- Chapter One -
- The Gemini Digital Computer: First Machine in Orbit -

Hardware

[12] IBM Corporation received the contract for the Gemini digital computer on April 19, 1962, amounting to $26.6 million. It provided for the construction of the on-board computer and for integration with other spacecraft systems [8]. The first machine was in its final testing phase by August 31, 1963, and IBM delivered the last of 20 such machines by December 1965[9]. Engineers at IBM believe that the main reason why their company received the contract was the successful development of a core memory used on the Orbiting Astronautical Observatory [10]. One of them, John J. Lenz, said that the contract for Gemini came just at the right time. The best of the engineering teams of the IBM Federal Systems Division plant in Owego, New York were between assignments and were put on the project, increasing its chance for success.

Restrictions on size, power, and weight influenced the final form of the computer in terms of its components, speed, and type of memory. The shape and size of the computer was dictated by the design of the spacecraft. It was contained in a box measuring 18.9 inches high by 14.5 inches wide by 12.75 inches deep, weighing 58.98 pounds[11]. An unpressurized equipment bay to the left of the Gemini commander s seat held the computer, as well as the inertial guidance system power supply and the computer auxiliary power supply. The machine consisted of discrete components, not integrated circuits [12]. However, circuit modules that held the components were somewhat interchangeable. They were plugged into one of five interconnection [13] boards, and it took 510 of the modules to build the logic section alone [13]. The computer had no redundant circuits, which meant that failures in the computer canceled whatever activity needed to be controlled by it. For example, a failure in the power switch three quarters of the way through the Gemini IV mission caused cancellation of the planned computer-controlled re-entry. It was possible to fly the Gemini computer without a backup because whatever the computer did erroneously could be either abandoned (such as rendezvous) or handled. albeit more crudely, in other ways (such as re-entry using Mercury procedures).

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Figure 1-2. Locations of key components of the Gemini Guidance System. (From McDonnell Corp., Gemini Familiarization Manual)

The machine had an instruction cycle of 140 milliseconds, the time it required for an addition. Multiplication took three cycles, or [14] 420 milliseconds, with division requiring double that time[14]. The arithmetic bit rate was 500 kilocycles, and the memory cycle rate half that[15]. The computer was serial in operation, passing bits one at a time, which explains the relatively slow processing speeds, slower than some vacuum tube computers such as the Whirlwind. Also, its fixed decimal point arithmetic unit design limited the precision of the calculations but greatly reduced complexity. The Gemini digital computer used ferrite cores for its primary memory. Core memories store one bit in each ferrite ring by magnetizing the ring in either a clockwise or counterclockwise direction. One direction means a one is stored and the opposite direction is a zero. Each core is mounted at a perpendicular crossing of two wires. Thousands of such crossings are in each core plane, consisting of rows of wires running up and down (the x wires) and others running left and right (the y wires). Therefore, to change the value of a bit at a specific location, half the voltage required for the change is sent on each of two wires, one in the x direction and one in the y direction. This way only the core at the intersection of the two wires is selected for change. All the others on the same wires would have received only half the required voltage. By the use of a third wire it is possible to "sense" whether a selected core is a one or a zero. In this way, each individual core can be read.

The ferrite core memory in the Gemini computer had a unique design. It consisted of 39 planes of 64 by 64-bit arrays, resulting in 4,096 addresses, each containing 39 bits. A word was considered to be 39 bits in length, but it was divided into three syllables of 13 bits. The memory itself divided into 18 sectors. Therefore, it was necessary to specify sector and syllable to make a complete address. Instructions used 13 bits of the word with data representations of 26 bits. Data words were always stored in syllables 0 and I of a full word, but instructions could be in any syllable. This means that up to three instructions could be placed in any full word, but only one data item could be in a full word[16].

The arithmetic and logic circuit boards and the core memory made up the main part of the Gemini computer. These components interfaced to a plethora of spacecraft systems, most of which were concerned with guidance and navigation functions. This system was the Gemini digital computer through the Gemini VII mission. Beginning with Gemini VIII, the computer included a secondary storage system, which had impact on the spacecraft computer systems built by IBM and flown on the Skylab and Shuttle.

During the 1950s and well into the 1960s, the most ubiquitous method of providing large secondary storage for computers was the use of high-speed, high-density magnetic tape. By 1980, tape was used mainly to store large blocks of data unneeded on a regular basis or to mail programs and data between sites. Disk Systems have considerably faster access times and have rapidly increased in storage [15] capacity, rivaling or even exceeding tape, and thus supplanting it in common use. In 1962, disk systems were large, expensive, and far from fully reliable. When the software for the Gemini computer threatened to exceed the storage capacity of the core memory, IBM proposed an Auxiliary Tape Memory to store software modules that did not need to be in the computer at lift-off. For example, programs that provided backup booster guidance and insertion assistance would be in the core memory for the early part of the flight. The re-entry program could be loaded into the core shortly before it was needed, thus writing over the programs already there. This concept, fairly common in earth-bound computer usage, was a first for aerospace computing.

(MISSING PICTURE)
Figure I-3. Cores like these were used in Gemini’s memory. (IBM photo)

IBM chose the Raymond Engineering Laboratory of Middletown, Connecticut to build the device[17]. The unit weighed 26 pounds and filled about 700 cubic inches of space in the adapter module of the Gemini spacecraft[18]. The tape memory increased the available storage of the Gemini computer by seven and one-half times with its capacity of l, l 70,000 bits. Programs loaded from the tape would fill syllables 0 [17] and l of the core memory locations[19] . It took 6 minutes to load a program from the tape drive into core[20].

(MISSING FIGURE)
Figure 1-4. Layout of the Gemini Digital Computer core memory. (From McDonnell Corp., Gemini Familiarization Manual)

NASA’s natural insistence on high reliability in manned spaceflight operations challenged the computer industry of the early l 960s. Tape error rates were l bit in 100,000 and IBM wanted to raise this rate to l bit in 1,000,000,000[21]. The method used was to triple record each program on the tape, pass each set of three corresponding bits through a voter circuit, and send the result of the vote to the core memory[22]. This scheme was later used on the Shuttle.

Gemini VIII was the first mission with the Auxiliary Tape Memory on board. Shortly after a successful rendezvous with an Agena, the combined spacecraft began to spin out of control. Mission Control decided to disengage the Agena and bring the Gemini down, as large amounts of attitude control thruster fuel had been wasted trying to regain control of the spacecraft. Thus, the first attempt to load a program from the tape was made while the spacecraft was spinning. Even though the Auxiliary Tape Memory design parameters specified low vibration levels,[23] the re-entry program was successfully loaded and used in the subsequent descent.

IBM obtained this sort of reliability beyond the original specifications as a result of an extensive testing program. For example, the Auxiliary Tape Memory had failed prequalification vibration tests, so IBM added a brass flywheel and weights on the tape reels to increase stabilization[24]**.** This ensured a successful program load under adverse conditions. There were also problems with transistors shorting out due to loose particles too small to be seen on x-rays but which shook loose during acceleration[25]. Increased cleanliness in manufacturing was one solution to this problem.

The only in-flight failure of a computer component was on the 48th revolution of the Gemini IV mission, when astronaut James McDivitt tried to update the computer in preparation for re-entry. The machine would not turn off, and it could not be used for the planned "lifting bank" re-entry[26]. IBM could not duplicate the failure on the ground, but the manufacturers did install a manual switch that bypassed the failure for Gemini V[27].
