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1965 (2nd) New Dimensions in Space Technology

Apr 5th, 8:00 AM

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DIGITAL DATA ACQUISITION SYSTEM IN SATURN V

by

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and

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ABSTRACT

This paper describes the digital data acquisition system (DDAS) and explains its use in the calibration and checkout of the Saturn V space vehicle.

The size and complexity of the Saturn V vehicle necessitates computer controlled checkout. The DDAS combines the functions and hardware normally required for a flight telemetry system into a relatively low-bit-rate, high capacity pulse code modulated (PCM) system. This system may be used in ground or airborne checkout and calibration and as a PCM telemetry system for R&D and operational flight-control data.

The overall design of this system and its relation to the Saturn V automatic checkout scheme is described with emphasis on the ground support hardware.
BACKGROUND AND INTRODUCTION

The acquisition of data concerning the condition of certain parameters associated with the Saturn space vehicle is a prerequisite to checkout and performance verification. Checkout of a multistage, liquid fuel vehicle as large and complex as the Saturn requires that thousands of parameters be monitored and recorded. Calibration is also provided to authenticate the monitoring system. Forerunners to the Saturn vehicle used hardwire transmission as a means of transferring pertinent data from the transducers to the ground support consoles during factory and prelaunch checkout.

In the past, onboard data multiplexing has been successful for telemetering flight data, although its use in vehicle checkout has been limited. These limitations were caused by the short service life and poor reliability of mechanical commutators. Mechanical commutators served adequately in flight, but were not reliable for the long operating periods required in vehicle checkout. In the past ten years, solid state multiplexers (commutators) have been perfected to the extent that they can be used reliably and economically in serializing data for test and checkout as well as for inflight telemetry.

Early in the Saturn V program, the design of a pulse code modulated (PCM) data system was initiated. PCM was planned for use in transmitting relatively low frequency time division data. These data were originally handled by a pulse amplitude modulated (PAM) system in the early Saturn I program. The Saturn I required a high capacity solid state multiplexer which had undergone a considerable evolution in design changes to improve its reliability. The decision was made to design the PCM system to be compatible with the Saturn I solid state multiplexer to take advantage of its proven reliability, and to phase PCM transmission capability into the schedule at minimum cost. By testing the PCM system during the Saturn I program, a proven reliable system could be provided for the Saturn IB and Saturn V vehicles. After the checkout requirements for Saturn V had been determined, it was apparent that computer controlled checkout was essential to correlate the data in a timely manner. Telemetry system analysis indicated that the PCM system could be readily adapted to acquire most of the data necessary for computer controlled checkout. Since most of the flight data were already multiplexed into the PCM channels, only minor modification of the flight hardware was necessary to transform the PCM equipment into a combination checkout, calibration, and airborne data system. The changes essentially involved paralleling the higher frequency flight data into additional multiplexer channels, increasing the number of discrete inputs, providing mode switching, and adding a 600 kHz carrier for transferring the data (closed loop) into the ground support equipment (GSE). Since the calibration and checkout data are quasi static, a relatively low sampling rate was adequate. Consequently, the checkout measurements could be added without increasing the bit rate. The instrumentation system was
designed so the SS/FM and FM/FM subsystems, required for wideband data in the early R&D flights, could be removed as the demand for R&D data decreased. The removal of the wideband systems can be accomplished without major redesign. In this manner, the operational data system can be thoroughly proven on R&D missions without changing the operational portion of the system, and operational weight can be reduced by strip-out capability rather than costly redesign.

**VEHICLE DIGITAL DATA ACQUISITION (DDAS) SYSTEM**

The combined measuring, DDAS, and telemetry system of the Saturn V launch vehicle measures physical quantities and signals on the vehicle and transmits the data to ground stations. The data transmitted by the measuring and telemetry system supply information for the following:

- Automatic preflight checkout of the vehicle
- Monitoring of vehicle performance during powered flight
- Postflight evaluation of vehicle performance
- Monitoring and checkout of the vehicle during orbital flight
- Verification of commands received in the vehicle from ground stations.

Each stage of the launch vehicle has an independent measuring system with very little interfacing of measurements between stages. Likewise, each stage has its own independent DDAS and telemetry system. This makes the vehicle DDAS output usable for checkout and calibration at the contractor's facility and for static firing as well as prelaunch checkout.

The measuring system includes transducers, signal conditioners, measuring distributors, and the remote automatic calibration system (RACS). An example of the measuring system is shown in Figure 1. The transducers are precision electromechanical measuring instruments containing sensing devices carefully designed for accuracy, reliability, and resistance to unfavorable environment. Signal-conditioning modules are employed to adapt the outputs of the transducers to the electrical input requirements of the telemetry system. The modules are mounted in measuring racks that provide flexibility and ease of maintenance. Certain transducers have output signals that do not require signal conditioning. These signals are fed directly to the measuring distributor.
The measuring distributor is similar to a junction box. Most measurements are connected through the distributor and are directed to their preassigned telemetry channels. The distributor provides versatility in changing channel assignments, with the changes being made by physically rearranging jumper wires within the distributor. For computer controlled checkout, it is necessary that some means be provided for verification of the measuring system. This capability is provided by the RACS. This system provides a means by which the computer can select a specific data channel, effect a change in the signal conditioning module, and check the output to preselected tolerances. The system has three modes - HI, LO, and RUN. The HI mode presents a calibrated input to the signal conditioning modules that gives a calibrated output to verify the high end of the transducer range. The LO mode verifies the low end of the transducer range. The RUN mode is the normal operating condition for the system. The system is controlled from the launch control center computer or other programing device. Data readout and display equipment is provided in the launch control center.

A block diagram of a typical Saturn V stage telemetry and DDAS is shown in Figure 2. From one to six time-division multiplexers are synchronized from a central timing source located in the PCM/DDAS assembly. Each time-division multiplexer provides an output to the PCM/DDAS assembly, which combines the outputs into a single serial wavetrain. The individual analog samples are digitized and combined into a digital format that is transmitted via coaxial cable to the ground checkout equipment. These data are also transmitted via a PCM/FM carrier for inflight monitoring. Each of the time-division multiplexers has a second data output that is identical to the output provided to the PCM/DDAS assembly except that it is conditioned for PAM transmission. These outputs may modulate a 70 kHz voltage-controlled oscillator (VCO) in FM/FM telemeter assemblies. On the R&D vehicles this arrangement provides redundant transmission of some multiplexer outputs using both PAM and PCM techniques. Since all of the data required for automatic checkout are not available from telemetry, additional time division multiplexer channels are provided for these measurements. The FM/FM continuous data channels are also paralleled on this multiplexer for ground checkout.

In the R&D vehicles, data with medium frequency response characteristics (50 to 1000 Hz) are applied to VCO's of the FM/FM assemblies. Vibration and acoustic data channels are typically applied to channels of the SS/FM assembly. These channels transmit a data spectrum from 30 to 3000 Hz. The number of SS/FM channels available is expanded by time-sharing specific channels through a slow time-division multiplexer. The central calibrator assembly provides calibration commands and calibration reference signals to all assemblies. The reference signals are derived from the stage measuring supply. Calibration sequences are of two types: preflight, which is initiated from ESE, and inflight, which may be initiated either from ESE or the vehicle programer.
A typical stage PCM/DDAS assembly is shown in Figure 3. Data that originate in digital form are inserted into the PCM/DDAS format. Typical sources of data in this category are the guidance system, the horizon sensor system, the command system, and discrete (off-on) measurements. These data channels are programmed into selected time slots of the digital format in the PCM/DDAS assembly. The number of digital input channels available is expandable by adding remotely located digital submultiplexers.

The PCM/DDAS in the S-IVB/IU functions during launch, earth orbit, and lunar injection. During these phases, periodic checks are required of the vehicle's performance or operating status. This is accomplished by inserting specific segments of the telemetered information into the onboard computer. To accomplish the necessary interchange of information between DDAS and computer, a computer interface unit (CIU) has been designed.

During orbital checkout, which is initiated by a command signal to the digital computer via the IU command, the digital computer requires real-time data which are part of the total data being telemetered by the S-IVB/IU stage PCM system. The computer provides a 15-bit address identifying the specific measurement value required from the PCM/DDAS. The computer also supplies a data-request signal. Upon receipt of the address and data request, the CIU scans its own stored addresses until a correct comparison is obtained. The CIU then seeks the required data which are normally being transmitted at a rate of either 120, 40, 12, or 4 samples per second. When the CIU obtains the correct data, it puts the data (a 10-bit word) into an output register, then provides a "data-ready" signal to the data adapter. When the computer receives the "data-ready" signal, it branches to a subroutine which operates to transfer the data from the CIU output register to the data adapter. Synchronization is accomplished as follows: Each time the CIU receives an address from the data adapter followed by a valid data-request signal, it recognizes this input as the initiation of a new data-seeking cycle as well as a signal to read in the data. Upon this recognition, the output data register is reset and then begins seeking the data requested by the data adapter. The data adapter and digital computer insure that a new address with a valid read bit is not generated until data from the CIU register have been received in response to the previous address.

During the launch, earth orbiting, and lunar-injection phases, there are times when information processed by the computer is desired at the ground station. Also, during periods when specific commands are being given through the IU command system to the digital computer, it will be necessary to transmit to ground a verification command prior to processing by the digital computer. Since the information to be telemetered is dependent on particular missions and has a random characteristic, provision will be made in the telemetry to accommodate these outputs. Specific PCM channels are assigned to accommodate the 40-bit data adapter outputs. The assigned channels are sampled at a rate of 240 times per second.
The data adapter identifies valid data by the presence of a validity bit that has no significance to the telemetry but is transmitted as part of the data telemetered to the ground. The ground computer automatically determines the existence of valid data by recognizing the validity bit in a data word. The validity bit is present with the valid data for at least 4.5 ms to insure at least one transmission of the valid data.

**DDAS GROUND SYSTEM**

**General Description**

Measurements designated for vehicle checkout and launch are assigned a data channel on the vehicle PCM/DDAS. Measurements are sampled by solid state electronic multiplexers at rates of 4, 12, 40, or 120 samples per second. Each sample is digitized with a 10-bit analog-to-digital converter and placed into a PCM format. Transmission to the DDAS receiving stations is made by frequency modulating a 600 kHz voltage controlled oscillator. A PCM/DDAS similar to the vehicle system is provided for GSE measurements.

A block diagram of the DDAS is shown in Figure 4. The 600 kHz signal from each stage and the GSE monitor is fed to the mobile launcher DDAS receiving station, where the 600 kHz carrier is demodulated and fed to the digital receiving stations (DRS-3) in the mobile launcher. Part of the 600 kHz signal from each stage is amplified and fed by video cables to the launches control center where the signal is demodulated and fed to the digital receiving stations (DRS-2) in the launch control center. All data are available at both the mobile launcher and launch control center computers through the computer interface. The primary difference in the DRS-3 and the DRS-2 is the number of channel outputs available for real time display.

A block diagram of the DDAS model DRS-2 is shown in Figure 6. A demodulated stage DDAS signal is brought via coaxial cable to the digital signal synchronizer. The reshaped NRZ (S) data from the synchronizer is clocked into a 40-bit serial shift register in the correlator panel assembly, using the data-derived clock from the synchronizer.

Demultiplexing counters, which correspond to counters located in a stage telemetry system, are contained in the data control panel assembly. The binary state of these counters represents the "address" of data in the correlator panel assembly.

Parallel data and their binary address are supplied to the DDAS computer interface via the output register panel assembly. Decoded (decimal) data address outputs from the data control panel assembly are used in the quick-look panel assembly for manual data channel selection and in the data switch panel assemblies.
Figure 5 shows a DRS-2 receiving station layout. The DRS-3 station consists of only one rack of equipment, similar to the one on the right.

A demodulated stage DBAS signal is brought via coaxial cable to the digital signal synchronizer (Figure 6). This assembly low-pass filters the incoming pulse train with a bandwidth appropriate to the bit rate. An internal phase-lock loop locks to the signal bit rate and provides a clock source for logic functions in the remainder of the receiving station.

The digital signal synchronizer (DSS) shapes and restores the incoming data and provides the correlator panel assembly with a clean, noise-free digital signal in NRZ (S) format. The DSS also provides a data output in NRZ (M) and RZ form.

The correlator panel assembly contains a 40-bit serial-in/parallel-out shift register and a 10-bit parallel-in/parallel-out register. Two digital correlation filters are provided on the outputs of the last 30 bits of the 40-bit register for recognition of the unique code groups in the format allotted to frame and master frame identification. The filters are programmable for specific codes by using plug-in modules at the rear of the chassis. A threshold control for each filter is available on the front panel.

The restored and shaped digital pulse train from the digital signal synchronizer (DSS) is clocked serially into the 40-bit shift register. At any specific time, there are 40 bits of the serial pulse train in the shift register. The output amplitude of the digital correlation filter is proportional to the correlation (likeness) of the set of bits currently in the shift register with the unique programmed word groups. When the output amplitude from the filter exceeds the threshold selected by the panel adjustment, a sync indication pulse is generated. These indication pulses are fed to the data control panel for verification and for resetting the demultiplexing counters. Parallel data from the correlator panel assembly are supplied to the quick-look and output register panel assemblies from the 40-bit shift register.

The data control panel assembly examines the frame and master frame sync indications from the correlator for periodicity. It contains the logic that detects an out-of-sync condition and the search logic that locates the correct frame sync indications. The "true" frame and master frame sync indications reset a group of counters, which then count in a sequence conforming to the counter sequences in the vehicle telemetry system. The binary state of these counters represents the "address" of the data channel currently in the correlator panel assembly shift register. Channel selection times are defined by decoding the counter states.

The quick-look panel assembly allows the operator to select any one desired data channel. Data from the selected channel are presented in digital and analog form. Ten pilot lights on the front panel display the selected data channel in parallel binary form. The channel is also converted to analog form.
and presented on a meter. The quick look display is normally utilized for setup and manual testing of the receiving station.

The output register panel assembly provides a parallel data output of all DDAS information from a single source, e.g., a Saturn vehicle stage. The data are made available for input to the DRS computer interface, along with the data address, as defined by the data control panel assembly demultiplexing counters.

Logic for a bit-by-bit verification of the DDAS frame and master frame sync words, and for verification of the digital equivalents of zero and full scale reference voltages from the airborne multiplexers, is a part of the output register panel assembly. Errors detected by the verification circuitry set sync and/or calibration error flip-flops, whose outputs control error indication lights. These error indications are made available to the DRS computer interface.

The digital signal simulator provides a signal in PCM/DDAS format for setting up and checking the receiving station. The frame sync and master frame sync code groups are selected by a program plug that is similar to those used in correlator panel assembly. A series of bits, up to four words, is programmed into the format by switches on the front panel. These bits are inserted into the format at a location selected by controls on the front panel. The remainder of the format is filled by random sequences of ones and zeros generated by a random-bit generator in the digital signal simulator. Two outputs are available: one is a frequency-modulated carrier at the DDAS VCO frequency (600 kHz); and the other is an NRZ (S) PCM wavetrain.

Mobile Launcher Receiving Station

A block diagram of the mobile launcher DDAS is shown in Figure 7. The 600 kHz DDAS signal from each stage and the ground ESE monitor is amplified, demodulated, and distributed by the carrier interface panels in the mobile launcher. A video signal is provided to the measuring checkout equipment at the vertical assembly building. Two 600 kHz signals per stage and mobile launcher ESE monitor are transmitted by video cable to the launch control center.

Each DRS obtains synchronization with the incoming data signal and presents parallel data along with the measurement address to the computer interface for storage in a magnetic core memory. One master frame (complete cycle) of data is stored in memory by the computer interface for each stage. Where necessary, discrete signals are brought out of the DRS on a limited basis for ESE display.

The RCA 110A computer at the mobile launcher has access to all DDAS data through the computer interface magnetic core memory system. A specific data sample is available to the computer in 20 microseconds access time. Several
modes of data transfer are available to aid the computer in processing data.

Launch Control Center Receiving Station

A block diagram of the launch control center DDAS is shown in Figure 8. The 600 kHz signals from the mobile launcher receiving station are amplified, demodulated, and distributed by the carrier interface panels to a demultiplexer (DRS-2) for each DDAS link 1. PCM video wavetrains via air link from the vehicle may also be conditioned and provided to each DRS-2. Each 600 kHz signal received from the mobile launcher is amplified and recorded on magnetic tape using a wide-band tape recorder.

Each DRS-2 obtains synchronization with the incoming data signal and presents parallel data along with the measurement address to the computer interface for storage in a magnetic core memory. One master frame (complete cycle) of data from each DRS-2 is stored in memory by the computer interface. One hundred analog and 160 discrete outputs are available to ESE from each DRS-2. Output capacity may be increased by adding digital to analog converters and data registers. The analog outputs are 0 to +10 V and the discrete outputs are 0 ±.5 V false and -12 V true.

The RCA 110A computer at the launch control center has access to all DDAS data through the magnetic core memory system. Access to any specific data sample can be made in 20 microseconds. Several modes of data transfer are available to aid the computer in processing data.

The computer interface is a buffer-storage memory system that couples real-time telemetry data, in digital form, from the digital receiving station to the RCA 110A computer. A block diagram is shown in Figure 9.

The following functions are performed by the computer interface:

1. Input data scanning
2. Data storage
3. Data transfer (from computer interface memory to RCA 110A computer).

Scanning of a maximum of eight input data sources is performed continuously by the computer interface, which operates asynchronously with the input data.

Recognition of a "transfer" signal from one of the eight sources during the scanning period designated for that particular source allows the transfer of a 40 bit block of data, along with a 14 bit address, directly into the memory information and address registers, respectively. At the same time, a load sync
is supplied to the memory system which triggers the start of a 5 micro-
second "clear/write" (load) cycle. In the same manner, all eight data
sources are scanned and updated sequentially within 160 microseconds of
the 278 microsecond period that each data sample normally is available from
the data source.

As the last word of each frame is written into memory, the frame and
multiplexer portions of the address are stored in one of eight last frame
address registers (LFAR). Each of the eight registers corresponds to one of
the eight sections.

The stored address information in the LFAR is available for use during the
read (unload) cycle when the requested measurement has a sampling rate of more
than 4 samples per second. A higher sampling rate results in more than one
data sample per master frame and, consequently, more than one location in
memory. The LFAR, therefore, provides a reference for determining which of
several locations in memory contains the most recent data word.

Forty-bit data words are stored in a random access magnetic core memory
having a capacity of 8192 address locations. Access to the memory system
is provided at a 20 microsecond rate for loading data and at a 10 microsecond
rate for unloading.

Transfer of information from the computer interface to the RCA 110A computer
input/output data channel (IODC) is accomplished in response to a request from
the IODC for information stored at a specified address or sequence of addresses.
One of three transfer modes may be selected by the IODC:

1. Single channel repeat mode.- Latest data stored in memory is
   transferred immediately after processing an SCR request. Subsequent
   updated samples are transferred automatically as they are stored in
   memory until a new address or new instruction is received.

2. Sequential mode.- This mode provides for the transfer of
   information from a given reference address, after which the address is
   increased sequentially by a specified amount, automatically, as data from
   the previous address are transferred to the IODC.

3. Block transfer mode.- A block transfer bit provides for transfer
   of information from a sequence of addresses, starting with the beginning
   of the first master frame after the block transfer bit is recognized and
   processed. Successive data transfers are performed as requested after
   each preceding address is increased, and new data corresponding to the
   increased address is entered into memory.
SUMMARY

The purpose of a launch vehicle checkout system is to provide accurate, up-to-date information on vehicle status before and during launch. Checkout of a vehicle as large and complex as the Saturn V would be time consuming and difficult if attempted with the conventional manually operated equipment. The digital data acquisition system (DDAS) described has been designed to provide rapid, automated checkout and calibration of the Saturn V launch vehicle under the control of a digital computer.

The vehicle-contained portion of the DDAS has been integrated into the stage telemetry design. This combines the functions and hardware normally required for a flight telemetry system into a relatively low-bit-rate, high capacity PCM system that may be used in ground or airborne checkout and calibration. It is also suited for use as a PCM telemetry system for R&D and operational flight control data. Each stage of the Saturn V vehicle has its own PCM/DDAS with the necessary telemetry "building-block" equipment to satisfy the specific requirements of that stage. It can therefore be used for checkout and calibration at the stage contractor's facility and for static firing.

From one to six time-division multiplexers are synchronized from a central timing source in the PCM/DDAS assembly. Each of these multiplexers provides an output to the PCM/DDAS assembly where the analog samples are digitized and combined into a digital format. The resulting serial PCM wavetrain modulates a 600 kHz carrier and is transmitted by coaxial cable to the ground DDAS receiving station.

The ground DDAS receiving station receives the modulated carrier from each stage and performs the following:

a. Demodulation, bit-rate clock reconstruction, and regeneration of the serial digital data

b. Demultiplexing, buffer storage, and presentation of any specific data channel in parallel digital form on command from the computer

c. Demultiplexing and presentation of selected data channels to visual displays and analog recorders.

The launch site version of the DDAS receiving station must provide the checkout computer with data channels from any vehicle stage with an access time that is compatible with critical prelaunch decisions. It must also provide uninterrupted outputs to displays and monitoring equipment. This requires that demodulation and demultiplexing be performed in parallel channels that terminate
in a common buffer storage and computer interface unit. The ground DDAS receiving station therefore appears as a memory to the computer from which it may obtain data from any stage on command.

The same data that are transmitted closed loop by the PCM/DDAS are also transmitted on an RF carrier. These data can be utilized for airborne checkout and operational flight control.
FIGURE 1. SATURN V MEASUREMENT SYSTEM
The telemetry equipment associated with a Saturn V stage consists of a "building-block" arrangement, which may be connected in numerous combinations to satisfy specific requirements.

**FIGURE 2. TYPICAL R&D SATURN V STAGE TELEMETRY SYSTEM**
FIGURE 3. TYPICAL STAGE PCM/DDAS ASSEMBLY

FIGURE 4. SATURN V DIGITAL DATA ACQUISITION SYSTEM (DDAS)
FIGURE 5. DIGITAL RECEIVING STATION
FIGURE 6. DIGITAL RECEIVING STATION BLOCK DIAGRAM
FIG 7

SATURN V ML DIGITAL RECEIVING STATION SYSTEM

FIG 8

SATURN V LCC DIGITAL RECEIVING STATION SYSTEM
SATURN V DRS COMPUTER INTERFACE

FIGURE 9