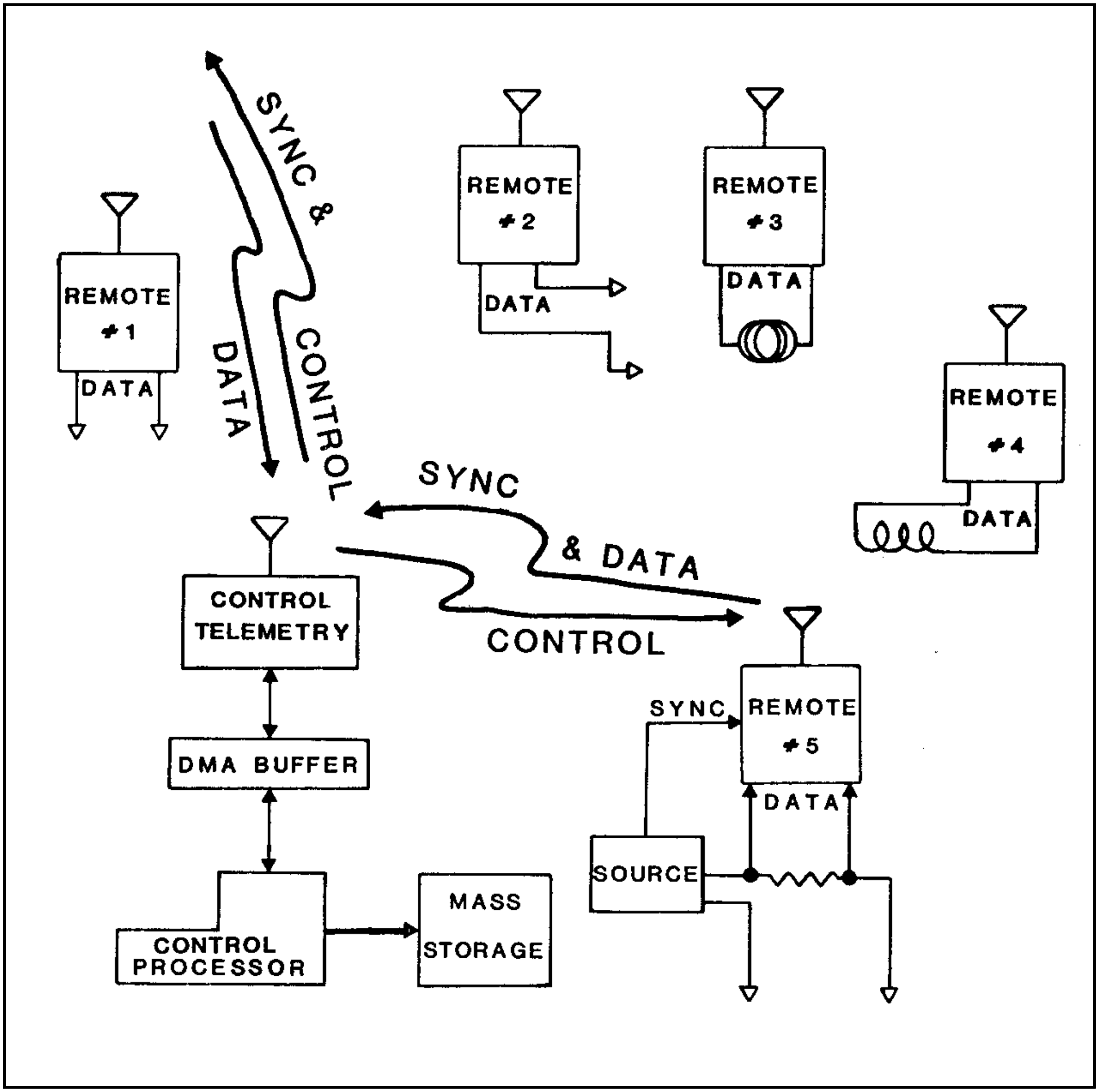

Figure 1. - Broadband Digital Geophysical Telemetry System Block Diagram

TELEMETRY PROTOCOL AND TIMING

An important feature of this system is its telemetry protocol which was designed to minimize routine interactions between operators at the control and remote stations. This protocol is the orderly exchange of commands and sync pulses from the control station to the remote stations and of status and data from the remote stations to the control station. Each remote station operator sets switches that indicate that station's location and sensor orientation, turns on the power switch, and then stands back while data is collected. The control station operator selects operational parameters from a menu on a computer

(HP9845C) and views incoming data from each of the five remote stations on a graphics screen, determining which data is to be stored, discarded, or used in a real time analysis program. Although data from each of the five remote stations is transmitted over a separate broadband (100 kHz) telemetry channel, only one narrow band (10 kHz) telemetry channel is used to transmit control and sampling sync pulses from the control station to the remote stations. Each remote station is assigned an identification (ID) number and executes only those commands preceeded by its ID number. The control computer keeps track of time and transmits commands only when the remote stations are not digitizing data. Sync pulses are detected at the remote stations using maskable interrupts so that sync pulses can be ignored when a station is not in the sampling phase of protocol and so that digitization can begin with minimum time jitter when sampling is to be performed. Timekeeping and hardware masking prevent data loss by not interrupting critical software (such as high speed sampling or data transmission routines).

The transmission of a sync pulse does not guarantee the synchronization of sampled signals at remote stations relative to the source signal. A different period of time (delay) is required between the transmission of the sync pulse and the start of the first sample of data at each remote station. This delay is dependent upon fixed variables such as 1.) range between a transmitter and a receiver, 2.) transmitter modulation and receiver demodulation times, 3.) sync pulse decode time, and 4.) microprocessor instruction cycle time. Transmitting the sync pulse before the source signal actually starts can compensate for these fixed delays. But one can not compensate for the variations (jitter) in these fixed delays and for variable delays caused by decoder and microprocessor clocks (and dependent software) that run asynchronously relative to each other. The total jitter of this system has been maintained at less than 15 microseconds so that the time resolution will be within one half of a sampling period (about 30 microseconds) at the highest sampling rate of 32,768 samples per second.

Note that one of the remote stations accepts (from the source generator) and transmits (to the control station) the sync pulse used to start digitization, 100 milliseconds before the start of the source. Using a remote station as a sync pulse relay station enables the system to sample the source voltage or current. These digitized data can be compared with previous or expected values and used to warn the control operator when malfunctions or irregular source levels occur. Statistical data can be collected and used to inform the control operator when queried or when the source deviates from the mean by preset limits. Perhaps the most important reason for sampling the source is to get a replica for deconvolving data received at the other remote stations. The replica can be taken during each individual “shot” or it can be an average of source signals taken during successive shots according to parameters set up by the control operator. The opportunities available for digitally filtering data or correcting data for changes in source amplitude or frequency content easily justify dedicating a remote station for source monitoring.

CONTROL STATION PROCESSING

Because the remote stations operate independently of each other, they are usually performing different parts in the above described protocol. Therefore the control station must maintain five asynchronous “conversations” with the remote stations: communicating control data and accepting preprocessed data according to protocol. The control station also displays the results from the last data set received, calculates and displays analysis results, and saves data in mass storage (for processing at a later date). These overlapping requirements place severe demands on the control station’s processing and display capabilities. Needed functions include: 1.) high-speed data transfers (eg. direct memory access, or DMA) to memory, 2.) interactive graphics display and control for data presentation, 3.) sufficient memory and matrix mathematics to satisfy analysis requirements, and 4.) high speed data output (again DMA) to record data or computational results on a mass storage device. In addition to these requirements, the control processor must survive severe environmental conditions (vibration, dust, and temperature extremes) and run on imperfect power supplies (portable generators). The selected processor (HP9845) has been used under similar environmental conditions with other systems, but this processor cannot control more than one DMA at a time. An intermediate data buffer/processor(LSI-11/23) is used between the control telemetry and the control processor to collect data into five separate and complete data sets before sending the data to the control processor over an IEEE-488 I/O channel Although the buffer unit is programmable, its main virtue is being able to process the data from six (5 from telemetry and 1 from the control processor) uncoordinated inputs quickly enough to avoid data loss, and having enough memory (256 kwords) to temporarily hold 5 or more data sets. Additional interfaces in the buffer computer include 5 separate timers that manage the timekeeping mentioned above and a DMA disk interface for storing processed data sent from the control processor (via the IEEE-488 interface) in mass storage (a 15 megabyte Winchester disk).

CONCLUSION

A system has been developed that enables the simultaneous collection of field data from 5 different locations. The number of data points(as many as 30,000) and the transmission time limitations (30 seconds maximum) dictated the use of broadband UHF telemetry channels. Although this system was developed for high frequency (up to 10 kHz) transient response applications, its input amplifier can be programmed with sufficient gain to measure either voltage potentials or loop currents (through a fixed resistance). Using lower sampling rates (selectable in factors of two from 256 to 32,768 samples per second), this system can be programmed to make nearly any geophysical measurement. Using computer controlled variable gain (1 to 256 in binary steps) amplifiers increased the amplitude resolution of data by more then 40 dB over analog recording techniques and decreased data collection time by automatically (instead of manually) adjusting the gain. When several stations collect data based on the same source signal, then time dependent variations in the source and the environment are eliminated and noise can be reduced by adaptive filtering and common mode signal subtaction.

The advantages of this system include: 1.) ability to measure transient responses (eg.TDEM); 2.) faster data acquisition due to simultaneous sampling at several remote stations and automated control of operation; 3.) improved time and amplitude resolution of data due to selectable sampling rates and signal averaging at the remote stations; 4.) adaptability to a variety of geophysical measurements (resistivity, IP, SP, TDFM, seismic, etc.) due to high sampling rates and programmable gain amplifiers; 5.) real-time data reduction so that subsequent stations can be chosen for optimum geologic definition; 6.) noise reduction of data generated by exactly the same source signal and sampled at several locations: and 7.) retention of preprocessed data for further analysis in large computer analysis programs.

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