Helios Mission Support

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Project Helios is the first NASA international deep space project—although there have been prior NASA international sub-orbital and earth-orbiting cooperative space projects. Helios is a joint undertaking by the Federal Republic of West Germany and the United States of America, who divide the project responsibilities. Two unmanned scientific satellites are planned for heliocentric orbits—the first to be launched in mid-1974, and the second in late 1975. Prior volumes of this series describe the history and objectives of this program, the contemplated spacecraft configuration, and its telecommunications and telemetry systems. This article deals with the spacecraft's command system, its requirements, and conceptual block diagrams.

I. Introduction

This is the fourth of a series of articles pertaining to Project *Helios*. A detailed description of the *Helios* spacecraft radio system was given in Ref. 1. Specifically, the transponder's coherent versus noncoherent modes of operation and the telemetry portion of the spacecraft's data handling system were described. This article will complete the discussion of the data handling system by describing the command system.

II. The *Helios* Telecommand System

A. Redundancy

The *Helios* spacecraft is designed with two actively redundant *receiver/command detector* chains. These are shown in Fig. 1. The first chain is fixed-wired to the low-gain (omni) antenna system, while the second chain is fixed-wired to the medium-gain antenna system. (As discussed in previous articles, the spacecraft's high-gain antenna provides a transmit-only function.) Since both *receiver/command detector* chains are continuously active, there are redundant means to enter commands into the spacecraft in case of a failure in one of the chains. Since both receivers operate on the same S-band carrier frequency, means are provided whereby ground control can select the desired chain through which to enter the command. They are described in the following.

First, there is a desired path due to the gain differential between the low- and medium-gain antennas. During the near-earth and cislunar portions of the mission, the preferred path will be via the low-gain antenna system, since the spacecraft will not yet have been oriented such that the medium-gain antenna pattern impinges upon Earth (Refs. 2, 3). However, after the step II orientation maneuver, the situation will be reversed, with the medium-gain antenna having a 6- to 8-dB advantage over the low-gain antenna system.

Second, each *receiver/command detector* chain has a separate command subcarrier frequency—i.e., 448 versus 512 Hz—thereby permitting ground control to select the chain they desire regardless of spacecraft orientation, even though the 8 symbols/s command rate is coherent with both subcarrier frequencies.

Third, as further protection, each chain's command verifier has a unique address in the command word structure. This will preclude commands accidentally appearing in the wrong chain from entering the decoding matrix.

The combination of the above features provides a truly redundant, fixed-wired active command system that can be operated in either the non-coherent or coherent transponder mode, while at the same time providing ample insurance against a double command entry.

B. *Helios* Command Requirements

The performance requirements for the *Helios* command system are shown in Table 1. It is interesting to note that, while the performance of the command system is dependent upon having sufficient uplink signal strength, the redundant *receiver/command detector* chains previously described do not otherwise significantly contribute to achieving the requirements listed in Table 1. This is because the commands are entered through only one chain or path at a time. The redundancy does, however, provide hardware reliability. Command bit or word error reliability must be coded into the command symbol structure itself.

C. *Helios* Command Code

1. General. To achieve the low error probabilities listed in Table 1, *Helios* commands are Manchester-coded, which translates each command bit into two symbols (the original bit followed by its complement) for transmission to the spacecraft. The coded 8 symbols/sec command symbol stream is phase-shift-keyed (PSK) modulated onto one of the two (i.e., 448 or 512 Hz) command subcarrier frequencies which is, in turn, phase-modulated onto the S-band uplink carrier. (Ranging modulation may or may not be also present on the S-band uplink carrier — depending upon the mission mode at the time.) Upon receipt at the spacecraft, the command signal follows one of the paths described in the foregoing *Paragraph A* and is routed through the appropriate command verifier to the decoding matrix. The decoding matrix has 256 separate hard-wire outputs which are routed to the individual items to be controlled aboard the spacecraft. These 256 outputs represent the total (i.e., maximum) list of commands that can be sent to the *Helios* spacecraft.

2. Idle sequence. Due to both the relatively low frequency of the command subcarriers and the stringent requirements for low bit or word error probability, the spacecraft command detector loop will have a fairly narrow bandwidth. On the other hand, narrow bandwidths do not respond well to square-shaped pulses. The latter problem can be minimized if the spacecraft command detector is kept in synchronism with the incoming command symbol stream. For *Helios*, this is accomplished by sending an uncoded *idle stream* of bits/symbols to the spacecraft during the intervals between commands. The *idle stream* has the following pattern:

. . . 001001001 . . .

This *idle stream,* which is sent at a rate of 8 bits/symbols per second, is also coherent with the two command subcarrier frequencies — i.e., 448 or 512 Hz. As mentioned in Ref. 1, it is necessary for the spacecraft to receive the *idle stream* for a few minutes prior to receiving a command or series of commands in order to ensure that the bit synchronizer (Fig. 1) is in lock. However, once the bit synchronizer is in lock, the *idle stream* may be interrupted on either a "0" or a "1" to start the actual command sequence.

3. Command symbol sequence. Each *Helios* command consists of a sequence of 68 symbols sent at a rate of 8 symbols/sec. The 68 symbols compose one command word. One command word must be sent for every command desired to be executed. The allocation of symbols within any one command word is shown in Fig. 2. From Fig. 2 it is noted that each command word repeats the command address twice and also contains three synchronizing subwords. In addition, each command word of 68 symbols also contains flag, verification, and parity bits which are similarly repeated twice within the total command word. The flag bit symbols are used to determine if the address is to be processed by the command decoder to generate one of the 256 command outputs or if the address bit is to be delivered directly to the data handling system to prepare it for the next mode of operation. The verification bit symbols are used to determine which *receiver/command detector* is permitted access to the decoding matrix (see Fig. 1). The parity bit symbols are used in a conventional manner to validate the address and verification portions of the command message. The foregoing structure plus the benefits of Manchester coding, are designed to fulfill the requirements set forth in Table 1.

On occasion, it may be desirable to send a series or chain of commands in one sequence, i.e., without interruption. In such a situation, the final 8 sync bits of the preceding command in the chain are eliminated because they duplicate the leading 8 sync bits of the next command to be sent. In other words, sync words are only eliminated when they: (1) appear adjacent to one another, and (2) when commands are chained together and sent without interruption. At present, there is no spacecraft limitation regarding the number of commands in a chain; however, the high-speed data line between the SFOF and the DSSs does have a *data block size* limitation that, for practical purposes, will probably limit the number of commands in any one chain to approximately ten.

4. Impact on the DSN. A pre-coded command table of 256 potential commands does not present a difficult problem to the SFOF. Neither does the transmission of a selected pre-coded command or series (up to ten) of commands from the SFOF to the DSS over the high-speed data lines present a significant problem. Upon receipt at the station, the DSS telemetry and command processor (TCP) will both log the total command message and repeat it back to the SFOF for verification and subsequent enabling prior to transmission. At the time of transmission (either immediate upon enabling or at a specified time) the precoded command symbols stored in the TCP will be synchronously and coherently modulated onto the appropriate command subcarrier for transmission to the *Helios* spacecraft. To accomplish the latter requires that the station:

(1) Derive the command subcarrier frequency, the *idle stream* frequency, and the timing for the command symbols themselves from one coherent source, and

(2) Receive prior instructions as to which *Helios* command subcarrier frequency to employ for a given command.

Both of these requirements can be met by the Mark III command system presently being implemented into the DSN. Therefore, as long as the proper operational procedures are followed, there does not appear to be a problem for the DSN to execute the *Helios* commands as presently conceived.

III. Conclusion

This article concludes the present series of descriptions of the *Helios* Spacecraft radio system and its associated data handling subsystem. The discussion to date has been intentionally restricted to conceptual block diagrams because at this stage of the spacecraft's development many of the design details have not yet been finalized. Therefore, the reader should consider this and preceding articles to be only conceptually correct and subject to change as experience with specific design details dictates modification.

References

1. Goodwin, P. S., "*Helios* Mission Support," in *The Deep Space Network Progress Report,* Technical Report 32-1526, Vol. IV, pp. 22–27. Jet Propulsion Laboratory, Pasadena, Calif., Aug. 15, 1971.

2. Goodwin, P. S., "*Helios* Mission Support," in *The Deep Space Network Progress Report,* Technical Report 32-1526, Vol. II, pp. 18–27. Jet Propulsion Laboratory, Pasadena, Calif., April 15, 1971.

3. Goodwin, P. S., "*Helios* Mission Support," in *The Deep Space Network Progress Report,* Technical Report 32-1526, Vol. III, pp. 20–25. Jet Propulsion Laboratory, Pasadena, Calif., June 15, 1971.

Table 1. *Helios* command requirements

Requirement	Value
Bit error probability	$\leqslant 10^{-5}$
Detected word error probability	$\leqslant 10^{-3}$
Undetected word error probability	$\leqslant 10^{-10}$

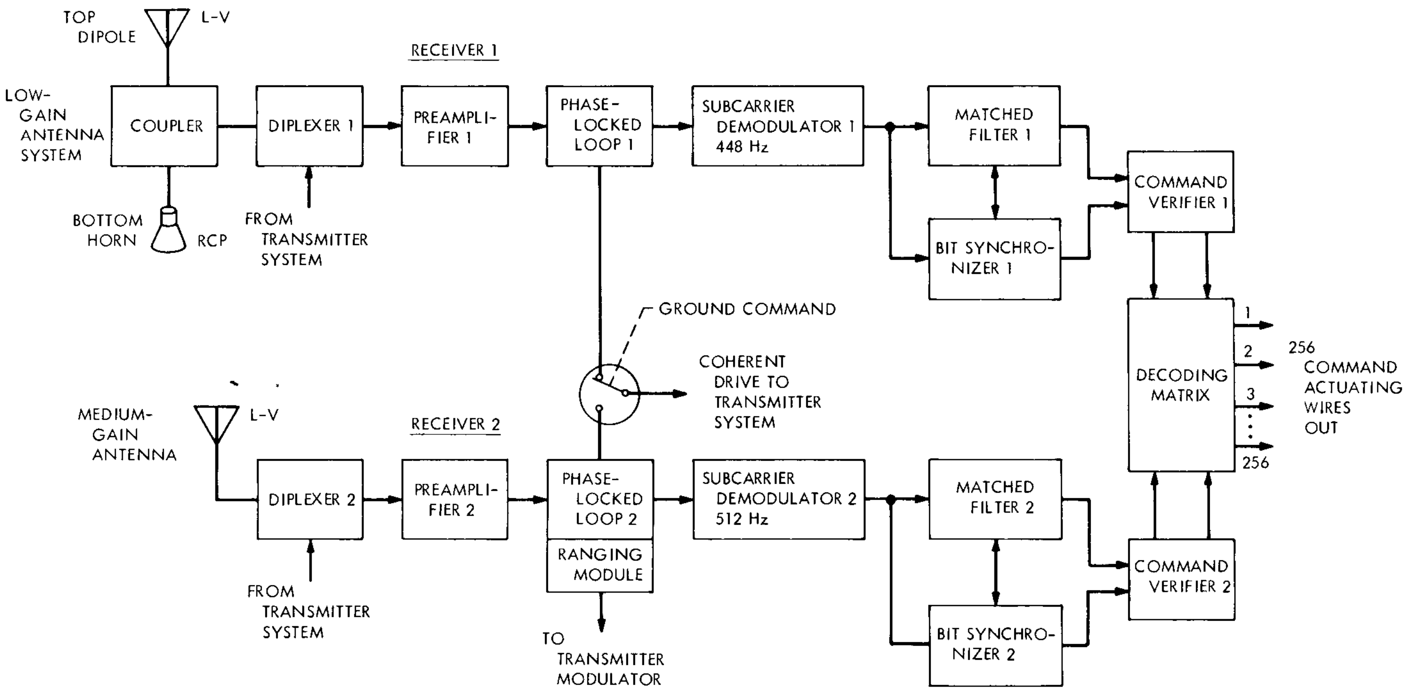

Fig. 1. *Helios* command detection system block diagram

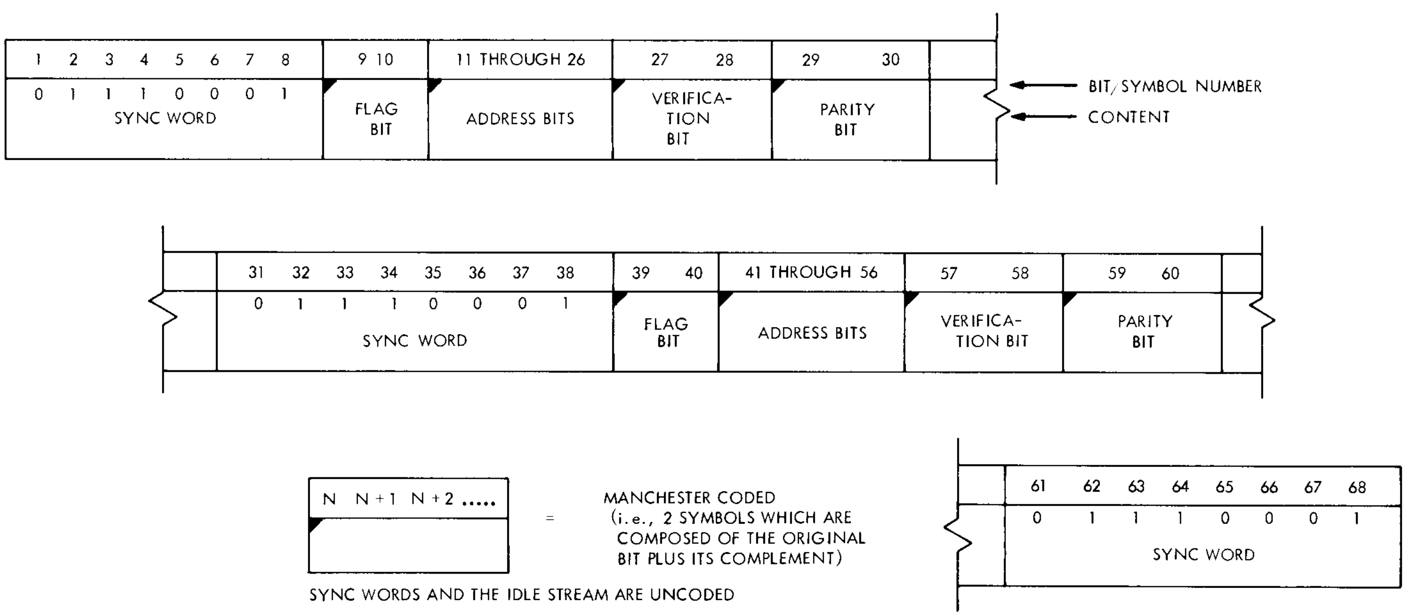

Fig. 2. *Helios* command bit/symbol sequence