

**64 K Byte  
Memory  
Module**

The memory module holds 65,536 bytes of memory and connects to the LSI-11 Bus. It has a typical access time of 210 nanoseconds and up to four modules can be connected in a single system.

**Williams  
Tube  
Electrostatic  
Memory**

The electrostatic memory was invented by Professor F. C. Williams and Dr. T. Kilburn of Manchester University in 1948. The tubes were used extensively in high speed computers requiring random access memories. The ILLIAC I, an engineered version of the Princeton IAS machine used 40 tubes, in a 32 by 32 (ie 1,024) word memory.

**Early  
Slide  
Rule  
1672**

Edmund Wingate

Edmund Wingate put two Gunter Scales together in 1672, forming the sliding rule. While this first sliding rule was mainly for multiplication and division without a pair of dividers, the idea was the basis for the modern, multifunction (multi-scale) slide rule.

*USE: The slide rule works by sliding one end of the movable rule next to a multiplicand, measuring off the multiplier on the sliding part, and then reading off the product on the fixed rule.*

**Tates**  
**Arithmometer**

1184

The manufacturing model of the Thomas  
Arithmometer.  
Manufactured by Charles and Edwin  
Layton, London.  
3 p.c. (1800-1890)

**Computer  
Controls  
Corporation  
Delay  
Line  
Memory/  
Logic  
Module  
c.1958**

Register and Logic Technology  
Late First Generation

This logic and delay line memory was used to hold bits for operations in a serial fashion. The logic scheme circulated data through registers at a 20 megahertz rate.

**Mercury  
Delay  
Line  
Primary  
Memory**

Metal tubes were filled with mercury, to propagate an acoustic wave, and hold the information. A two meter tube held about 1000 bits, with a delay time of approximately 1 millisecond (i.e. a bit separation of about one microsecond, or two millimeters). Although no long delay lines are on display, short register delay lines of 64 bits (64 microseconds) from the English Electric DEUCE computer are shown in the logic display. The earliest computers, such as EDSAC and the Bureau of Standards computers used the mercury delay line.

The young Blaise Pascal seated at the mechanical adding-machine "Pascaline." Based on an engraving in Jean-Gauffin Gallon's "Machines et inventions approuvees par l'Academie Royale des sciences," Paris, 1735.

**French  
Pocket  
Calculator**  
1800

Combines the abacus with a mechanized version of Napier's Bones in which the four-sided bones are replaced by rotatory cylinders carrying the four columns of multiples of digital numbers.

3 p.c. (1800-1890)

Photograph courtesy of IBM, Armonk, N.Y.

**64 Bit  
Magnetic  
Shift  
Register**

Harvard MARK IV  
First Generation (1948)

**54 by 128  
Bit  
Core  
Plane**

From University of Illinois ILLIAC II.  
Courtesy of Professor Clifford E. Carter  
Second Generation (1962)

**Atlas I  
Computer  
1962**

Piece of fixed store. Read at .8 micro-seconds. The fixed store had 8K words (50 bits) which housed permanent programs called "extra codes," such as arithmetic functions.

Courtesy of Robert Hopgood, Rutherford Laboratories, Oxfordshire.

2 c. (1958-1966)

**Selectron  
Tube  
Johnniac  
Computer**  
1 c.  
1950

One of the forty RCA Selectron tubes installed on the Rand Corporation Johnniac Computer in 1950. The tubes constituted the 256-word, 40-bit memory. In 1954 a 4000-word magnetic core memory replaced the tubes.

Gift of John Postley, Head of Data Processing at Rand Logistics Department in 1954. D215.80

**Honeywell  
Plated  
Wire  
Memory**

Primary Memory Technology

Third Computer Generation

The plated wire memory was developed as an alternative to the core memory. Because it was expensive to produce, it was not widely used, except by Honeywell and NCR (called a rod memory). Bits were stored using the co-incident current principle to magnetize the plated magnetic coating on the wire.

**Casio  
Calling  
Card  
Sized  
Calculator  
1978**

With the advent of large scale integrated circuits and liquid crystal displays, card sized calculators became possible. Although the common calculator has only the four functions, its scientific counterpart provides logarithms, exponentials, trigonometrics (in degrees and radians), factorial and common statistical functions. Like all recent calculators, a general purpose stored program computer (micro-processor) in the calculator is programmed to carry out the calculator's functions.

**1. The Rabdologiæ** This book was written by John Napier in 1617. It contained instructions on the manufacture and use of Napier's Bones. The bones, themselves, were then often carved by sailors on their long journeys.

*From the collection of Gwen and Gordon Bell*

## **Navigator's Sector**

Galileo and Thomas Hood (English) described the sector about 1600 as two pieces of wood hinged together to measure angles and distances so that the calculations required for navigation could be carried out. The sector is also used for various trigonometric calculations on triangles and circles. Edmund Gunter added the logarithmic lines so that direct table look-up of a result was possible for a given angle.

**Quixsum**  
1924

A Pascal-Type calculator used to add English measures. The dials give fractional inches, inches and feet.

**Williams  
Tube  
Electrostatic  
Memory**

1 p.c.  
1949

From the Maniac computer, built in 1949 and functioning at Los Alamos Scientific Laboratory until 1962. This Williams tube Electrostatic memory was one of 40, each containing one memory bit.

Maniac was an asynchronous machine with an access time of 10 microseconds. Logic and CRT plugs are on the back of the module.

Gift of Dale Sparks, Los Alamos Scientific Laboratory, 214.80

## Curta Calculator

The Curta, manufactured in Leichtenstein by Contina, is the ultimate example of the rotary (Odhner-type) mechanical calculator. It's small size requires better manufacturing technology than any other mechanical calculator. Two models were manufactured:

	Register Size (in Digits)		
	Set- ting (Input)	Counter (Multi- plier)	Accumu- lator
MODEL I	8	6	11
MODEL II	11	8	15

Prior to the electronic calculator, the Curta was used as a portable device because it could be used for the four arithmetic operations. It was especially popular as a car rally calculator.

## **Semiconductor Memories**

With the invention of the transistor and the integrated circuit, it was possible to fabricate a complete array of memory cells using the Metal Oxide Semiconductor technology in a large scale integrated circuit configuration. Although smaller memory arrays were fabricated prior to 1972, the array of  $32 \times 32 \times 1$  (1,024 bits) was the first memory chip to be useful as a primary memory element. Subsequent larger memory arrays became even more cost effective and eventually replaced core as the dominant primary memory. The chip memories included the *4,096 bit chip*, 1974; the *16,384 bit* 1976; and *65,536 bit chip*, 1978. Using a rapid technology improvement model of doubling bits every two years, a 1 million bit chip would first appear in 1982.

## **Core Memory**

The *PDP-11* 16,384 word (16-bits/word) *planar structured core memory* was introduced in 1975. The cycle time was 1.5 microseconds and the access time, .75 microseconds.

Comparing the various core memory systems:

<b>Computer</b>	<b>Time</b>	<b>Memory Size</b>
Whirlwind	1953	32 x 32 x 17
PDP-1	1962	64 x 64 x 18
PDP-11	1976	128 x 128 x 17

<b>Computer</b>	<b>Physical Size</b>	<b>Cubic Feet</b>
Whirlwind	3' x 3' x 6'	54
PDP-1	1.5' x 1.5' x 2'	4.5
PDP-11	15" x 8" x 1"	.07

**Gunter's  
Scale  
1620**  
Edmund Gunter

The Gunter Scale was invented in 1620 by Edmund Gunter and was the predecessor of the modern slide rule. Gunter's Scales were used in navigation and commerce to carry out multiplication and division. Although Napier conceived of the idea of tables of logarithms which could be added or subtracted enabling multiplication or division, Gunter put the table along a rule, forming a line called the Gunter Line.

*USE: Multiplication is carried out by using a "pair of dividers" to measure a distance (multiplier) along the rule and adding it to another distance (multiplicand), forming the combined distance (product) which is "looked up" on the rule. The accuracy of an answer is limited by the length of the rule and users ability to resolve a number in an analogous fashion. Typically, a rule can give an answer correct to about 1%.*

**8-digit  
Millionaire  
2 p.c.  
1895**

One turn of the crank automatically multiplies the accumulator by the digit specified by the pointer in the upper left-hand corner. The answer is read across the bottom.

These machines, invented by Otto Steiger, were the workhorse of many scientific laboratories through the 1930's.

**Magneto-  
Strictive  
Delay  
Line**

2 c.  
1960

From the Ferranti Sirius Computer. Delay line stores hold information as a series of impulses circulating continuously along a closed path. In a magnetostrictive delay line, electrical impulses signifying data are converted into stress waves which travel the length of the nickel wire. The application of a magnetic field to the wire causes it to change dimension, thus converting electrical impulses to stress waves, or vice versa. Coils similar to those found in an electro-magnet are used for inserting and recovering digital information from the delay line. The Elliott Brothers' computers in England were the first to use the magnetostrictive principle for storage of data.

Gift of Science Museum, London  
D230.80

**Two-function  
Calculator**

4 p.c.  
1645

The first mechanical adding machine built by the French physicist and mathematician, Blaise Pascal.

**Use.** The dials show the French monetary unit, the livre, which was divided into 12 deniers, each subdivided into 20 sols. The essential part of the machine was its decimal carry: each toothed wheel moved forward one unit (one-tenth of a revolution on each wheel except those of deniers and sols) when the previous wheel had completed one revolution. Subtraction was based on complementary numbers that could be revealed by moving the strip at the top of the calculator.

Model made by Dr. Roberto Guatelli. On loan from G. Bell collection. B150.81

## ***HP-01 Digital Wristwatch Calculator, 1977***

This was the first wristwatch calculator and weighs half-a-pound. It initially sold in 1977 for a considerable \$800. The accompanying pen was used to enter keystrokes for the ham-fisted.

*Gift of Hewlett Packard Ltd.*

## ***Digitor Learning Arithmetic Module, 1974***

The Digitor, with its embedded Intel 4004, is the first use of a microprocessor in education. The difficulty and length of arithmetic problems were set by adjusting the two side knobs. Students answered problems posed on the display panel by entering a number on the keypad. Correct answers were rewarded by a happy face and incorrect ones by a sad face. At the end of the exercise, Digitor displayed the number of problems answered correctly. Over 100,000 Digitors were sold worldwide by Centurion Industries of Redwood City, California.

*X558.85 Gift of Centurion Industries, Inc.*

**AMD K5 8-Inch Wafer, 1996**

*On loan from Advanced Micro Devices.*

## **RCA *COSMAC VIP* Single Board Computer, 1977**

Designed for home hobby use, the COSMAC VIP (Video Interface Processor) generated standard composite video for use with any television. Program storage was via audio cassette recorder while programming itself was done in "CHIP-8," a simplified assembly language, and entered using the on-board hexadecimal key pad. The system board came complete with a "512-byte ROM operating system."

*X686.86 Gift of Robert F. Casey.*

## Texas Instruments *Speak & Spell*, 1978

One of the earliest and most successful electronic learning aids, *Speak & Spell* helped children with spelling and reading. It used a TI TMS 1000 microprocessor augmented with a custom voice synthesizer. Since the synthesizer was not sold separately, some developers are said to have purchased *Speak & Spell* as a source of that chip for other applications.

*Gift of Gary Boone, Micro Methods.*

## **Handbook of Chemistry and Physics**

The "Rubber Bible," as it is affectionately known among physical scientists who use it, is almost an institution. First published in 1914 by the Chemical Rubber Company, it goes through constant revision as more is known about the physical constants. Like Burington's Tables, it contains numerous useful mathematical tables and formulae.

The late 1980's will mark the replacement of it as a reference standard. Electronic hand held reference guides will store and evaluate all the functions. Unlike the tables they replace, their electronic counterparts are capable of showing many of the relationships in graphical form. In addition, the various physical constants are available by natural language query. The reference guides also display complete pictures such as the periodic table.

**Napier's  
Bones  
or  
Rods**  
John Napier  
1550-1617

Although Napier was best known for his invention of logarithms, he invented the set of rods (or bones) as a mechanical aid to paper and pencil multiplication. The rods allow multiplication in a digital fashion by a table look up method, negating the need for the user to remember the multiplication tables.

Some historians credit the bones as stimulating modern mechanical calculators, where a four sided bone became the ten sided wheel. The rods were constructed of metal, ivory or boxwood, but those widely used to calculate tariffs were longer and made from strips of heavy paper.

*USE: The multiplicand is laid out along the top of the table by rotating the rods to the appropriate number. The row specifies a particular, single digit multiplier for which the product is looked up in the table. A one above a diagonal line specifies when a digit is to be carried to the next significant digit.*

**Burroughs  
Adding  
Machine  
1899**

William S. Burroughs

Based on the same principle as the Comptometer, the first machines numbering about 50, were manufactured in 1899, were too difficult to operate. Although most problems were subsequently solved allowing it to become popular, the design has a fundamental flaw: if a key is not fully depressed only a part of the addend to be used is recorded. Ease of operation, human engineering, was taken into account resulting in a keyboard with a greater slope than that of the Comptometer. Some models had glass panels on the side which enabled the inner workings to be viewed. The Burroughs company went on to build printing-type machines for both general purpose and specific use.

**Sang  
Platometer  
also  
Planimeter  
1851  
John Sang**

Sang invented the platometer in 1851 as an instrument to measure the area of irregular planar figures such as maps. Its main use was in surveying. This platometer measures areas up to 4.5 by 22 inches.

The operation of the platometer is based on continuous integration. A curve is traced using the pointer, with the area read off in the dial (in square inches) after the complete area has been traversed.

*USE: The dial readings (area), corresponding to the pointer are shown in the figure. Note that as the pointer is moved the rollers that measure distance on the conical shaft calculate the product of the vertical distance times the horizontal distance. As a curve is traversed in a clockwise direction, the top area (shown in the figure) is integrated in a positive position until the rightmost point is reached. On the return trip, the area below the line is subtracted giving a net value.*

**Burrington's  
Mathematical  
Tables  
1933**

Richard S. Burrington

First published in 1933, this handbook includes many tables of useful mathematical functions including logarithms, trigonometric, roots, and interest. In addition, there are tables of formulae for integrals and derivatives. The tables are typically used by scientists, engineers and mathematicians.

Until recently, tables such as this were essential for determining transcendental functions that were too laborious to calculate with four function calculators. The first scientific and business calculators of the early 1970's negated the need for many of the tables. The early 1980's mark the replacement of tables such as this by hand held calculators which compute the various functions, remember all the formulae, and then evaluate them.

**Hollerith  
Card,  
Fujitsu  
Read Only  
Card  
and  
Paper  
Tape**

Early U.S. Calculators used Hollerith (IBM) Cards to hold programs. Programs with loops were constructed by either multiple copies of the card deck or by reading the card multiple times.

Fujitsu's relay computers built in the 1940s used *read only card memories* to store programs. Longer programs were stored on *continuous paper tapes*. Code breaking machines, especially those operated at Bletchley Park (U.K.) used one inch wide paper tape arranged in loops to hold programs.

**Thomas**  
**Arithmometer**  
**1820**  
**Charles Thomas**  
1785-1870

The Arithmometer was invented in 1820 in France and patented in 1851 in England. Though based on the concept of the stepped wheels of Pascal and Gottfried Leibniz machines, it went beyond these, introducing a second addend register for multiplication. His early machines provided four digits in the multiplicand and six digits in the product, while machines built after 1870 have an eight digit multiplicand. Although this was the first calculator commercially available, the machine was not terribly reliable due to lack of quality control in manufacturing technology. It advanced the state of the art and was the predecessor to later calculators.

**USE:** Arithmetic operations are carried out by placing a number in the slider position register at the bottom of the calculator. The crank is turned and the number is added to the wheels of the accumulator.

**Thales  
Patent  
Calculator  
1930's**

The Thales calculator is typical of European wholly rotary calculator designs based on the Odhner-type (or Baldwin-type) mechanism. Capable of all four arithmetic functions the calculator continues to be widely used in business and science.

*USE:* Wheel positions store the number and by a single turn of the crank, the rotary wheel position of the keyboard is added to the rotary position of the accumulator. Multiplication is carried out by successive turns of the crank. The crank turns are recorded in a separate multiplier register in order to verify that the operation has been carried out correctly.

**Atlas I  
Computer  
Memory  
1962**

From 1K working store, exclusively  
used by operating system called "The  
Supervisor."

Courtesy of Robert Hopgood, Rutherford  
Laboratories, Oxfordshire.

2 c. (1958-1966)

**1024 Bit  
Electrostatic  
Storage  
Tube**

(Williams Tube) from University of  
Illinois ILLIAC I.  
Courtesy of Professor Clifford E. Carter  
First Generation (1952)

**Fuller  
Calculator  
1902**  
George Fuller

Invented in 1902 by Fuller, the manufacturer claimed: "It costs only a fraction of an Arithometer, and is far less complicated to use." Like Thatcher's rule, this "hand held calculator" obtains a length of about 42 feet, by winding the scale around a cylinder, giving it almost 5 digits of accuracy. It was designed for convenience and to compete with the digital calculators beginning to be manufactured.

**Thatcher's  
Calculating  
Instrument**

1881

Edwin Thatcher

Edwin Thatcher devised and patented the rotary slide rule in 1881. It is essentially a conventional slide rule, wound around a cylinder with 60 feet in length providing accuracy of up to 5 digits, or about .01%.

**Autonetics  
Minuteman  
Missile  
Guidance  
Computer**

Primary/Secondary Memory Technology  
Late Second Generation

This fixed head disk memory was part of  
an on-board guidance computer for the  
Minuteman Missile.

Courtesy of Aron Insinga, LSI-CAD

**Musketry  
Rule  
Model**

2 p.c.  
1918

The slide relates the width of a shot to range in yards. The back has a rule for measuring.

$$\text{Range} = \frac{W \times 1000}{M}$$

$$\text{Mils} = \frac{W \times 1000}{R}$$

$$\text{Width} = \frac{R \times M}{100}$$

On loan from the G. Bell collection,  
B79.80

<b>T</b>	<b>H</b>	<b>E</b>	
<b>C</b>	<b>O</b>	<b>M</b>	<b>P</b>
<b>U</b>	<b>T</b>	<b>E</b>	<b>R</b>
<b>B</b>	<b>O</b>	<b>W</b>	<b>L</b>

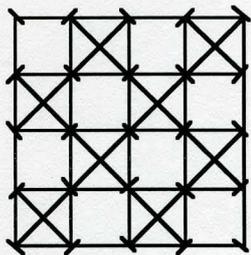
Table Artifacts Provided By The Computer Museum

**You may handle gently but...**

**Please do not remove from this table. Thank you.**

## 3M Data Cartridge

The quarter-inch data cartridge was invented by 3M in the early 70's, and was designed for telecommunications and data acquisition applications calling for the storage of serial data. The tape shown here uses 4 serpentine tracks (accessed by moving the head, not the tape). The quarter-inch cartridge operates with a thin belt that stretches throughout the cartridge mechanism, looping around (and making contact with) both the supply and take-up spools on their outer perimeters. This allows for rapid tape movement. The cartridge shown here held 20MB. Today, data cartridges are inexpensive and have capacities ranging up to 15GB. They are now used widely for backing up of data from PCs.



From the collection of  
The Computer Museum History Center.

## Selections from The Computer Museum's historical collection

**Blue Box, 1972**

**Steve Jobs and Stephen Wozniak**

**Gift of Richard Prelinger**

Stephen Wozniak on the Blue Box: "One day at my parents' house, I read an article characterized as "fiction" about these weird phone phreaks who drove around the country in vans with racks of equipment in their buses, plugging into communications networks. The author, Captain Crunch, philosophized that exploring the phone system would improve it for Ma Bell. I fell in love with this philosophy. I wanted to explore a system and a computer and I didn't care about free calls. Halfway through the article, I called up Steve Jobs and started to read it to him. Suddenly I realized there were too many details in the article -- frequencies of 700 hertz and 900 hertz. They gave too much information. It's too real. These are not things that a fiction writer can make up. My source for [technical] material at the time was the Stanford Linear Accelerator [library]; I knew I could always get in there on the weekend. With those high end research types, the door was never locked. Steve and I went to the library and started to research the phone system. We discovered that the frequencies mentioned in the article were correct. Now we knew that we could build a box and make free phone calls all over the world. We even managed to meet the author of the article, Captain Crunch. I was so pure about the philosophy of the phone company as a system that I paid for my phone calls home. Then, late at night, I'd call every country in the world. I showed it off. I told phone jokes. I sold blue boxes on the campus. I just wondered how far I could get. But I was still pure, I paid for everything I should pay for -- I was just using unused wires."

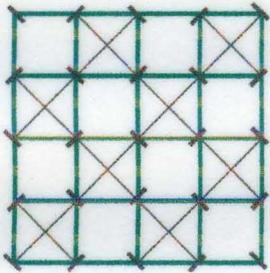
From a talk at The Computer Museum, 1986.

This particular box was purchased by Richard Prelinger for \$120.00 after a Cal Berkeley dormitory demonstration. The box used a crystal oscillator and was switched on or off simply by inserting or removing the plug leading to the earpiece. The early boxes were equipped with a safety feature, a reed switch inside the housing operated by a magnet taped onto the outside of the box. Should the phone phreak be caught, the magnet could be removed, whereupon the box would generate off-frequency tones, rendering it inoperable. "You tell them it's just a music box," said Wozniak.

**Chess Set, ca. 1968**  
**Honeywell Information Systems (Jack N. Rindner, sculptor)**

**Gift of Honeywell Information Systems**

Between 1964 and 1978, Honeywell Information Systems ran an advertising campaign featuring the work of several Boston-area artists. Starting with a pterodactyl-like bird, animal likenesses were rendered using computer components such as transistors, resistors, cables, diodes, and, later, integrated circuits. The Computer Museum possesses a fox, a St. Bernard, a grasshopper, and several other examples of the sculptures.



## Digital Equipment Corporation

**The  
Computer  
Museum  
History  
Center**

# PDP-8

The is a classic PDP-8 in blue smoked plexiglass box. The PDP-8 is sometimes considered the first true minicomputer as its half cabinet size meant it could sit on top of a lab bench. Much of its small size and low price (\$25,000) came from use of the new Flip Chip module technology (introduced in 1964) and the automatic wire-wrapping machine this approach permitted. Like its predecessor the PDP-5, it was a 12-bit machine. Several follow-on models to the basic PDP-8 were introduced at regular intervals over the next 15 years, incorporating advances in packaging technology and device fabrication. The final implementation was based on a CMOS IC manufactured by Intersil and Harris, the CMOS-8 and 6120 respectively.

Donor: Digital Equipment Corporation  
X1366.97

(over)

# *Specifications*

Speed:

Technology:

Size:

Weight:

Power:

Cost:

Etc:

(over)

Diodes were clustered in plug-in units (lower left). Longer plug-in units (upper right) contained short electrical delay lines.

The astronaut used a verb/noun language with a similar syntax to English. Examples of verbs included "display," "monitor," "load" and "proceed." Examples of nouns included "time," "gimbal angles," error indications and star identifications. Each command included a verb and a noun, such as "display velocity." The astronaut pressed the VERB key followed by a two digit code and then the NOUN key and a corresponding code.

The Display and Keyboard Unit, designated DSKY, was specifically developed for ease of in-flight computer operation. The DSKY was mounted remotely from the computer to be within reach of the astronauts.

Developed by the MIT Instrumentation Laboratory and manufactured by Raytheon, the innovative Polaris design met the size and stability constraints of launching a ballistic rocket from a submarine. Innovations included cordwood construction (later used on the CDC-6600) and wire-wrapped interconnections (later widely used throughout the industry).

Although the astronauts were subjected to many simulated computer failures, none occurred in the 14 missions in which the computer was used. If the computer had failed during flight, the Apollo spacecraft was equipped with computerized and manual backup systems that would generally have enabled the vehicle to return safely.

**Architecture:** Wired program DDA (Digital Differential Analyzer): The DDA is an integrator and pulse rate multiplier, with similarities to analog implementation.

**Memory:** Twelve 17-bit words of magnetic core shift register.

**Logic:** 512 3-input NOR gates.

**Clock Rate:** 81.6 KHz.

**Size:** 0.1 cubic feet.

**Weight:** 12 pounds.

**Power:** 40 watts.

"Before the missile and Apollo guidance programs, the problem of airplanes attacking ships at sea was a difficult one, so I began to do the ballistics myself, plotting on a sheet with a pencil and a slide rule. This analysis worked well enough so that ships were able to defend themselves against air attacks. When it came time to develop the Polaris and Apollo programs, the prevailing attitude among designers and engineers was much the same—we couldn't afford any failures, so we didn't have any."

Dr. Charles S. Draper, Chief Scientist, C.S. Draper Laboratory

An early instance of an analog navigation and control device is the auto-pilot assembly developed for use in the Hawk Missile System by Raytheon in the late 1950's. The Hawk Missile is used in an air defense system against high speed, low altitude targets. During flight the assembly receives inputs such as acceleration, attitude, direction and distance to target. It then computes the necessary corrective signals to be sent to the wings control system. This control causes the missile to follow the most direct intercept path to its assigned target.

Gift of Joe Kuprevich

**Word Length:** 15 bits plus parity.  
**Fixed Memory Registers:** 36,864 Words.  
**Erasable Memory Registers:** 2,048 Words.  
**Number of Normal Instructions:** 34.  
**Number of Involuntary Instructions  
(Increment, Interrupt, etc.):** 10.  
**Number of Interface Circuits:** 227.  
**Memory Cycle Time:** 11.7 microseconds.  
**Addition Time:** 23.4 microseconds.  
**Multiplication Time:** 46.8 microseconds.  
**Number of Logic Gates:** 5,600 (2,800 packages).  
**Volume:** 0.97 cubic feet.  
**Weight:** 70 pounds.  
**Power Consumption:** 55 watts.

1959 marked the first flight of a ballistic missile with an on-board digital computer. The guidance computer was used to solve the guidance and control equations for a small ballistic missile launched from a submarine, the U.S. Navy's Polaris.

The Apollo Guidance Computer not only fulfilled the requirements of space navigation and control, but also proved the reliability of integrated circuits, stimulating the development of third generation computers.

The rope memory was a special type of core memory that relied on the patterns in which its sense wires were woven during manufacture for information storage.

The computer in the Lunar Excursion Module (LEM) guided the LEM from the lunar orbit through its descent to the lunar surface. It was capable of providing the computations for a computer-piloted landing, however the astronauts invariably took over manual control of this delicate procedure.



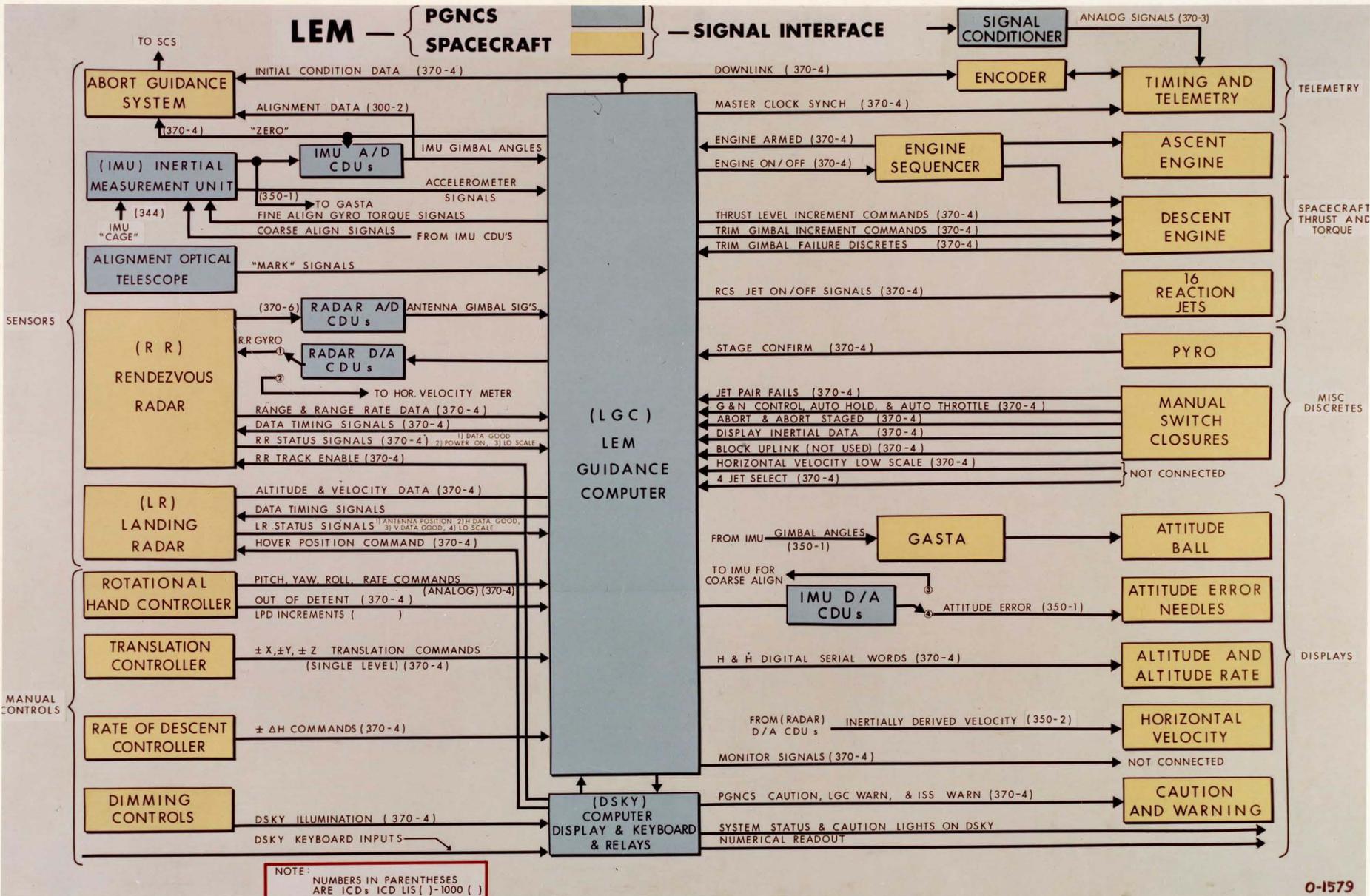


Diagram of mercury delay line memory. Bits circulate as ultrasonic pulses in the memory tank and are converted to electrical signals which can be amplified, rectified, and read in or out.

This drum, or "abacus," is the only remaining portion of the ABC. Two drums were built, each with 32 50-bit tracks of small paper condensers, with the outer end connected to a contact stud and the inner ends connected together and brought out through the mounting plates. A positive charge on the outer end of a condenser corresponds to zero, a negative charge to one. The drum rotates on an axis at a speed of one revolution per second. Brushes bear upon their contacts to read the charge and recharge them.

A typical SEAC chassis. Heat-sensitive elements such as diodes were on one side of the chassis (left); heat-generating elements — tubes and resistors — were on the other (right).

**While still under construction, the EDVAC influenced a number of computer projects.**

**SWAC block diagram. "The plan was to build a computer with the minimum of circuit development. Thus, the circuits in the arithmetic unit were derived from Whirlwind circuits, and the development of the memory circuits depended heavily on the published work of F. C. Williams of Manchester University."**

**Harry D. Huskey,**

**"The National Bureau of Standards Western Automatic Computer, (SWAC),"  
Annals of the History of Computing, 1980**

Press the metal strips separately, then together.  
In binary,  $1 + 1 = 10$ .

**"All of the logic throughout the machine was done by germanium diodes. This, as I understand it, makes it the first computer to do all of its logic with solid-state devices."**

Ralph J. Slutz, "Memories of the Bureau of Standards' SEAC,"  
in *A History of Computing in the Twentieth Century*, 1980