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THE MAGSAT TELECOMMUNICATIONS SYSTEM

The Magsat telecommunications system, consisting of the command and telemetry subsystems, performed the command, control, data-gathering, and transmission functions between Magsat and the NASA ground stations.

INTRODUCTION

The design of the Magsat telecommunications system was based in part on using hardware from the Small Astronomy Satellite (SAS-3) wherever possible. However, the telemetry modulation control and tape recorder interface electronics were new designs. In addition, the need to accommodate the new NASA phased shift keying (PSK) uplink format, together with other considerations, led to a new command processor design, supported by existing SAS-3 power switching modules and command DC/DC converters. Figure 1 illustrates the major telecommunications hardware functions and indicates the primary signal flow paths.

The NASA standard transponder and associated diplexers, couplers, and antennas were shared by the command and the telemetry subsystems. From each command receiver, the bit stream from the command decoding unit went to the command processor, where the commands were decoded, checked for validity, and distributed to the users, either as relay drive pulses from the pulse command matrix or as relay contact closures from the power switching unit. Command sequences could also be loaded into the command processor for delayed command execution at times when the satellite was out of range of a ground station. The command subsystem was completely redundant and was designed so that a single failure could not prevent commands from being processed.

The telemetry subsystem received data from all of the spacecraft systems, formatted the information into a single serial digital bit stream, and routed it to the transmitter and to the two tape recorders. Redundant precision crystal oscillators and digital clock divider logic in the telemetry subsystem provided timing signals for other spacecraft systems. The telemetry subsystem also had a data interface that allowed the command processors to preempt the entire telemetry frame for verification

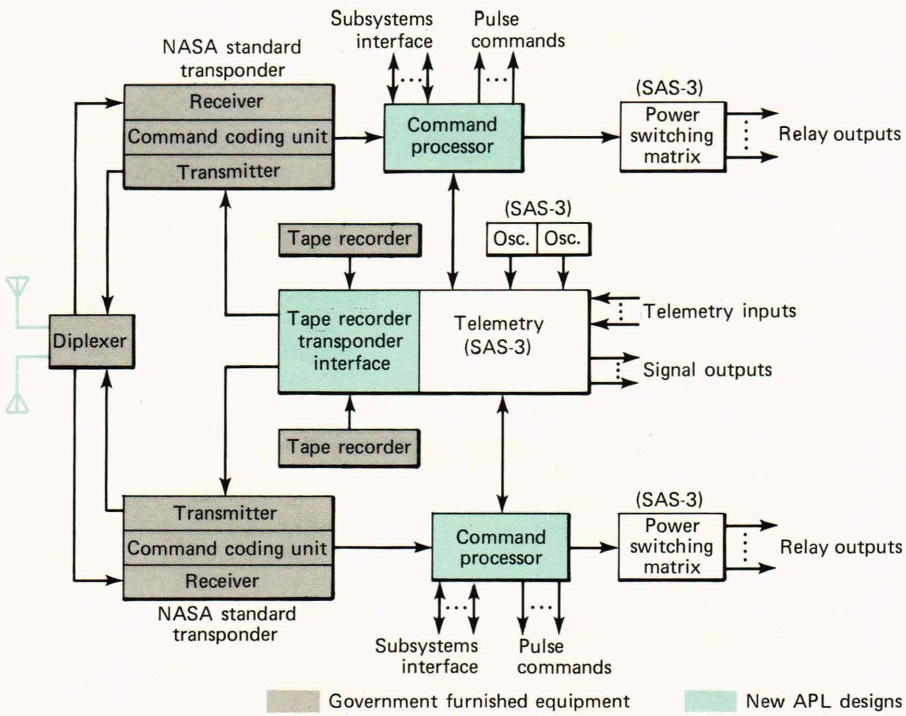

Fig. 1—Magsat telecommunications system.

of the stored command sequences before execution was begun.

COMMAND SUBSYSTEM

Since the introduction of the first integrated circuit controllers in the early 1970's, microprocessors have matured to the point where the design of complex spacecraft electronics must consider the alternatives of microprocessor-based versus random logic design. Trade-off evaluations resulted in the selection of a microprocessor-based design for the Magsat command subsystem.[1] This new design represented the first in a new generation of command subsystems, offering expanded capabilities and increased flexibilities in real-time and delayed commanding operations for APL satellites.

A block diagram of the command subsystem is shown as part of Fig. 1. Except for the S-band antenna, it incorporated full addressed redundancy. Two receivers detected the PSK RF uplink and delivered command data to each respective command processor for execution of the following functions: RELAY, SHORT DATA, LONG DATA, and PULSE commands. All command functions were executable in real time or on a delayed basis. Additionally, each command processor was programmed for limited semiautonomous operations with the telemetry, power, and attitude subsystems.

Multiple command execution was an important feature of this new design. Figure 2 shows the uplink command message depicting a real-time command sequence that must be limited to a maximum of 2048 bits (the equivalent of 32 real-time commands). Within the microstructure of each command, a truncated Hamming code byte was used for error control.

Both command processors processed the uplink command message; however, only the selected processor executed the desired command once all interlocks were enabled. Both processors would normally be in the main general polling routine shown in Fig. 3. The routine sampled flags according to a prescribed priority to determine the desired command operation: real-time commands, low battery-voltage commands for load minimization, delayed commands, spacecraft attitude maneuvers, and automatic transmitter power turn-off. The routine could be interrupted for the loading of a real-time command message bit stream by the INTRCDLD subroutine. Upon sensing a real-time hardware interrupt from the command decoder unit, the command sequence was loaded into a working area in the random access memory for processing by the general polling routine. All real-time commands were processed similarly for either RELAY, PULSE, SHORT DATA (24 data bits), or LONG DATA (memory load) commands. Delayed command sequences were extracted from the working random-access-memory space and loaded into a designated delayed-command random-access-memory space. The delayed-command storage area could accommodate up to five different sequences totaling 82 commands; however, each delayed-command load was limited to a maximum of 31 commands. For each load, an automatic telemetry readout was generated for ground verification before sequence execution was started with an epoch set command. The delayed commands were handled by two flags (for preservation of delayed-timing integrity) within the polling routine.

Subsystem Hardware

The considerations that led to the decision in favor of independent, redundant command channels were reliability, the reliance of other subsystems on the command subsystem for configuration and control, and their use as a troubleshooting tool with the telemetry subsystem. Both channels had equivalent command capabilities so that a failure in either channel would not impair any command function. Within each channel there existed a measure of circuit redundancy to reduce the probability of executing erroneous commands. Reinforcing the hardware redundancy were numerous software checks on the command message that had to be successfully verified before command execution could proceed.

Each channel consisted of a receiver, a processor, and the power switching electronics. The receivers are discussed in the transponder section.

The command processor was implemented with the RCA CDP 1802 family of circuits consisting of the CDP 1802 microprocessor, CDP 1852 interface circuit, CDP 1822 1K × 1 random access memory, and HA 6611 256 × 4 programmable read-only memories . Complementary metal-oxide semiconductor (CMOS) support circuits were utilized for power considerations. The CDP 1802 is the large-scale-integration CMOS, 8-bit register-oriented central processing unit with circuitry for fetching, interpreting, and executing instructions in external memory and generating input-output control signals.

Each command processor contained four electronics boards that were interconnected via flexible cabling, as is seen in Fig. 4. The four boards folded in accordion fashion and were housed in a magnesium casing.

The centralized power switching modules were housed separately. In addition to relay contact out-

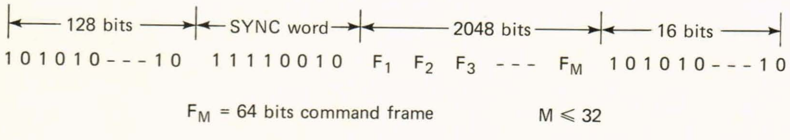

Fig. 2— Command message stream.

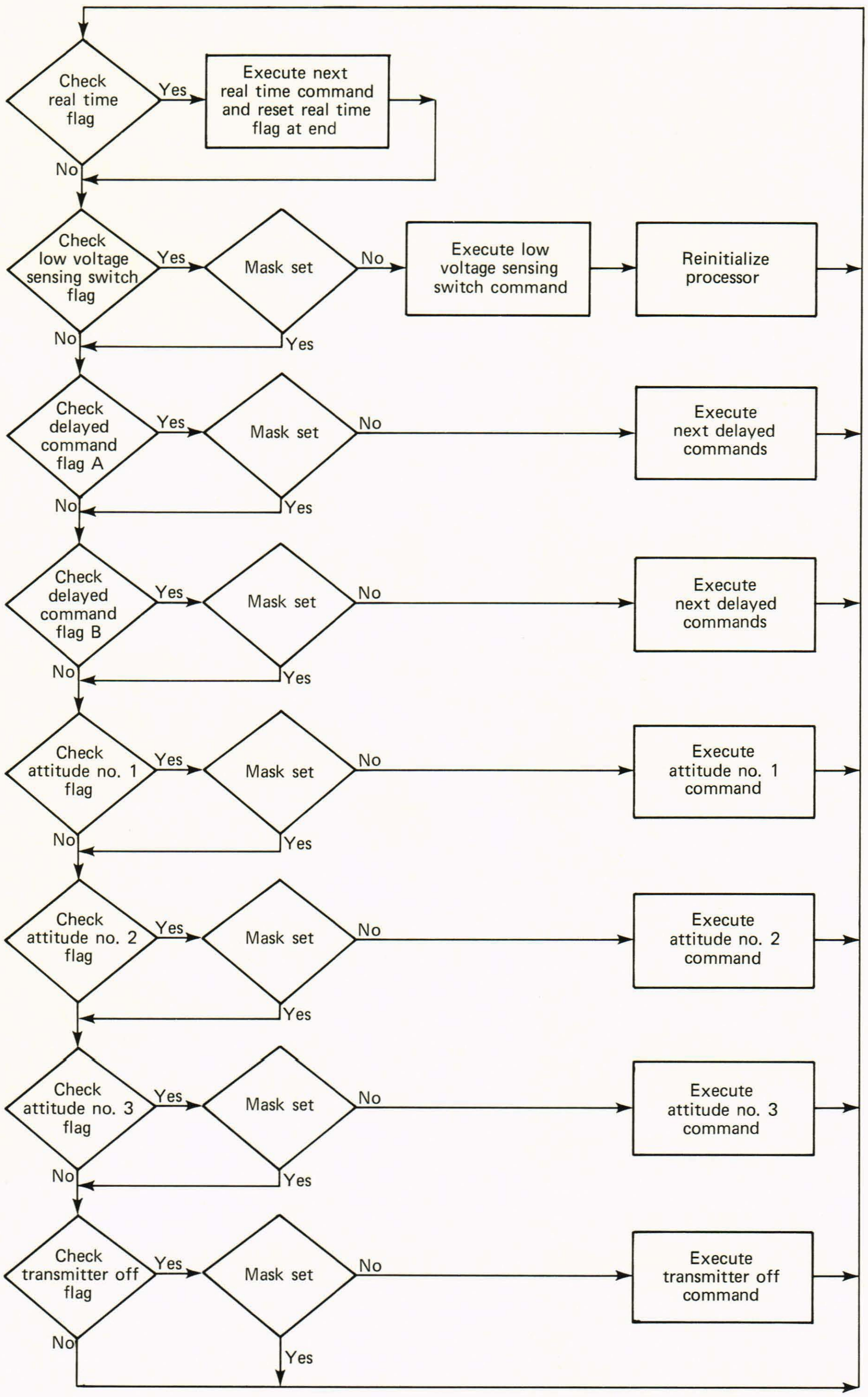

Fig. 3—Magsat command; general polling scheme.

puts, the two relay matrices also provided for low voltage sensing switch operations. A low voltage sensing circuit external to the command system provided a pulse to selected relays to switch off all nonessential loads upon sensing low battery voltages. The same pulse was also routed to each command processor to initiate the low-voltage stored commands. Functions not accommodated by the SAS-3 power switching modules were assigned to the pulse command matrices (board 4 of Fig. 4).

Subsystem Software

There are four routines for each command processor, labeled as follows: INGENPOL, CMDEX, INTRCDLD, and STORED CMDS. INGENPOL performed all initialization operations and continually executed the general polling routine during the background mode (Fig. 3). Within each loop the CMDEX routine was called to process command frames individually after each real-time command load.

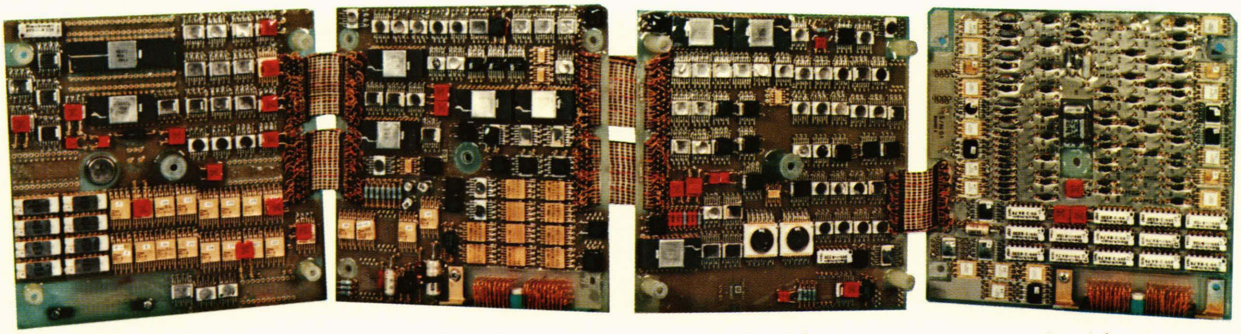

Fig. 4—Command processor. Each of the four electronics boards is 5.9 inches square.

After servicing subsequent flags, INGENPOL again invoked CMDEX to execute another real-time command until all real-time commands were executed.

Real-time command sequences were loaded into each processor's random access memory by interrupting INGENPOL with INTRCDLD. The STORED CMDS portion of the firmware consisted of stored commands that were executed via software for spacecraft operations.

The entire command firmware required 2.8 kilobytes of programmable read-only memory. Software for this project was developed with the aid of the APL 1802 cross assembler.

TELEMETRY SUBSYSTEM

For Magsat, the flight-qualified spare telemetry "books" from the SAS-3 spacecraft were modified and requalified. Some of the flexibility designed into the SAS-3 telemetry subsystem[2] was not required; this allowed some hardware to be deleted. The changes included deleting the variable format generator and its memory, the variable bit rate, and the transmitter and recorder interfaces, and changing the time code generator to a major frame counter. Also, the programmable read-only memories that contained the SAS-3 fixed format program were removed from the format generator board and replaced with programmable read-only memories containing the Magsat format. The relative ease with which the Magsat frame format was accommodated illustrates the flexibility inherent in a programmable controller like the SAS-3 format generator.

Since the interfaces to the transmitter, the NASA standard tape recorders, and the SAS-3 spare telemetry hardware were all predetermined and were not mutually compatible, a section of interface electronics had to be designed to interconnect them. The recorder-transponder interface represents the only new hardware design that was required for the telemetry subsystem. It provided the signal cross-strapping and mode selection that allowed data from either tape recorder to be played back via either of the transmitters. The telemetry subsystem as a whole was not completely immune to single-point failures, but there was much redundancy in the hardware (such as two independent format memories). In addition, the recorder-transponder interface was completely redundant. The interface unit required two standard welded wire boards of circuitry that fitted into the space that became available by eliminating the variable format generator. Pertinent characteristics of the telemetry electronics are summarized in Table 1.

Table 1

TELEMETRY CHARACTERISTICS

Bit Rate (b/s)	
1953	Split phase PCM on 640 kHz subcarrier
312,000	Tape recorder playback on baseband
Frame	
Size	
Minor frame:	960 bits
Major frame:	256 minor frames
Rate (s)	
Minor frame:	0.49
Major frame:	125.8
Subcommutators	
Number:	4 analog, 4 digital
Length:	shortest, 4 channels; longest, 256 channels
Size (cm)	
Main telemetry hardware	16.0 × 18.3 × 35.6
Crystal oscillators	10.4 × 13.0 × 15.5
Dual power converter	16.0 × 18.3 × 5.1
Weight (kg)	
7.7 (excluding NST* and tape recorders)	
Power (W)	
9 (excluding NST* and tape recorders)	

*NASA standard transponder

S-BAND TRANSPONDER

The S-band transponders used on Magsat were the NST – near earth type. They served as command receivers, phase-coherent ranging transponders, and telemetry transmitters. Each transponder consisted of a double-conversion, phase-coherent receiver and a transmitter that was integrally related in both frequency and phase with the receiver.

The transponder operated on a 2102.723 MHz uplink received signal and produced a 2283.5 MHz downlink transmitted signal. The phase-locked downlink RF carrier signal was precisely 240/221 times the uplink received RF signal frequency when operated in the ranging mode. On ground command, the transponder would provide a noncoherent downlink RF signal frequency. In this nonranging mode of operation, the transponder operated strictly as a command receiver and a telemetry transmitter that were independent of each other. In the absence of an uplink RF carrier signal, the downlink RF carrier signal was derived from a self-contained oscillator.

MAGSAT TAPE RECORDERS

Tape recording the real-time telemetry data ensured that no information was lost during the time the spacecraft was out of contact with a ground receiving station. Two recorders, manufactured by Odetics Corp., recorded up to 9×10^7 bits each, over a 12.5 hour maximum period. Upon command, the accumulation of data was played back to the ground at 312,000 b/s, which is 160 times the rate at which it was recorded. This took less than 4.7 minutes, well within the 6 to 10 minute duration of a satellite pass over a ground station. The reels of tape were stacked one above the other and contrarotated to minimize disturbances to the spacecraft attitude by recorder speed changes. To reduce angular momentum transients further and to eliminate rewind time, the tapes were played out backwards so that the last datum recorded was the first recovered. Each recorder had three capstans coupled by redundant Kapton belts and was driven by a servo-controlled brushless DC motor with optical commutation. Housings were pressurized by nitrogen to protect the recorders from the vacuum of space. Table 2 summarizes other tape recorder parameters.

Table 2

SALIENT CHARACTERISTICS OF THE MAGSAT TAPE RECORDERS

Record speed	0.55 cm/s
Playback speed	88.2 cm/s
Tape	256 m × 0.635 cm × 25.4 μm
Power consumption	9 W record, 25 W playback
Weight	7.85 kg
Size	35.4 × 22.9 × 15.5 cm

PERFORMANCE

Operation and performance of the telecommunication system were highly satisfactory both during prelaunch and in orbit. For the prelaunch qualifications, the command processor, power switching, and telemetry electronics were extensively tested in automated test configurations controlled by an SEL 32 computer. The spacecraft operators found the versatility, in orbit, of the command processor in handling delayed commands particularly useful. Successful execution of stored commands was crucial to spacecraft operations during the first orbit when the spacecraft was not in view of a ground station.

REFERENCES

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[2] M. R. Peterson, "The SAS-3 Programmable Telemetry System," *APL Tech. Dig.* **14**, No. 4, pp. 7 – 13 (1975).

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