THE DATA HANDLING SYSTEM OF THE HELIOS PROBES

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Summary. The Helios probes A and B will have a maximum distance of 2AU from Earth. The typical requirements which are applicable to all deep space missions, especially decreasing link capacity, need a flexible data handling system. Taking the Helios probe as an example, it will be shown how the specific problems of data handling in deep space probes were solved from the technical standpoint.

The system processes 4 selectable scientific formats at 8 to 4096 bit/sec with 320 subcommutated housekeeping channels, also to be transmitted in a separate engineering format. Simultaneously, a special format is stored cyclically with up to 16kbit in a 0.5Mbit memory, which can also be used for the storage of all the other data in an automatic sequence mode. Telemetry data are convolutional coded. Due to its flexibility and its multiplicity, the data handling system is a useful instrument for deep space missions.

Introduction. The primary mission of the Helios probes is to investigate the interplanetary space close to the sun. The spacecraft will be at a maximum distance of 2AU from Earth.

The explorations will measure solar winds and their mechanics of acceleration, magnetic and electrical fields, cosmic rays and cosmic dust. For this scientific goal, ten experiments are provided.

A specific attribute of the probes is that as the distance from Earth continually increases, the capacity of transmitting data becomes continuously more difficult. The power available on-board is limited, as is the antenna gain; one must therefore reduce the bit rate when the limits are reached. Reduction of the transmission bit rate has direct consequences: the measurement frequency must be reduced and the data sharing of the experiments has to be changed. The measurement of fast-occurring events necessitates an on-board storage capacity because transmission of the resulting high bit rate is not possible. The change of data-handling modes should not entail loss of synchronization and therefore data, which would be costly since they are few due to the low bit rate. It is advantageous to employ technical solutions thich avoid the reduction of the data transmission, e.g., a special coding of data.

The required flexibility obviously necessitates an on-board computer which controls the sequence of the data flaw, The idea of using an on-board computer was abandonded in an early stage of the project because of various reasons. The major objection was the risk of too complex a system. An alternative solution would have been the use of a programmable PCM- Encoder in order to get flexible telemetry formats. This idea also had to be abandonded because it was not possible to use the proposed telecommand link for the purpose of programming or at least up-dating the on-board program storage.

It will be shown how the specific, complex requirements for large data handling systems in deep space probes can be solved without using a computer and how one can nevertheless achieve flexibility.

Telemetry Formats. In order to remain optimal, reduction of the transmission bit rate necessitates a change in the share of the measurement data. This applies as well to the data of a single experiment as to the data of all of them. Figure 1 shows the data shares which are required for the various transmission bit rates. In order to adapt to the shares, the data handling system provides four different formats which can be selected by command; these are the formats 1, 2, 3 and 5. Figure 2 shows the minor frame of format 1 as an example; the frames of the other formats are built up in a similar manner. A minor frame of any format consists of 144 words (8 bit/word), and a frame of 72 minor frames. These proportions allow the optimum in distribution of the very different data block lengths(4 to 504 words) of the experiments on the frames, considering also the various bit rates.

Format 4 contains the housekeeping data and is subcommutated in the scientific formats. In format 5, which is used with the highest bit rate, there are two words per frame; in format 3, which is used with the lower bit rate, there are 16 words per frame. Therefore the housekeeping data flow does not vary as much as does that of the scientific data. If a shorter access time for housekeeping data is needed, format 4 can also be operated alone.

The words No. 72 to No. 75 of every minor frame contain all information which is needed for the identification of the data. These are: the minor frame number, the spacecraft time and the data handling mode identifications.

Measurement of Shock-Data. When researching interplanetary space, the measurement of shock events becomes especially important. So much data is gathered in such a short time, that the down-link transmission capacity is insufficient. In order to ensure that all the necessary data arrive at the ground station, storage, followed by a slower transmission, is unavoidable. The shocks will occur seldom, but for that very reason they are important. A sensor is necessary which identifies a shock event. The signal from such a sensor, which is built into an experiment, should start write-in of the shock data into the 0.5 Mbit memory. The data which were measured just before the signal, would be lost, but exactly these are especially interesting. In order to collect them, the data are continually cycled into the “A” portion of the memory so that always the lost, newest data which are only a few seconds old, are stored. Figure 3 shows this procedure. Identification of a shock event stops the cyclical data write-in, and the data which follow it are sent to section “C” of the memory. In section “A” of the memory, therefore, are the data which were collected during a definite period immediately preceding the shock, and section “C” stores the data immediately succeding the event. As soon as section “C” is filled, the cyclical procedure in section “B” starts, in case a new shock event occurs.

The shock data, which are delivered by five experiments, are compiled into one format before being stored; the necessary time information is included in the format. Depending on what amount of resolution is desired, 4, 8, or 16 kbit/sec can be chosen by command. Collection of the shock data runs parallel with that of the other scientific data.

Interruption of Data Link. The radio link with the spacecraft will be interrupted for certain specific periods. These black-outs occur whenever the spacecraft is either in front of, or behind the sun. Figure 4 shows the trajectory of the probe referenced to the sun-earth axis.

It can be seen that the first black-out (lasting approx. three days) occurs 70 days after launch, and after 108 days, the second black-out (lasting approx. eight days) will occur, etc.

It is desired that measurements will continue to be made during these periods, and the 0.5 Mbit memory makes this possible, although with some limitations. These are caused by the fact that, even with the lowest bit rate, the memory capacity is insufficient to store all the data accumulated during the longer black-outs; read-in of data is therefore interrupted for a while. These pauses last for the duration of multiples of the longest data-block, that is one frame. The duration of a black-out depends on one hand, on the trajectory, and on the other hand depends on the characteristics of the Helios link capability, which, up to now, have not been tried. In order to achieve high flexibility, it has been provided that, by command, pauses lasting for the duration of between 0 and 63 frames can be set.

In operating the spacecraft, there is the risk that the start of a black-out could be missed; circuits were included which enable the black-out mode to start automatically. Hours before a black-out is calculated to start, the appropriate mode can be placed on stand-by. A time-delay then places it into operation 4.5 - 9 hrs later, if a command has not re-set it to

“0”. Therefore, if the transmission should suddenly fail, it is assured that the black-out mode will start.

Modes and Mode Change. It is desirable that a minimum amount of data be lost when a mode change causes a loss of synchronization. The loss can be avoided during all kinds of switching except when bit-rates are changed. Therefore the selection of bit rates was separated from the other mode changes. Thus it is possible to use all formats at the some bit rate. The change of formats is performed within the pattern of the minor frames which assures that no data is lost. Another independence exists between the format mode and the distribution mode, as shown in figure 5. Switch position 1/6 causes the real-time transfer of data to the ground station. In position 2/6, shock data is stored in parallel with the real-time transmission. The bit rate selection and position 2/6 is initiated by the same command. Switch position 3/6 is used for “Black-out” operation phase. Besides selection of pattern 3/6 by single command, a combined black-out command also selects 3/6 together with format 3 and the bit rate of 8 bits/sec. The execution is delayed as described above. Switch position 1/7 is used for the read-out of stored data. At the end of the read-out phase, the operation mode changes back to that mode which had been selected when the read-out operation was initiated. This is done in order to avoid breaks and subsequent data losses.

In case a ground station is not able to pick up all data from the core storage at the low bit rate, a command can be used to set back the storage address by two minor frames. Thus a second ground station can continue the reception of stored data and during the unavoidable synchronization phase of this second ground station, only such data will be lost which had already been received before, by the first station. All switching occurs within the pattern of, and between the frames or minor frames.

Coding of the Telemetry Data. The measurements are greatly limited as a result of the limiting of the bit rate. It is therefore worthwhile to encode the data if more data can thereby be transmitted. A special code, the convolutional code, provides a gain of about 5 dB compared with an uncoded transmission. Every information bit is given a code bit according to a previously determined sequence, whereby the bit (or symbol) rate doubles, but which provides a gain in spite of this if the ground station provides an equivalently large effort in evaluation. For the reverse direction (the transmission of commands), such a procedure is not useful because the investment on the receiver side would be too large.

Coding of the Commands. For transmitting commands, a PCM process was chosen which allows the transfer of 9-bit command words in a sequence of 7.5 seconds. One command format can be divided into two parts, each containing 30 symbols; the second part is a repetition of the first one. 8 of the 30 symbols are used for frame synchronization, the rest contain the 9 bit-command word, which is extended by an address and a parity bit, and all are represented in Manchester coding. Assuming a bit error probability of 10^{-5}, calculations have shown that one out of 1000 commands might be lost; nevertheless only one command out of 10^{10} could be improperly interpreted.

Spin-Synchronization and Timing. Since the spacecraft turns once every second, those measurements which are directional must be synchronized with this rotation speed. One of the duties of the data handling system is to generate these synchronization pulses; they are derived from one pulse which is produced by a sun sensor every rotation. With the help of these “see-sun-pulses”, pulse-sequences are generated which are directly related to the angle of the spacecraft to the sun. Figure 6 shows the angular relationship of Pulse Sequence 8 as an example.

The experiments require various pulse rates ranging from 8 pulses per revolution up to 2048 per revolution; the accuracy must remain within ± 5 ppM. This spin-synchronized timing system assures, when necessary, that the experiments measurements will be made in exactly the correct direction.

All measurements must, however, also be referenced to time and location; for this, an accurate spacecraft time reference is built in. The moment of the read-out is directly related chronologically with the measurements. The time reference has an accuracy of ±10 ppM, is binary coded and has a range of 125 ms to one year. The ground station relates the timing of the probe to that of the Earth a maximum of once each day, and takes into account the change in transmission time. By means of the time and orbit-data, the location of the measurement can be precisely determined.

Conclusions. The link capacity is the principle determinant for the design of a data handling system in a spacecraft, especially if, as in deep space missions, the data rate has to be changed over a wide range. The effects of this and other limitations/requirements on the various functions of the data handling have been shown, together with the solutions applied in Helios. Additionally, information has also been given on other important attributes of the system.

This system, which is capable of handling the data of ten experiments and can process 320 housekeeping channels, can perform a shock data measurement program and provide a storage capacity of 0.5 Mbit is a useful instrument for deep space missions because it can accomodate a large range of bit rates.

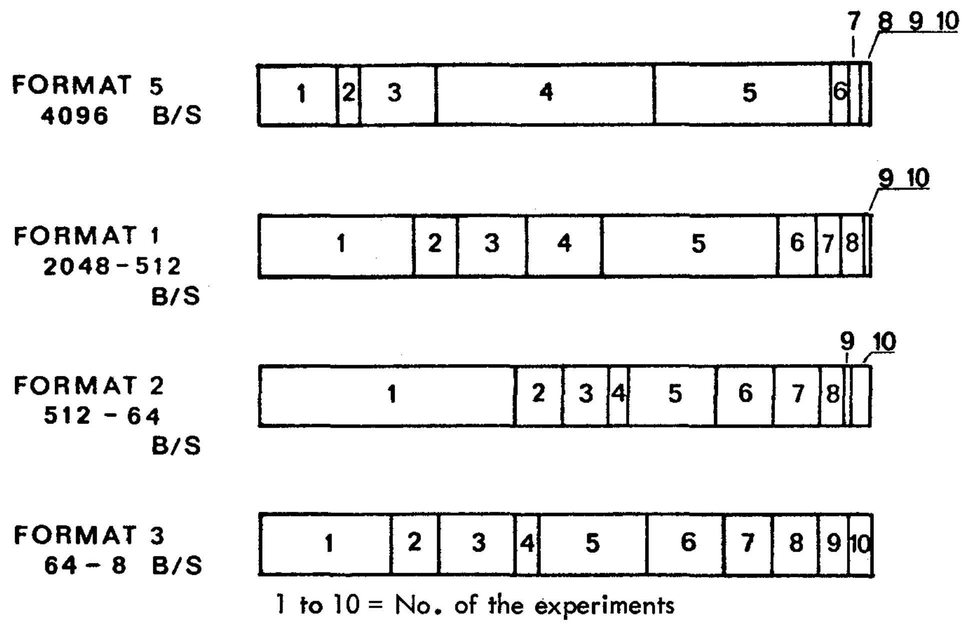

FIG. 1 DATA SHARING AS A FUNCTION OF THE BIT RATE

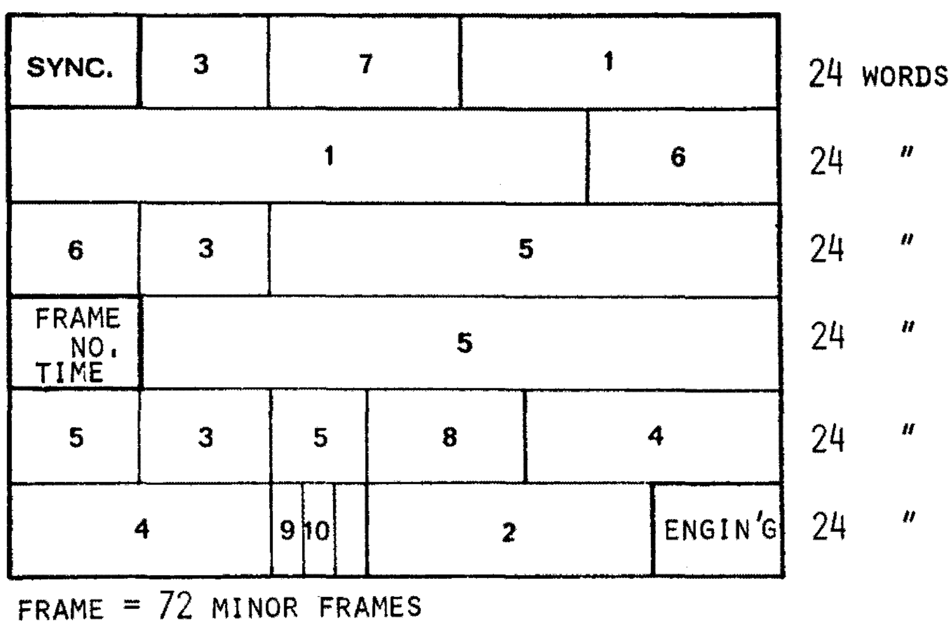

FIG. 2 FORMAT 1

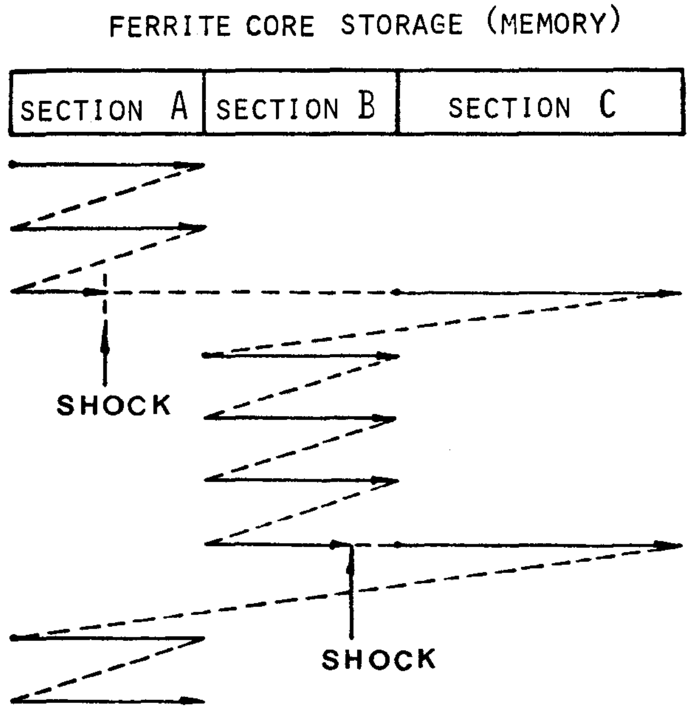

FIG. 3 SHOCK DATA STORAGE SEQUENCE

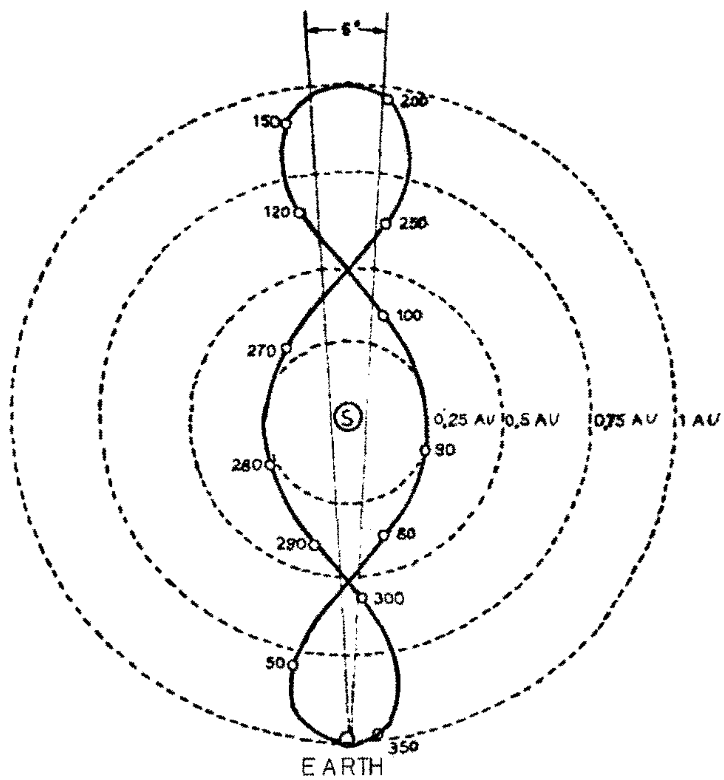

FIG. 4 HELIOS TRAJECTORY, RELATIVE TO THE SUN-EARTH AXIS

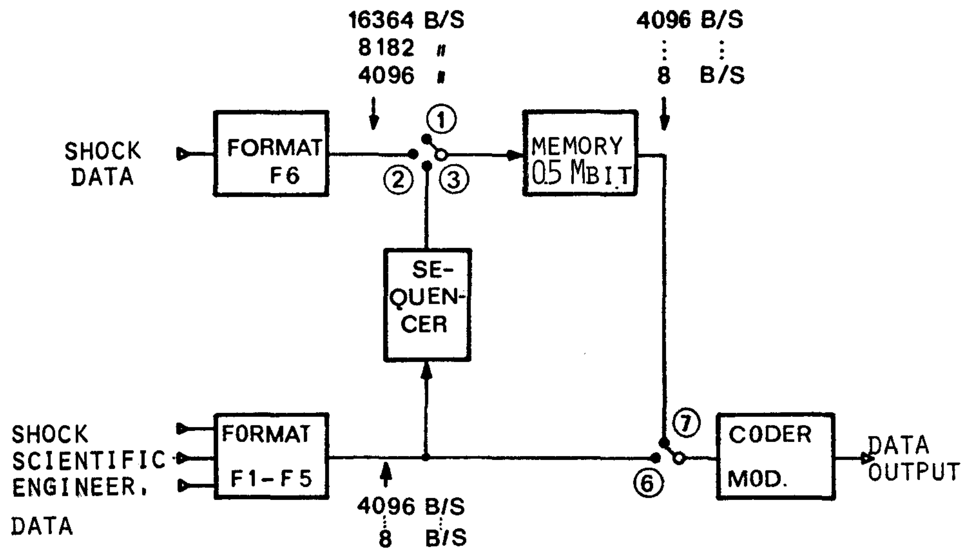

FIG. 5 DATA DISTRIBUTION IN THE DATA HANDLING SYSTEM

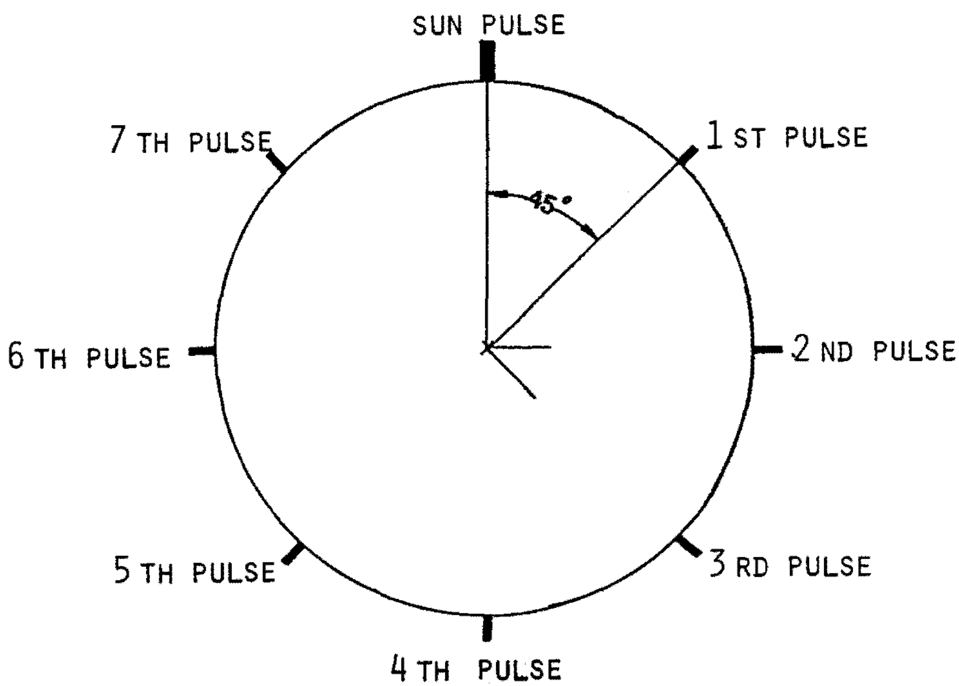

FIG. 6 ANGULAR RELATIONSHIP OF PULSE SEQUENCE 8