AN ON-BOARD PROCESSOR (OBP) FOR OAO C

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This report concerns a stored program computer for spacecraft use and its application on OAO C. The computer, referred to as OBP-I, is a medium scale, parallel machine and has a memory capacity of 16,384 words of 18 bits each. It possesses a comprehensive instruction repertoire and requires 45 W, including the dc-to-dc converter. It operates at a 500-kHz rate and executes add instructions in 10 μs. The primary functions of OBP-I on OAO C will be auxiliary command storage, spacecraft monitoring and malfunction reporting, data compression and status summary, and possible performance of emergency corrective action for certain anomalous situations. Although the OBP-I will be initially applied to the OAO series of spacecraft, the computer was designed to have features which would fulfill the requirements of a variety of future scientific satellites. The system is modular and consists, in a minimum configuration, of one central processor unit (CPU), two 4096-word memory units, and one input/output (I/O) unit. Figure 1 shows how these units are connected to a common and redundant data and address bus, with the minimum system shown by solid lines. Several unpowered spare functional modules, shown by dotted lines, can be attached to the bus to extend the life of the system.

The CPU contains a fully parallel adder and parallel data transfers. Data words and instructions are 18 bits in length with negative numbers being represented in two's complement form. There are 50 instructions in the repertoire, 30 of which require an operand fetch; the other 20 instructions have a minor operation code in the address field of the instruction word. A storage limit register reserves a block of memory in which the operating program may write; such a block has an increment of 128 words.

Each memory module has a capacity of 4096 18-bit words and uses a conventional destructive read-out core as the storage element. The most significant feature of the device is that it is capable of being completely power-switched on a cycle-by-cycle basis and consumes less than 150 mW in the standby mode. Several memory modules may be randomly addressed without paying the price of large power usage. For the OAO C application, the computer will have four memory modules for a total capacity of 16,384 words.

The important design feature of the I/O is that it has no direct data connection with the CPU. All data flow between the two units must pass through memory by way of the memory data bus. This method serves to minimize the number of connections required between modules and allows the easy interconnection of spare CPU, I/O, and memory modules. Also, by use of "cycle-steal" channels, the I/O can operate in a manner that is independent of the CPU, and any portion of memory can be loaded or dumped even though the CPU is either unpowered or executing a program.

Figure 2 shows the specific data interfaces between the various spacecraft subsystems and the computer. Inputs to the computer are commands from the primary processor and data storage unit (PPDS) and spacecraft data from the spacecraft data handling equipment. Outputs are commands to the PPDS, 30 bits per telemetry frame to the spacecraft data handling equipment, memory dumps at 50 K bits per second to wideband telemetry, three analog lines to the fine wheel and jet control, and a single analog voltage line to the power control unit.

The OBP-I sends commands to the PPDS by simulating the command receiver and outputting the 1042 bits per second command message. With this connection (made through a set of relay contacts) the computer can send commands to all spacecraft subsystems and experiments. The 1042 bits per second spacecraft data input provides computer programs with data relating to thermal conditions of all subsystems, charge and discharge rates of power subsystem, gimbal angle errors, spacecraft aspect from sun sensors, rate information from inertial reference unit, course and fine momentum wheel rates, jet gas usage, magnetometer outputs, and the status of many discrete functions. Some of the possible applications of these data are discussed next.

The computer outputs a 30-bit status word to telemetry each 1.6 second frame. These bits can be defined in a variety of ways. One type of message will consist of the compressed sensor data. For some sensors, OBP-I may compute and telemeter the high, low, or mean values for the preceding orbit. For other sensors, data may be telemetered only if the values exceed some predefined limit. Another message will contain the results of a self-test computer program.

For OBP-I memory dumps, up to 4096 word blocks may be transmitted to ground at a 50 K bits per second rate. This high frequency data link will be used to verify both computer program loads and auxiliary command loads. Another use will be the transmission of summary messages which relate to status and usage of various spacecraft subsystems during the previous orbit. For the first time, control center equipment can display historical data almost immediately after acquisition from the spacecraft by a ground station. This is of particular interest to a spacecraft operator in situations where action must be taken to correct an abnormal onboard condition.

Outputs of three, 6-bit, digital-to-analog converters are connected through relay contacts to the fine momentum wheels. In this way, the computer can control spacecraft rotation about the roll, pitch, and yaw axes. For safety, the connection of these analog signals can be opened or closed by ground command. Although normal spacecraft operation will not require this interface, the computer may be called upon to control spacecraft attitude in the event of certain equipment failures in the stabilization and control subsystem or to demonstrate experimentally the application of the computer to the control system. The output of a 6-bit, digital-to-analog converter is connected through a relay to the power control unit. With this connection, the computer can control the power regulator duty cycle and thereby influence the operating point on the solar array voltage-current characteristic curve. By considering factors such as sun angle and solar cell temperature, the computer can match load to source at maximum power. This interface may be enabled or disabled by ground command.

The auxiliary command memory expands the storage capacity from 256 to 1380 commands. The increase in capacity serves to reduce the required frequency of command loads from 4 or 5 per day to 1 per day which, in turn, means the loads can be transmitted from one ground station instead of several. For this auxiliary command memory function, 4096 locations of OBP-I memory are required to store the 1024 additional OAO commands.

Monitor and malfunction detection consists of the OBP-I acting as a ground station when the spacecraft is not in contact with a station. In one case, it monitors the commands issued by the PPDS and the response of the stabilization and control components and detects possible malfunctions. In a second case, the computer can monitor spacecraft and experiment equipment temperatures and compare them with maximum limits of dynamic models. Finally, the computer can perform energy "bookkeeping" to sense battery rundown or detect failure in other prime electrical power system hardware.

The emergency action functions would be actions taken in response to diagnosed malfunctions which, if left uncompensated for a short period of time, could cause mission failure. Emergency action could be taken if the temperature of any subsystem exceeds a maximum limit. Here, equipment and/or heaters could be commanded off. In the case of overheating of experiment optical structures, the spacecraft could be reoriented. In the case of abnormal battery discharge, the computer could command equipment shutdown and/or spacecraft reorientation to the sunbathing attitude.

OBP-I can assemble special telemetry messages that give a rapid time history of spacecraft system status during the previous orbit. Changes in status would be reported early in a contact so controllers can obtain a "snapshot" of spacecraft conditions. The malfunctions, if any, would be reported as a part of this quick picture, and the emergency action taken, if any, would be indicated.

There are a large number of failure modes which would leave the spacecraft ineffective if a computer were not on board to substitute an equivalent function. Since failure modes cannot be predicted, the routines required to provide a workaround capability will not be a part of any standard operating program. The backup capability is considered significant, however, since it could have a large and positive impact on the life of the mission.

Figure 3 is a picture of the operating flight hardware as it now exists ready for integration with the OAO C spacecraft. We are already looking ahead to an advanced OBP which could be produced in the 1972-1973 time frame and which would be significantly smaller and would consume considerably less power, making OBP readily adaptable to even the smaller spacecraft programs.

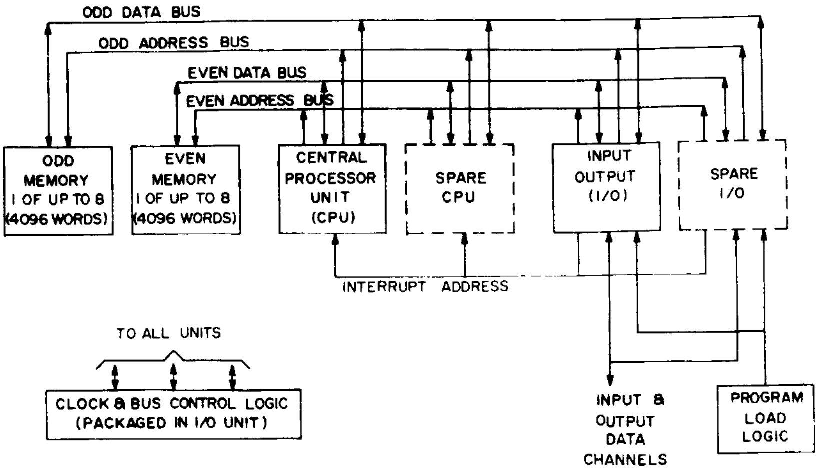

Figure 1—Functional block diagram of on-board processor.

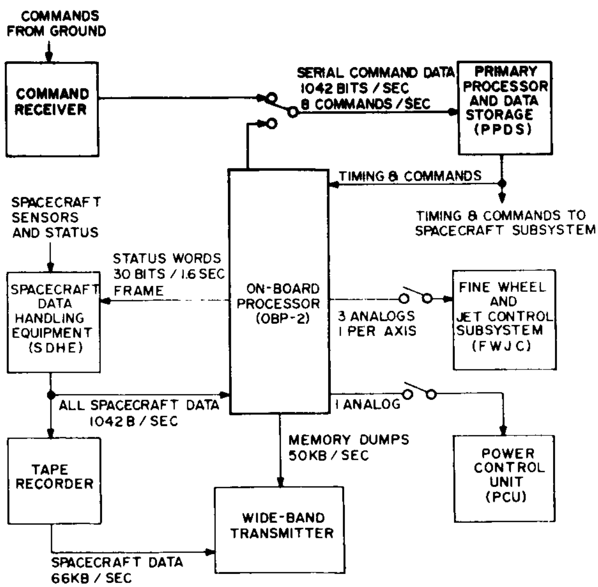

Figure 2—OBP-I interface with OAO C subsystems.

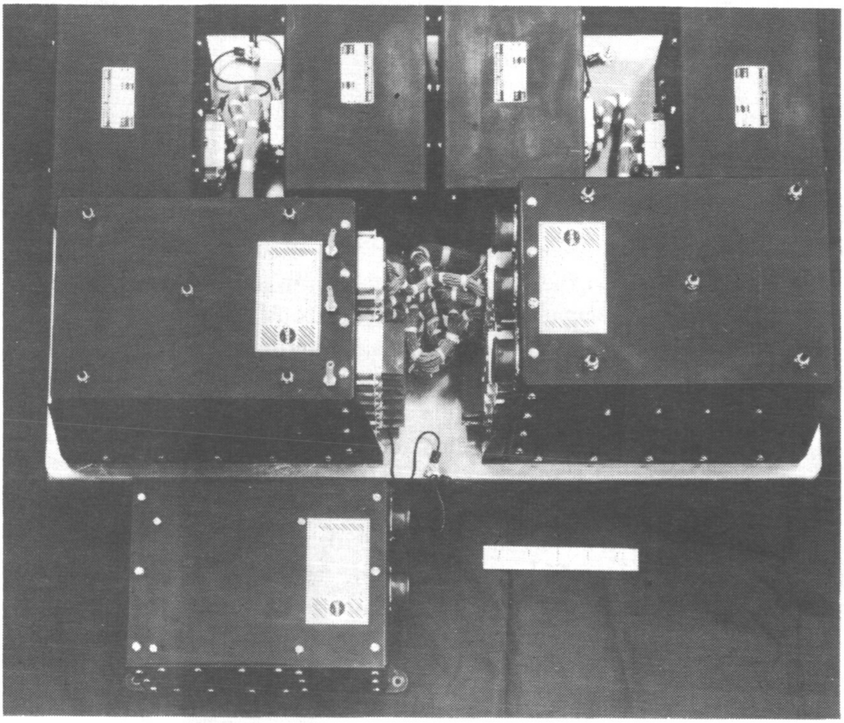

Figure 3–OBP-I flight hardware.