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TELEMETRY SYSTEM DESIGN FOR SATURN VEHICLES

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SUMMARY

This paper discusses the data system requirements for large space vehicles and describes a flexible telemetry system design which is used on all stages of the Saturn IB and Saturn V vehicles. The basic vehicle telemetry design provides standard assembly building blocks forming a versatile catalogue of parts from which a stage telemetry subsystem may be assembled to meet almost any conceivable monitoring requirement. In addition to its inflight monitoring function, the telemetry subsystem also provides real time data acquisition for automatic vehicle checkout.

INTRODUCTION

The landing of man on the lunar surface and his safe return to earth in this decade has been established as a national goal. In addition, a variety of sophisticated earth orbital, lunar, and planetary space missions are in the implementation, planning, and proposal phases.

A major role in the national space program has been assigned to the Saturn IB and Saturn V space vehicles. The Saturn IB consists of two propulsion stages with a first-stage thrust of 7.1×10^6 newtons (1.6 million pounds) and the capability for placing 14,600 kilograms (16 tons) into low earth orbit. This vehicle has been assigned a variety of missions such as orbital qualification of the Apollo spacecraft and Apollo crew training. It is expected to assume the role of workhorse vehicle for earth orbital operations, as the national space program progresses into the decade of the seventies. The Saturn V is a three-stage vehicle having first-stage thrust of 33.5×10^6 newtons (7.5 million pounds) and a capability for orbiting 109,000 kilograms (120 tons) or placing 38,800 kilograms (45 tons) into a lunar trajectory. This vehicle has been assigned the critical role of starting men on their journey to the moon in this decade. In addition, its status as the most powerful launch configuration available to the planners of the national space program assures it a key role in advanced lunar and planetary missions.

Undoubtedly, development of the Saturn family of launch vehicles represents one of the most complex technical efforts ever undertaken by man. To properly utilize the nations vast technical talent and industrial capability in this gigantic task, various industrial contractors were assigned key roles in the design, manufacture, and test of individual vehicle stages. These stages are then integrated into a complete vehicle system at the launch site. This approach to sharing the effort has generated unique and formidable problems in management relationships between government agencies and laboratories, stage contractors, and various system and subsystem contractors. These management-oriented problems, the solution of which are as essential as technical solutions to

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the reliability of the final vehicle system, have been found to rival the technical problems in complexity.

These technical and management problems as related to the choice of telemetry concepts, methods, and procedures, and the subsequent solutions to these problems are the subject matter of this paper.

SATURN TELEMETRY REQUIREMENTS

For any given application of telemetry system techniques, there exist various design and operational restraints imposed by the technical requirements, the current state-of-the-art, and the realities of value and economics. There is seldom one "optimum" solution; therefore, a design choice must be made from numerous alternatives based on trade offs in system capabilities and limitations. A complex array of requirements and considerations governed the selection of telemetry concepts, methods, and procedures for the Saturn vehicles. Some of the factors which guided the evolution of the Saturn telemetry design are discussed in the following paragraphs.

Data Transmission Capacity. -The size and complexity of the Saturn vehicles plus the small number of developmental vehicles presented formidable problems in telemetry system data transmission capacity. Each vehicle test required thorough instrumentation to obtain the maximum practical quantity of data; therefore, the capacity of the telemetry system, in terms of both data bandwidth and quantity of measurements, was important. In addition, a range of data types having widely varying characteristics had to be accommodated. These included vibration and acoustic measurements, flows, waveforms from servo control loops, off-on events with varied time-resolution requirements, digital outputs of special transducers and subsystems, strain measurements, and a myriad of temperature and pressure measurements.

Flexibility. -The total number and the quantity of each type of measurement were expected to vary widely as the program progressed from initial developmental to operational vehicles. The final operational vehicle configuration would retain a minimal telemetry system with greatly reduced capacity. A relatively long lead time (up to 18 months) was expected from the beginning of vehicle assembly to launch. Since the results of vehicle tests would likely modify the measuring requirements placed on subsequent vehicles, late changes were to be expected as the vehicles progressed through assembly and checkout. These considerations dictated considerable flexibility in telemetry design and integration into the vehicle. The telemetry design was required to accommodate these varying demands and late changes in measuring requirements without inconvenient and time-consuming modifications.

Monitoring of Vehicle Status and Readiness. -Verifying the readiness of all subsystems in a large, complex space vehicle system entails the digestion and analysis of tremendous quantities of data. This verification must be repeated a number of times during the life of a vehicle stage: (1) at completion of manufacture, (2) during and after static firing of a stage, (3) several times during prelaunch tests, and (4) during

the countdown and launch sequence. The criticality of these tests and the speed with which they must be performed in some situations indicate the use of automatic vehicle checkout procedures using capabilities of ground based digital computers. This checkout arrangement entails transmission of large quantities of real time data from the vehicle to the checkout computer. Adaptation of the vehicle telemetry subsystem to perform this checkout data acquisition function, in addition to its traditional inflight monitoring role, minimizes the vehicle equipment required and logically becomes a design requirement. This added assignment imposes several requirements on the telemetry system design: (a) The telemetry must operate in a closed-loop mode during prelaunch checkout application without RF radiation, (b) The telemetry equipment used in this application must be capable of extended hours of operation without significant degradation of performance, (c) Since checkout operations were required on individual stages prior to mating of the stages at the launch site, each stage needed an independent self-contained data acquisition capability, (d) The increased weight of the vehicle equipment required to adapt to the new role must be minimized by utilization of subsystems for both checkout data acquisition and flight monitoring, (e) The closed-loop monitoring output must provide a format convenient for computer entry and an appropriate means of "addressing" and identifying the channels, (f) The checkout data acquisition system must provide a means of checking the instrumentation itself; that is, it must possess a self-check capability. In addition, certain missions required a verification of vehicle readiness during orbital flight preceding second burn of the vehicle upper stage. The on-board guidance computer was to be utilized for certain of these tests; therefore a means of access to telemetry data by the on-board computer was an additional system requirement.

Design Commonality. -A number of considerations dictated use of the same basic telemetry design on all stages of the Saturn vehicle. Some of these factors are: (a) A common telemetry design ensured compatibility with integrated telemetry ground support equipment (GSE) and receiving equipment at the launch site and on the world-wide range. It also promoted compatibility of demultiplexing and data processing equipment at numerous locations, such as governmental laboratories, the launch site, contractor plants, static test facilities, and data reduction centers. It tended to minimize the types and variety of such required equipment and facilitated the exchange and correlation of telemetry data between the various organizations which were involved, (b) The important role of the telemetry system in acquiring data in real-time for use in automatic checkout and control required format and other telemetry signal characteristics of the individual stages to be identical, (c) The use of a common telemetry design provides cost saving due to: minimization of initial-design and development, decrease in production cost resulting from greater quantities of a given design, decrease in training requirements for personnel who must handle the integrated vehicles, and expediting of configuration control procedures, and (d) Reliability of the data acquisition system is improved by the concentration of effort and experience on a given design, the greater familiarity of operating personnel with the common design, and the opportunity for more comprehensive test programs.

Reliability. The Saturn IB vehicle is expected to assume operational status after the launch of four developmental test vehicles, and only five developmental launches are planned for the larger and more complex Saturn V vehicle. When this small number of development vehicle launches and the long lead time required for design, fabrication, and testing of each vehicle is considered, it is readily apparent that the loss of a substantial amount of data from an individual flight test would cause a tremendous setback in the national space program. It must be remembered that the life of an astronaut may well depend on how much is learned from the data gathered during the limited number of development flights. These considerations justify the following precautions: (a) Extensive care in the design, fabrication, and testing of instrumentation, (b) Use of parallel configurations in the instrumentation to ensure that a single black-box failure does not cause loss of a substantial portion of the measurements, (c) Redundant monitoring of some measurements by means of two transmission paths, and (d) A comprehensive program for proving the telemetry design including actual flight test experience as a "passenger."

Weight and Size. -Although volumetric size is usually of little concern in a large space vehicle, the weight of individual subsystems reflects directly into the payload capacity of the vehicle. Table I shows the distribution of weight between instrumentation system elements in a typical large space vehicle. This illustrates the often neglected fact that the weight of equipment which performs the telemetry multiplexing and modulation functions typically accounts for only 5 to 10 percent of the total weight chargeable to instrumentation. This means that a 10 percent reduction in weight of these items, for example, provides only 0.5 to 1.0 percent reduction in total instrumentation weight.

TABLE I
TYPICAL VEHICLE INSTRUMENTATION SYSTEM
WEIGHT DISTRIBUTION

Measuring Subsystem	12%
Telemetry Subsystem	6%
Antenna Subsystem	2%
Environmental Conditioning, and Mounting Hardware	25%
Electrical Wiring, Connectors, and Distributors	55%

It is apparent that heavy emphasis on weight consideration in the implementation of the telemetry "black boxes" has less than a revolutionary effect on overall vehicle system weight. Moreover, a disproportionate degree of emphasis placed upon weight of these items may well unduly penalize other essential design characteristics. Note, however, that electrical cable and connectors within the vehicle instrumentation system accounts for over 50% of the instrumentation weight. Consequently, a significant savings in weight is available by

reducing the length of cables to individual measurements. This reduction may be accomplished by utilizing a telemetry design which permits the data multiplexing equipment to be distributed at various locations convenient to the measurement sources.

TELEMETRY SYSTEM DESCRIPTION

The vehicle telemetry subsystem, as referred to here, accepts data signals from the vehicle measuring subsystem (Ref. 1) and delivers to the vehicle antenna subsystem (Ref. 2) modulated RF signals of the appropriate power levels. As shown in Figure 1, the measuring subsystem includes the transducers and signal conditioners needed to derive and condition voltage analogs of the measured parameters and a remotely controlled calibration system. The antenna subsystem includes multicouplers, RF power dividers, "dummy" RF loads and coaxial switches in addition to the antennas. Several RF carriers are required to provide telemetry capacity needed to handle the quantity and types of measurements for a typical developmental Saturn stage. Since specific telemetry techniques have characteristics especially well-suited to particular types of data (Ref. 3), multiple carriers present the possibility of using different telemetry techniques on the individual RF links to achieve more efficient transmission capabilities for a wide variety of data types. The Saturn telemetry design applies PCM/FM, FM/FM, and SS/FM techniques. Each stage telemetry subsystem generates one PCM/FM link, plus additional RF links allotted to FM/FM and SS/FM modulation as needed to provide an appropriate balance of data transmission capability to satisfy the specific data requirements. Each stage telemetry subsystem consists of a number of assemblies selected from a series of approximately 20 standard telemetry assembly "building-blocks." These assembly "building-blocks" (such as analog multiplexers, digital multiplexers, telemetry oscillator assemblies, FM-RF assemblies, etc.) may be arranged in any one of many allowable combinations to satisfy specific vehicle telemetry requirements. In addition, many of the assemblies afford optional modular plug-in arrangements and programmable features which provide a basic telemetry design with an exceptional amount of flexibility.

The data required for stage checkout is provided over special coaxial outputs from each individual stage. This feature of the Saturn system design has been designated the DDAS (Digital Data Acquisition System). The stage DDAS function is performed within each stage by various telemetry assemblies and the measuring subsystem, while the ground DDAS function is performed by an array of receiving, demultiplexing, and data storage equipment which provides the checkout computer with rapid access to any measurement.

PCM/DDAS. - The PCM/DDAS assembly, shown in block diagram form in Figure 2, may be appropriately considered the focal point of the stage telemetry subsystem. The PAM scanner connects each analog multiplexer output to the analog to digital converter (ADC) input in a programmed sequence which interlaces the PAM wavetrain from the individual multiplexers sample-by-sample and frame-by-frame to form

one of a number of permissible output formats. The scanner program patch allows the assembly to be programmed for operation with from one to six of the analog multiplexers described below. Programs for up to three different multiplexer arrangements may be incorporated into the scanner patch to allow the addition and deletion of specific multiplexers during a particular phase of the vehicle mission.

The ADC uses the successive approximation method to encode the analog samples into a 10-bit binary code. A "digitize and hold" process is used rather than the common "sample and hold" process. Each encode cycle has a duration of approximately 40 microseconds. The encode cycle occurs during the mid-portion of each PAM sample, thus avoiding switching transients from the analog gates. After encoding, the digital data is transferred to the digital multiplexing and formatting circuits. The encoding operation is timed by a 350-kHz clock which is independent of other assembly timing signals.

The assembly also contains a digital multiplexing section with inputs for up to 100 discrete (off-on) functions which will be described later. The assembly programming and timing, in addition to controlling its internal functions, generates synchronizing signals which are cabled to the external multiplexers.

The PCM/DDAS assembly provides simultaneous outputs in three forms: (1) a serial NRZ-L PCM wavetrain at 72 kilobits, which is routed to the modulation input of an FM/RF assembly; (2) a 600-kHz carrier FM-modulated by this serial wavetrain; and (3) a 10-bit parallel PCM output which is used by a digital tape recorder or (through an interface unit) by the on-board computer. The PCM/DDAS assembly with some details of its internal construction is pictured in Figure 3.

Analog Multiplexing. - The primary assembly for sampling of analog measurements is represented in block diagram form in Figure 4. This assembly houses gates for sampling from 27 to 234 high level (0 to 5 volts) data inputs, the exact number dependent upon the selected arrangement of optional plug-in modules. Essentially, it operates as a 30 x 120 multiplexer with provisions for submultiplexing individual channels to form ten subchannels, each sampled at 12 samples per second. Twenty-seven of the thirty primary channels are data channels, while the remaining three are utilized for amplitude references and PAM frame identification. Ten-channel submultiplexer modules which plug into the multiplexer assembly may be used to submultiplex selected primary channels. When a primary channel is used at the prime sampling rate, a "dummy" card (or a pre-sampling filter, if needed) is inserted in place of the submultiplexer module. Two 50-percent duty cycle PAM wavetrains are provided as outputs; one is routed to the scanner input of the PCM/DDAS assembly, while the second (which is identical to the first wavetrain except for addition of a pedestal) is used in some cases as an input to a 70-kHz \pm 30% subcarrier which is transmitted by one of the FM/FM links. A second analog multiplexer assembly design contains provisions for locating up to six 10-channel submultiplexer modules (either high or low level) remotely from the prime multiplexer assembly.

The sequential time-division multiplexing arrangement described above permits a flexible exchange between quantity of channels and two sample rates, 120 and 12 samples per second. The total output sample

rate is 3600 pulses per second. In a stage telemetry subsystem, two multiplexers are synchronized with their PAM wavetrains offset so that the sample on-time of one occurs during the off-time of the other. The PAM scanner operation of the PCM/DDAS assembly then combines the two wavetrains into a single 100% duty cycle wavetrain at 7200 samples per second. Two additional basic system sampling rates can also be generated by the scanner operation. This result is achieved by sharing the group of PCM time slots corresponding to a given multiplexer with two additional multiplexers in each sequence of three adjacent frames. This divides the sample rates of all channels on the three multiplexers by a factor of three giving 40 and 4 samples per second and achieving a corresponding increase of three times the channel capacity.

Digital Multiplexing. -Significant quantities of measurements on a typical space vehicle measurement list are discrete binary functions and events such as switch closures, lift-off, cut-off, and valve closures. In addition, some measurements, typically those from digital transducers, the guidance computer, and the digital command system, originate in digital form.

These measurements present special design problems quite different from those presented by analog data inputs. Discrete binary measurements are transmitted most efficiently by allowing individual functions to control the status of individual bits in the PCM wavetrain. This requires combining these inputs into groups of ten which are assigned specific word positions in the PCM format at the required sampling rate. Individual digital measurements are assigned one or more word positions in the PCM format as required to accommodate its word length. Special problems which arise in handling these inputs include the need for time correlation between measurements, or the requirement that a large quantity of binary or digital functions be "read" at the same time. These measurements are originated by various subsystems within the vehicle, and it is necessary that the telemetry inputs readily accommodate differing signal levels and polarities.

The digital multiplexing section of the PCM/DDAS assembly accommodates ten 10-bit groups of bi-level data. A specific data group is presented to the assembly as ten parallel logic inputs with voltage level and polarity selectable for each group. Each 10-bit group is buffered, stored temporarily in a magnetic core register (MCR), and then inserted into a selected word position in the PCM format. Both the time at which a specific 10-bit group of digital data is "written" into the MCR and the word position into which it is "read" into the output format are selectable by means of a programming arrangement within the assembly. The "write" command, which temporarily stores a 10-bit group in an MCR, can be programmed to occur during any word time after the preceding sample for that specific group is read into the output format. For example, several 10-bit data groups can be written into their MCR's simultaneously and then placed into convenient word positions in the format. This provides time correlation between the measurements without restrictions on locating the groups within the data format. Each group may be sampled at any one of the four basic system sampling rates. With certain restrictions, super commutation

to provide multiples of the basic rates is also permissible.

Each MCR, plus its ten associated buffers and other circuitry, is powered by an individual supply which is DC-isolated from the remainder of the assembly circuitry. This feature permits the monitoring of several bi-level sources without interconnecting their DC commons, as well as providing isolation of each source from the logic voltage common of the PCM/DDAS assembly which is connected to vehicle measuring voltage common. Because of the multiplicity of data sources, these DC-isolation features are essential to prevent the formation of undesirable ground loops within the telemetry and measuring subsystems.

FM/FM. -The telemetry oscillator assembly (TOA) is the assembly building block which contains the SCO's and mixer-amplifier(s) required for a single RF link, and one TOA is used for each link which is allotted to FM/FM transmission. Calibration relays located in the TOA provide a means of disconnecting the data input and applying a calibration signal to selected SCO's. An illustration of a typical TOA is shown in Figure 6.

Provisions are available in the TOA for modulating up to two high-frequency SCO's with the composite output of several low-frequency SCO's (FM³). The TOA can also accommodate a 70-kHz \pm 30% SCO which transmits the 3600-pps PAM wavetrain (with pedestal) from an analog multiplexer. This provides an optional method of redundant transmission for critical measurements assigned to a specific analog multiplexer. When this wideband SCO is used, channels 16, 17, and 18 must be eliminated.

SS/FM. -SS/FM is a relatively new frequency-division-multiplexed telemetry technique with characteristics especially well-suited to the transmission of vibration and acoustic measurements (Ref. 4). Essentially, the single sideband modulation process shifts the data signals to assigned baseband frequency locations. The translated data signals are then summed and the resulting frequency-multiplexed signal frequency modulates the RF transmitter. The SS/FM technique provides the highest bandwidth efficiency presently available for transmission of wideband data where the major interest is power spectral density and other statistical type analyses.

Each single sideband assembly provides the capability for continuous monitoring of 15 wideband data channels of a bandwidth from 20 Hz to 3 kHz. The channel capacity of an SS/FM link may be increased by time-sharing up to 75 measurements through use of the vibration multiplexer assembly. This multiplexer has a dwell time of several seconds per measurement input, a duration which is appropriate for recording a tape loop for spectral density and other statistical analyses during data reduction.

FM/RF Assembly. -Each telemetry link on the Saturn vehicle utilizes an FM/RF assembly which contains a VHF/FM transmitter, RF power amplifier, and related components. The assembly accepts an input from either a PCM/DDAS assembly, single sideband assembly, or telemetry oscillator assembly, and produces 20 watts of RF power to the vehicle antenna subsystem. To accommodate the divergent requirements of analog and digital modulation, the FM/RF assembly contains the interchangeable signal conditioning circuitry required for SS/FM, FM/FM

and PCM/FM transmission. A photograph of an FM/RF assembly is shown in Figure 5.

Airborne Tape Recording. -Temporary attenuation and perturbation of RF signal levels, due to retro-rockets or other causes, are expected during many space vehicle missions preventing reliable reception of telemetry data during a critical period. For this reason, it is desirable to record telemetry signals for playback during a period of more favorable reception.

The Saturn telemetry design utilizes a two-channel, analog tape recorder suitable for the recording and playback of composite FM/FM SCO signals in a vehicle environment. A digital recorder is also used in some cases for delayed transmission of PCM data. Commands for operation of the tape recorder are normally received from the stage sequencer.

Telemetry Calibration. -A telemetry calibrator provides a central source of calibrating signals for the stage telemetry subsystem. It generates an accurate ($\pm 0.1\%$) 5-level reference signal for calibrating the SCO channels of up to six TOA's and supplies a 28-VDC calibration command voltage to actuate the relays within each TOA which transfer the SCO inputs to the calibrate bus carrying the reference signal. This calibration command is also routed to the time-division multiplexers where it serves as the initiate signal for the multiplexer internal calibrator.

The telemetry calibrator also supplies AC reference signals of two types to the single sideband assemblies: (1) a variable-frequency signal generated by a sweep-frequency generator, located in the ground GSE, and fed through the calibrator to a maximum of three single sideband assemblies; and, (2) a fixed-frequency, 1700-Hz signal generated by an optional module within the calibrator and routed sequentially to each of the single sideband assemblies for a period of 1.4 seconds each.

Typical Stage Telemetry Subsystem. -The standard telemetry assembly building blocks form a versatile catalogue of parts from which a telemetry system designer may assemble a stage telemetry subsystem to meet almost any conceivable monitoring requirement. To illustrate application of the assemblies, the stage telemetry subsystem shown in Figure 7 is presented as a typical arrangement for discussion.

A stage telemetry design may utilize any quantity from one to six time-division multiplexer assemblies to handle sampled-data requirements. Figure 7 illustrates an application using four time-division multiplexer assemblies. Each time-division multiplexer receives synchronizing signals from the PCM/DDAS assembly and may be placed at locations convenient to the data sources to minimize cabling weight. The remote analog submultiplexer also may be used as appropriate to locate sampling gates near the data sources. Figure 7 illustrates the use of one remote analog submultiplexer which could be either a high level or a low level submultiplexer.

Each time-division multiplexer supplies a PAM wavetrain to the PCM/DDAS assembly where the scanning sequence combines the individual multiplexer outputs into a single serial wavetrain. The

individual samples are then digitized by the ADC and combined with multiplexed digital data and the appropriate frame synchronization codes to form the NRZ-L serial PCM wavetrain. This wavetrain FM-modulates a 600-kHz VCO, producing the output designated "DDAS output to GSE." The serial NRZ output of the PCM/DDAS assembly is routed to the FM/RF assembly for inflight monitoring. Discrete off-on signals and other measurements originating in digital form are routed either directly to the digital data inputs of the PCM/DDAS assembly or to the remote digital multiplexers.

Measurements with characteristics appropriate to FM/FM transmission are shown routed to one of the three telemetry oscillator assemblies. Two time-division multiplexers supply PAM wavetrains to provide redundant transmission of these measurements over an FM/FM link. The composite subcarrier signal from each telemeter oscillator assembly is applied to the modulation input of an FM/RF assembly.

Wideband measurements with characteristics and requirements suitable for SS/FM transmission are applied directly to the single sideband assembly or to the vibration multiplexer.

The telemetry calibrator accepts a 5-VDC reference voltage from the stage measuring supply and commands from GSE and the stage sequencer. When instructed by command from these sources, it supplies the appropriate calibration and reference signals to the other telemetry assemblies.

After engineering design of the vehicle and vehicle subsystems has been verified by data obtained on the development vehicles, the stage telemetry is reduced to a typical operational system configuration as shown by the unshaded assemblies in Figure 7.

The number of telemetry links and the types of modulation used on Saturn IB and Saturn V vehicles are illustrated in Figure 8.

CONCLUSIONS

The Saturn program presented a formidable array of challenging data acquisition problems and has resulted in several significant contributions to telemetry knowledge and technology.

The advantages gained in expanding the role of space vehicle telemetry systems to include real time data acquisition functions have been verified. The Saturn telemetry design has demonstrated adequate performance in data acquisition for computerized checkout of both individual stages and integrated vehicles.

Instrumentation systems experience with the Saturn vehicles has shown that the major instrumentation weight penalty is caused by electrical cabling and connectors within the vehicle rather than the weight of telemetry multiplexing and modulation equipment. An attractive design approach for future programs is a coded multiplexing system in which individual data sources (or groups of data sources) are interrogated by a coded address from a central assembly over a single cable common to all measurements. The response from the sources is received in either analog or digital form over a second cable.

Saturn experience has also demonstrated feasibility of utilizing a relatively large number of standard bandwidth RF carriers for

telemetry transmission. This approach, contrasted to often-proposed extremely wideband carriers, provides improved reliability, less link intermodulation distortion problems, increased power efficiency, and in many cases more efficient utilization of RF bandwidth. Another advantage accruing from this approach is the increased flexibility available by adding or deleting carriers to modify telemetry capacity.

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Most of the assembly building blocks used in Saturn vehicles are manufactured from standardized, detailed production drawings, allowing competitive procurement in production lots as needed by the individual stage contractors. Because of the large amount of telemetry equipment needed for Saturn vehicles, this procurement procedure has resulted in a significant cost savings for the Saturn programs. Typical assemblies have recently been purchased in moderately sized production lots at cost less than the parts cost of earlier production runs.

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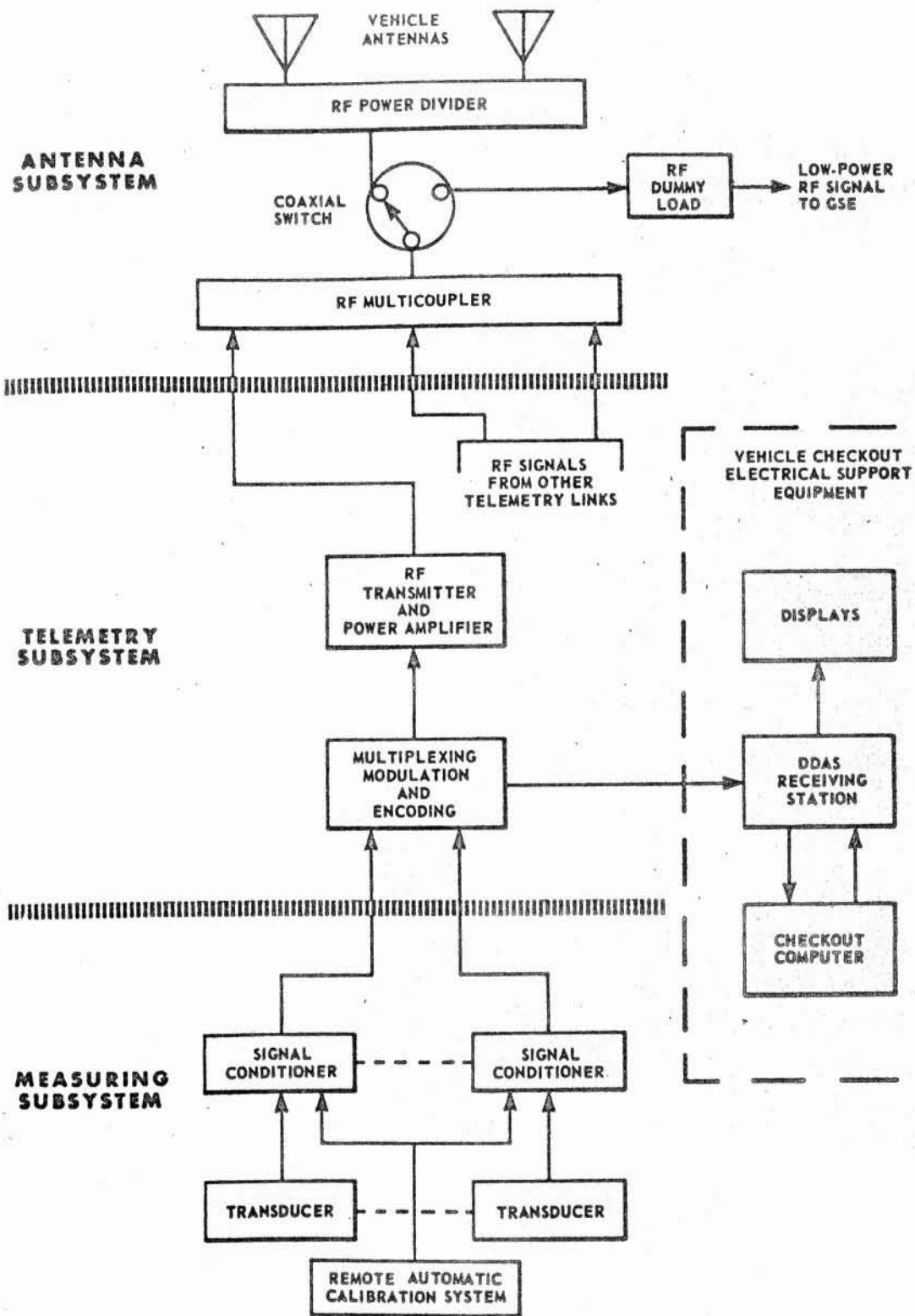


Figure 1. Vehicle Instrumentation System.

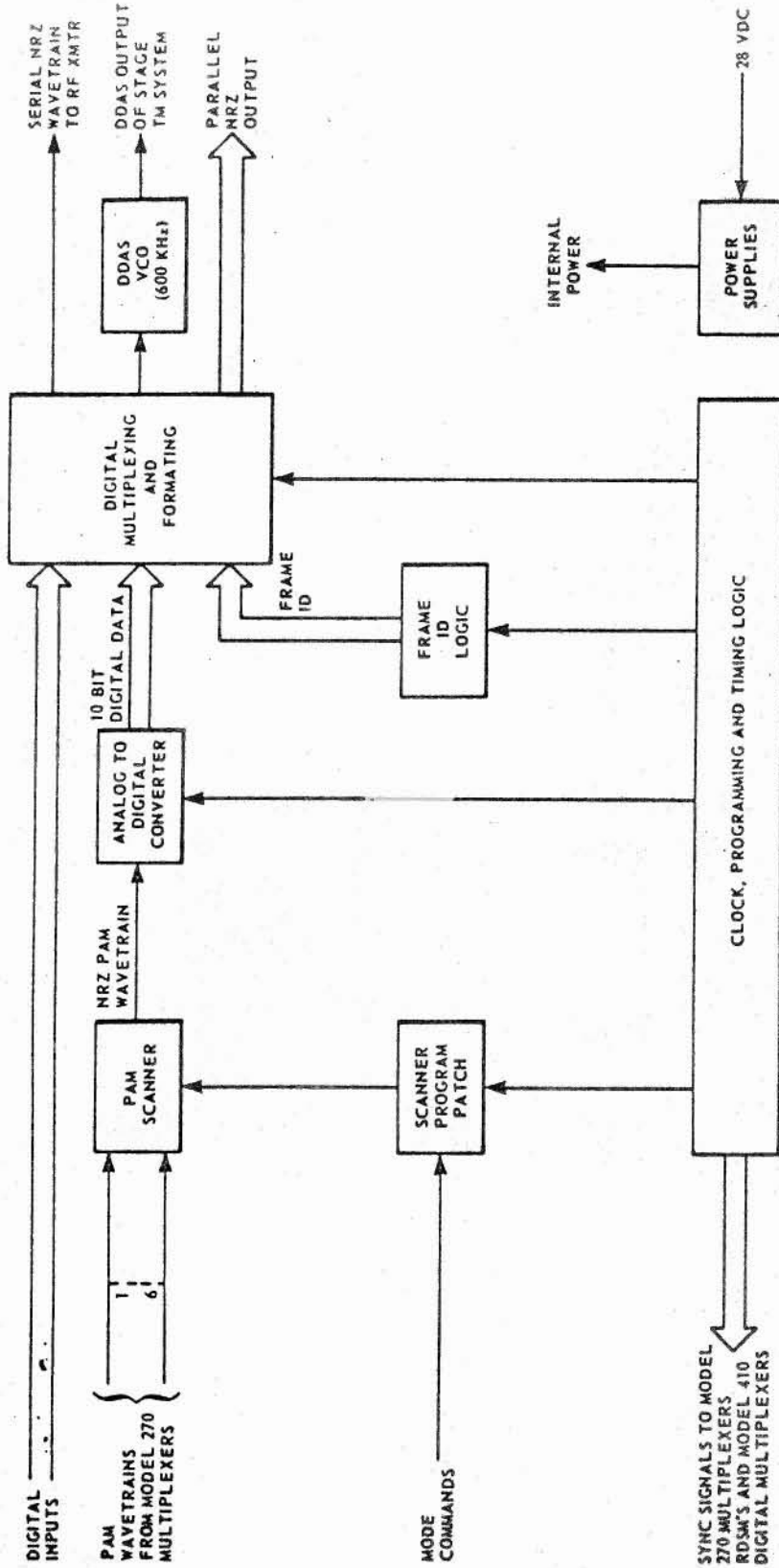


Figure 2. PCM/DDAS Assembly, Block Diagram.

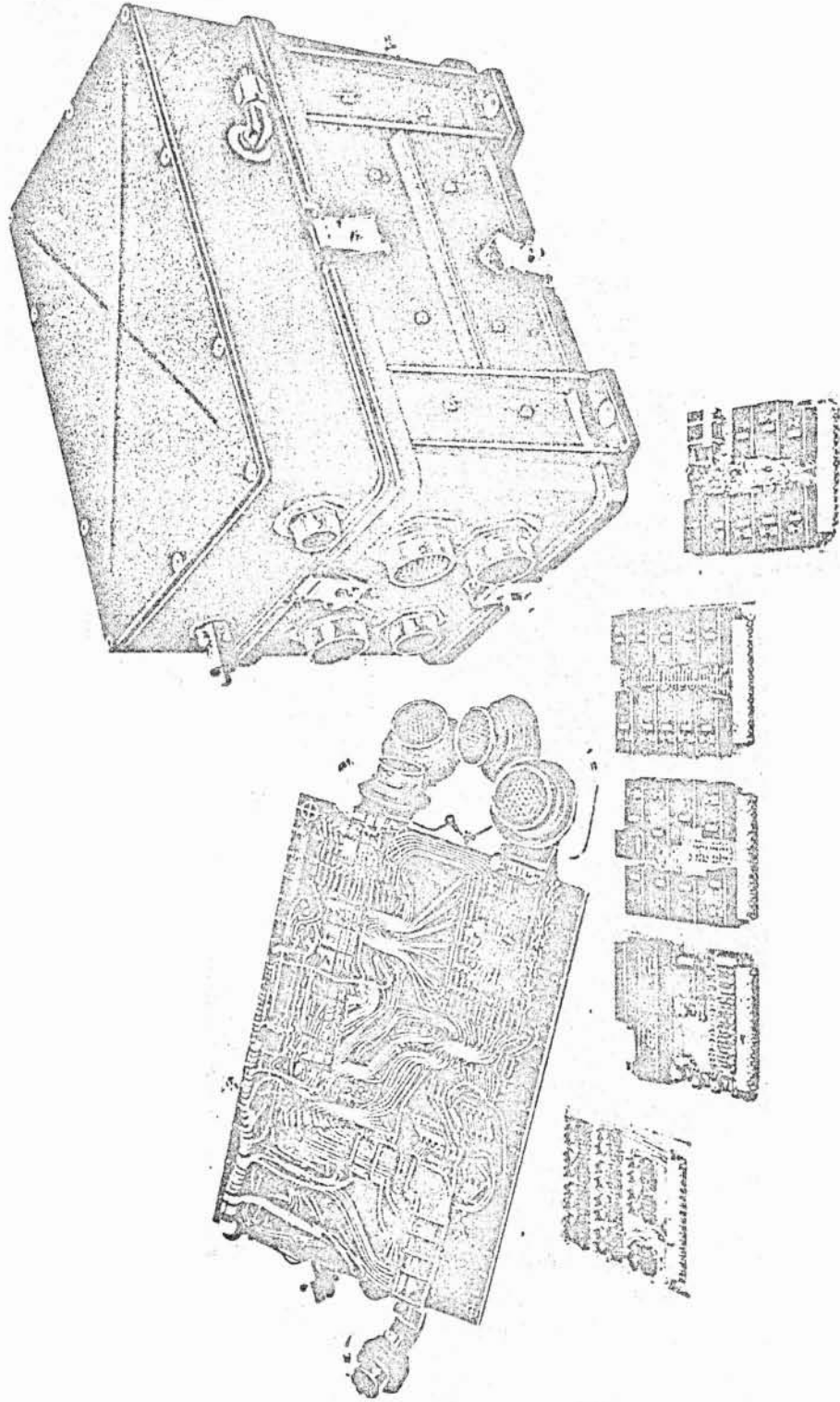


Figure 3. PCM/DDAS Assembly.

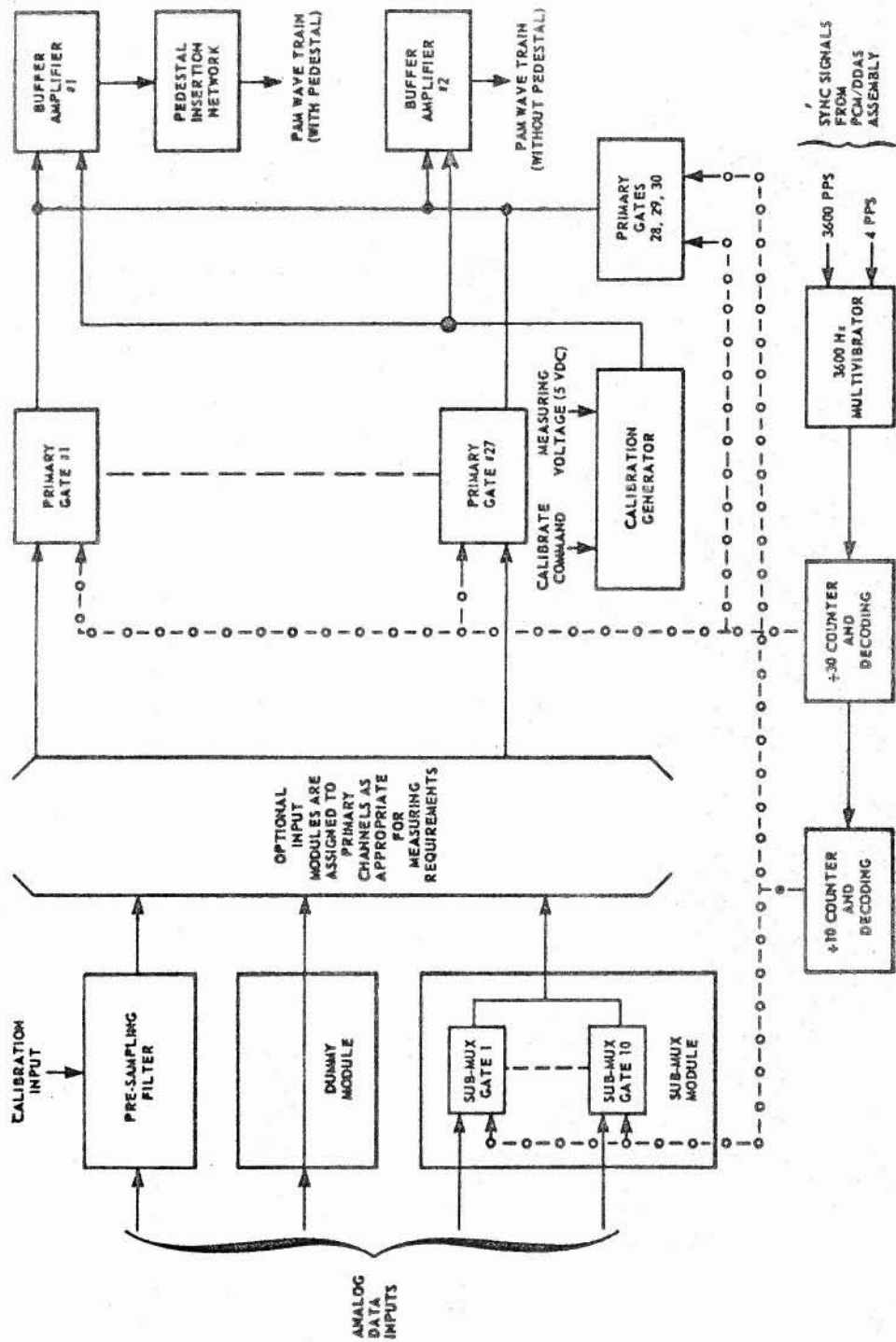


Figure 4. Analog Time Division Multiplexer, Block Diagram:

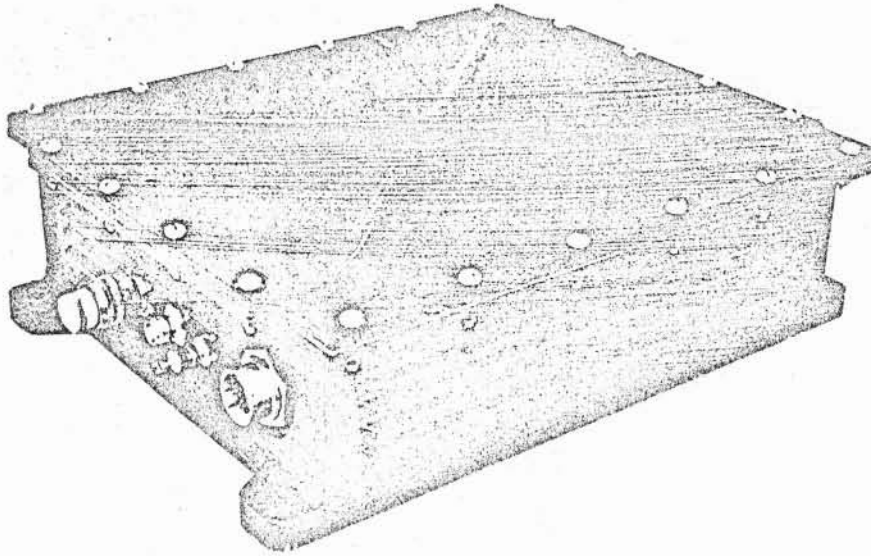


Figure 5. FM/RF Assembly.

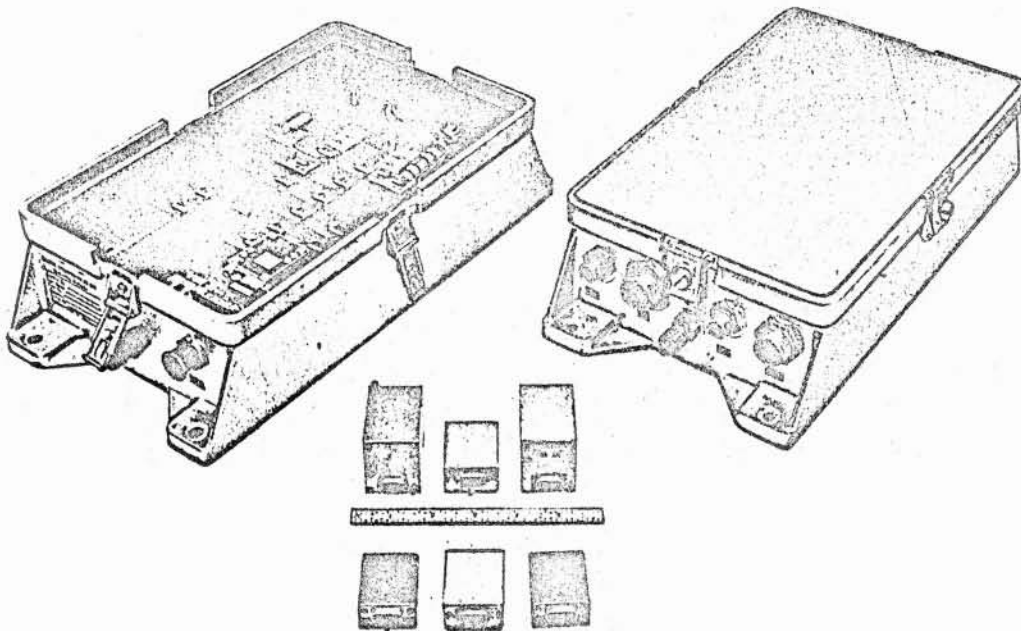


Figure 6. Telemetry Oscillator Assembly.

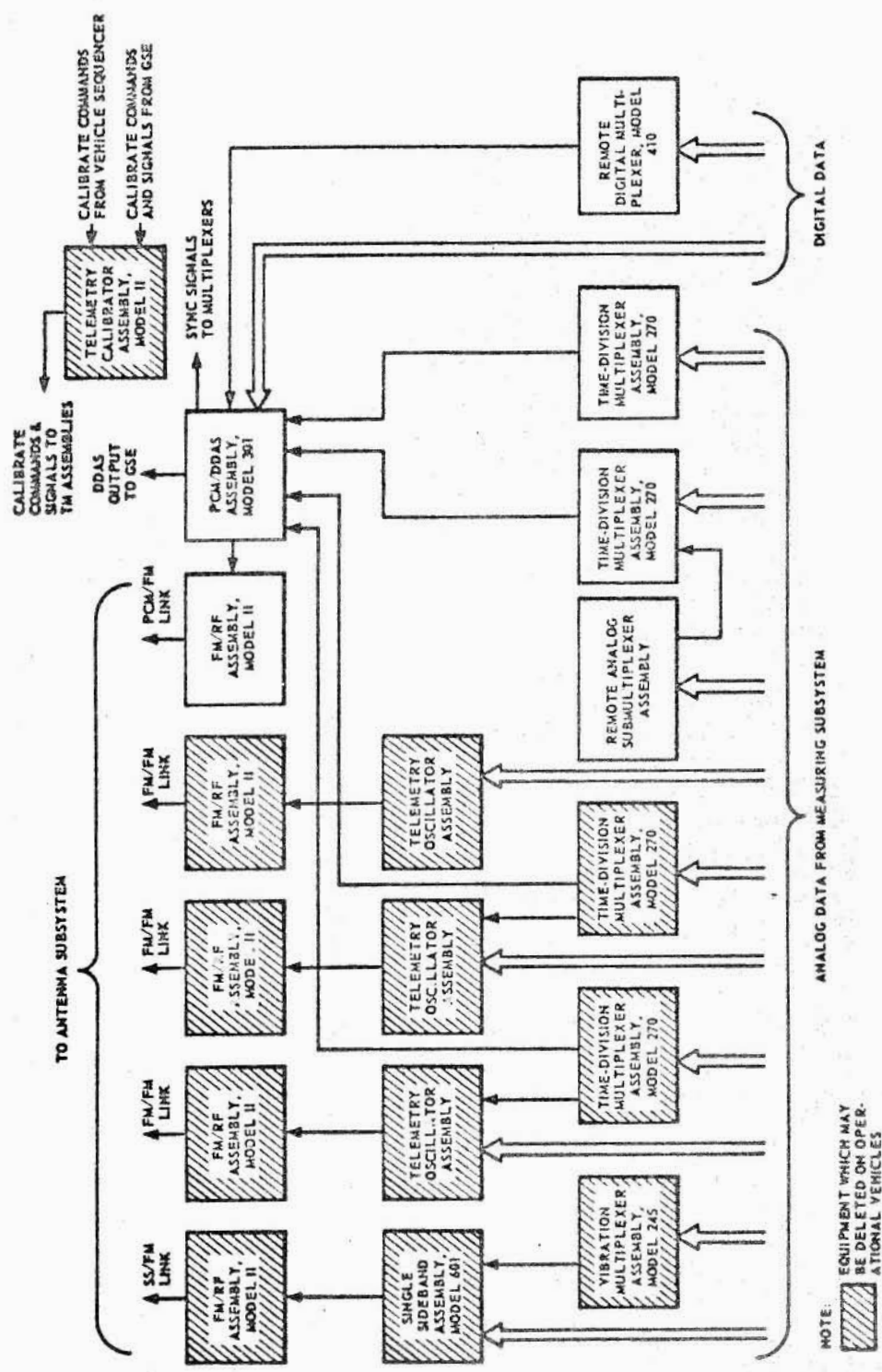


Figure 7. Typical Stage Telemetry Subsystem.

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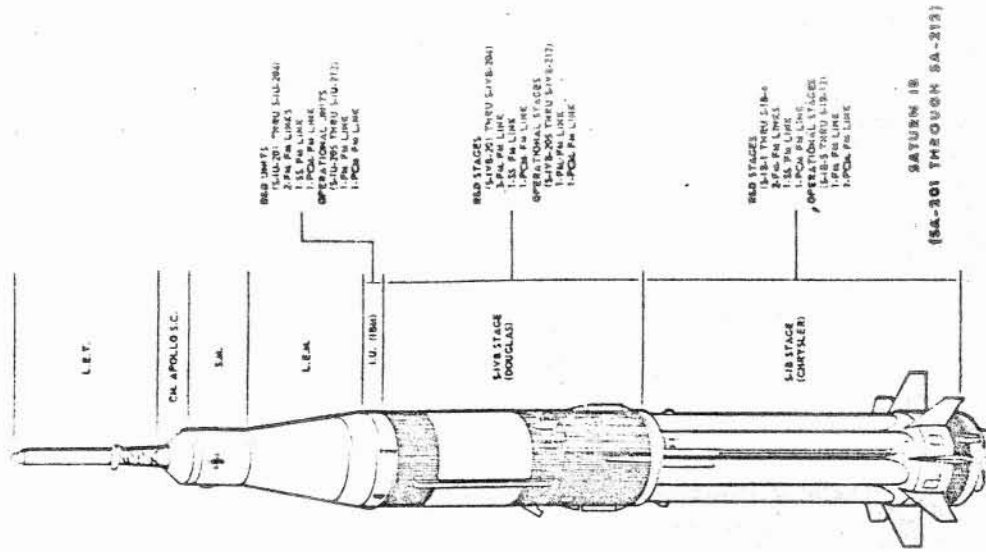
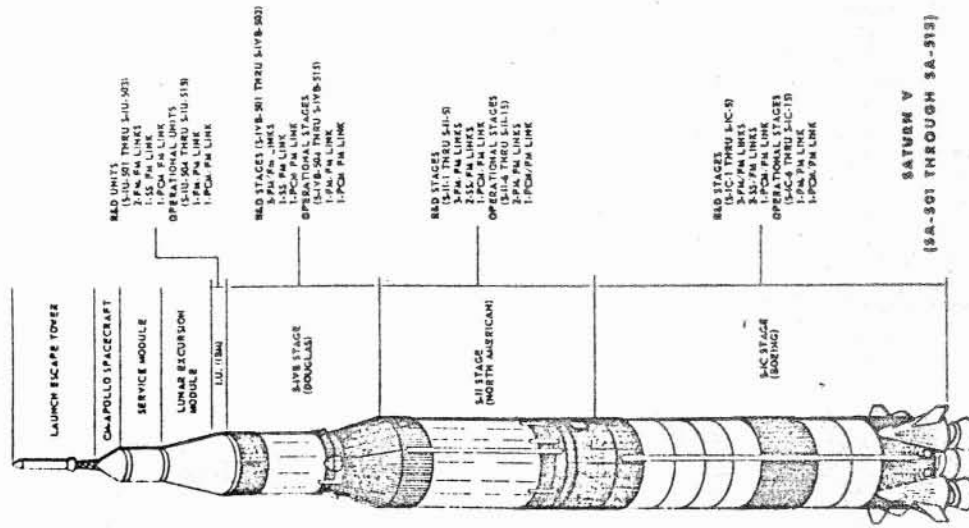


Figure 8. Saturn Telemetry Links.