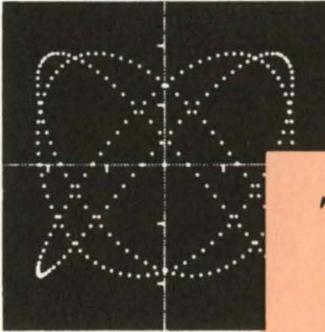


Oak  
Ridge  
Automatic  
Computer and  
Logical  
Engine

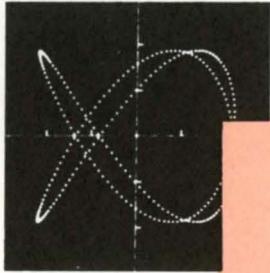


OAK RIDGE NATIONAL LABORATORY  
operated by  
UNION CARBIDE CORPORATION  
for the  
U.S. ATOMIC ENERGY COMMISSION



# The Oak Ridge Automatic Computer and Logical Engine

prepared by the  
MATHEMATICS PANEL  
of  
OAK RIDGE NATIONAL LABORATORY  
operated by  
UNION CARBIDE CORPORATION  
for the  
U.S. ATOMIC ENERGY COMMISSION



## Introduction

An ORBIT code for the approximation of  $\int_a^b e^x dx$  using Simpson's rule.

```
3,10,4
READ
Y1=C4*C2-C1
I1=1
Y2=(C2-C1)/2
Y8=" 3658E,C1"
Y9=" 3658E,C2"
Y3=Y2*(Y8+Y9)
1 Y4=0
3,I2,1,1,I1,
Y4=Y4+" 3658E,((2*I2-1)*Y2)+C1"
Y5=Y3+4*Y2*Y4
Y10=A(Y5-Y1)
G5IFC3VA(Y5-Y1)
Y1=Y5
Y3=(Y5+Y3)/4
I1=2*I1
Y2=Y2/2
G1
5 Y1=Y5/3
TY1
H
```

The Oracle (Oak Ridge Automatic Computer and Logical Engine) is a high-speed, electronic, digital computer of the Princeton family of machines. Many of its important design features are based on pioneer research in computer construction conducted at Princeton University and associated with the late John von Neumann. There are more than five thousand electronic computers in use in the United States, and the Oracle is numbered among the best of these. Outside this country, there are few comparable machines.

Many of the glamorous occupations of computers—the forecasting of election results, for example—have brought them into the public eye. These public appearances of computers, however, are misleading and give no real indication of their true value. The Oracle is not used to forecast election results or even tomorrow's weather. It is used,

however, 120 hours each week for important mathematical calculations needed in the diverse research projects of the Laboratory.

The Oracle and similar machines are valuable because they can execute the fundamental arithmetic operations (addition, subtraction, multiplication, and division) at speeds measured in millionths of a second. Although the operations differ little from those of an ordinary desk calculator, their speed provides answers sooner and with less error. In addition, computing projects—impossible a decade ago because their millions of additions and multiplications could not be done by hand in reasonable time—are now a matter of course.

A "code," such as is used in the Oracle, is a set of logical and arithmetic instructions constituting a coherent

sequence of operations. Usually considerable planning and mathematical analysis go into the preparation of a code. In some cases, this preparation may require more time than the actual computing. Mathematics Panel members devote much time to studying potential computing problems and to devising methods of solution suitable to the peculiar requirements of digital computers. Even the most complex problems must be formulated so that they can be solved by using the handful of elementary arithmetic operations of which a digital computer is capable.

The Oracle executes only instructions in "machine language" form which have been stored in the internal storage

unit or "memory." An example of machine language is the following:

```
24 000
20 001
3A 002
7F 003
```

These instructions would cause two numbers to be added, the resulting sum to be divided by a third number, and the quotient to be stored.

When a code extends several thousand instructions in length, the task of assigning Oracle storage space becomes great if instructions are written in machine language. To overcome this difficulty, most Oracle coding is done with a compiler. This is a code designed to simplify storage allocation by permitting computers to write their code in "compiler language." Compiler language is then converted by the Oracle into machine language. This operation is carried a step further in a new super-compiler called the ORBIT (Oak Ridge Binary Internal Translator), the most recent addition to Oracle automatic programming codes. In ORBIT language a machine language code might take the form:

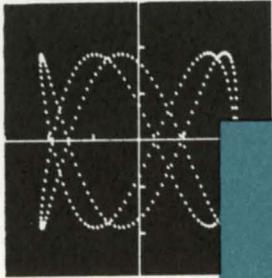
$$Y3 = (Y0 + Y1) / Y2 .$$

Using this algebraic formula, the Oracle, by means of ORBIT, can construct a machine language code for its own use.

The Oracle is not an electronic brain. Its capacity for remembering is limited to the storage of numbers. It does not think.

The Oracle console is centrally located in the computer room. Much monitoring equipment, such as the display registers and typewriter, is visible here. The paper-tape output unit can be seen in the left foreground.





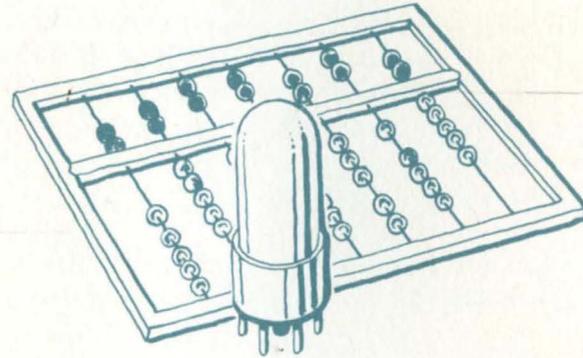
## Arithmetic of the ORACLE

The Oracle's language has an alphabet of only two characters, 0 and 1, called binary digits or "bigits." Its words are all the same length, 40 bigits. As a convenience, the 40 bigits are arranged into ten groups of four each. Their symbols, numbered 0 to 9 and lettered A to F, represent 16 possible combinations of four bigits. An Oracle word, therefore, can be represented by ten symbols or characters.

Some machines operate in the base 10. Four bigits are required to represent a decimal digit. In decimal machines, only 10 of 16 distinct combinations of four bigits are meaningful. In the Oracle, however, all combinations are meaningful. In normal arithmetic operations, if  $a_0$  to  $a_{39}$  represent bigits in some word, the word is taken to stand for the number:

$$a = -a_0 + a_1 \cdot 2^{-1} + a_2 \cdot 2^{-2} + \dots + a_{39} \cdot 2^{-39} .$$

The Oracle thus uses the base 2 for representing num-



bers. Although this burdens the human operator because he must accustom himself to an unfamiliar representation scheme, it results in considerable saving of equipment. First, there are no meaningless combinations, and, second, there is extreme simplicity of multiplication and addition. Multiplication and addition tables (in binary notation) are:

| x | 0 | 1 |
|---|---|---|
| 0 | 0 | 0 |
| 1 | 0 | 1 |

| + | 0 | 1  |
|---|---|----|
| 0 | 0 | 1  |
| 1 | 1 | 10 |

With a desk computing machine, one can easily keep track of the decimal (binary) point because only one operation is performed each time. In the Oracle, thousands of



Instructions and input numbers for the Oracle must be punched in coded form on paper tape.

unseen operations are performed, and the human operator sees only the results. Some system, therefore, is required to locate the binary point in numbers being represented.

In some machines, particular bigits designate location of the binary point. But in the Oracle, all numbers are presumed to satisfy the inequalities

$$-1 \leq a < 1 .$$

In preparing any problem, the numbers must be so scaled that the machine will deal only with numbers in this range.

All arithmetic is carried out in the Oracle's arithmetic unit. For two numbers to be added by the machine, one goes into the A register, which is part of the arithmetic unit.

The other number is then added to the current contents of the A register, and the result left in the A register. Storing this result in the memory requires a third operation.

A number going from the memory to the A register always passes through the adder, where it is combined with previous contents, although particular commands will clear the A register prior to the combination.

Electronic decoding equipment is used to interpret Oracle paper or magnetic tape.



## Arithmetic of the ORACLE

If subtraction is required, the complement gates replace the subtrahend by its complement, and this is then added. The complement is easily obtained by replacing each  $a_i$  by  $1 - a_i$  and then adding  $2^{-39}$  to the result.

A number represented by the machine is known as a digital number. The sum or difference of two digital numbers is not necessarily digital. It is sometimes difficult to ensure that the machine will not be asked, in the future, to form a nondigital sum or difference. As a result, the A register has an extra toggle so that the true sum of two digital numbers will always be formed there whether or not that number is digital.

An overflow toggle will record an illegitimate sum, and the programmer can require the machine to refer to the overflow toggle. The machine will proceed if no overflow is indicated, or take remedial steps (or stop) if an overflow exists.

Since the binary point is fixed in the A register, multiplication or division by powers of 2 can be made by a shift—the moving of the number with respect to the binary point. In a right shift, bigits on the right end of A spill off or are lost. Or they can be shifted to a second register (Q), which can be made to shift along with A. It is possible to shift A and not Q, but you cannot shift Q without shifting A.

Multiplication is a sequence of additions and shifts. The multiplier is placed in Q. If the final bigit in Q is 1, the multiplicand is added into A. Then A and Q are shifted one place to the right, spilling off the bigit just examined and putting in its place the next bigit to the left. When the final Q bigit is 0, the shift takes place without the addition. At the last stage, the bigit  $a_0$  will be the final bigit in Q. If  $a_0 = 1$ , the multiplicand is subtracted from A, but no further shifts occur.

Division is similar to that performed with paper and pencil. First, the dividend is sent to A. In the general step, the divisor is subtracted from the current remainder in A. The new trial remainder is accepted if its sign is the same as that of the old one. In this event, the final bigit in Q is made 1 and both registers are shifted left. Otherwise, the new remainder is rejected and the final bigit in Q is made 0, before the shift occurs.

Many of the Oracle's built-in operations are logical in character, rather than arithmetic. Copying a number from A or Q into a specified memory cell is one such operation. Others include copying from the memory onto tape, or from tape into the memory.

A very important class of logical operations is found in transfers. Transfers cause the control to interrupt its nor-

Oracle programmers can spot-check paper tapes, if necessary. In the foreground is a tape-winding machine.

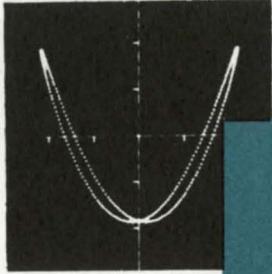
mal sequence and refer to another part of the memory for the next command. The transfer may be absolute or conditional.

Possible conditions are that the overflow toggle may or may not be set, or that the number in A register may be positive or negative. These make it possible to instruct the machine to repeat a cycle of operations for a specified number of times, or until some other criterion is satisfied. In addition, commands and numerical information can be stored in the memory and thereby eliminate separate memories for commands and numbers. This, in turn, makes it possible to operate upon commands as though they were numbers, with address (or location in memory)—and sometimes operations—being modified as the computation proceeds.

Because of the machine's great versatility and flexibility, it can be programmed to convert numbers from the decimal to the binary representation required for its own operations, and then to convert the answers back to decimal form.

Special arithmetics, such as floating-point, can be programmed to enable the machine to take care of the scaling as it goes along. Double-precision arithmetic is used when errors, due to rounding, threaten to overshadow the result, while complex arithmetic is utilized in operating with complex numbers.





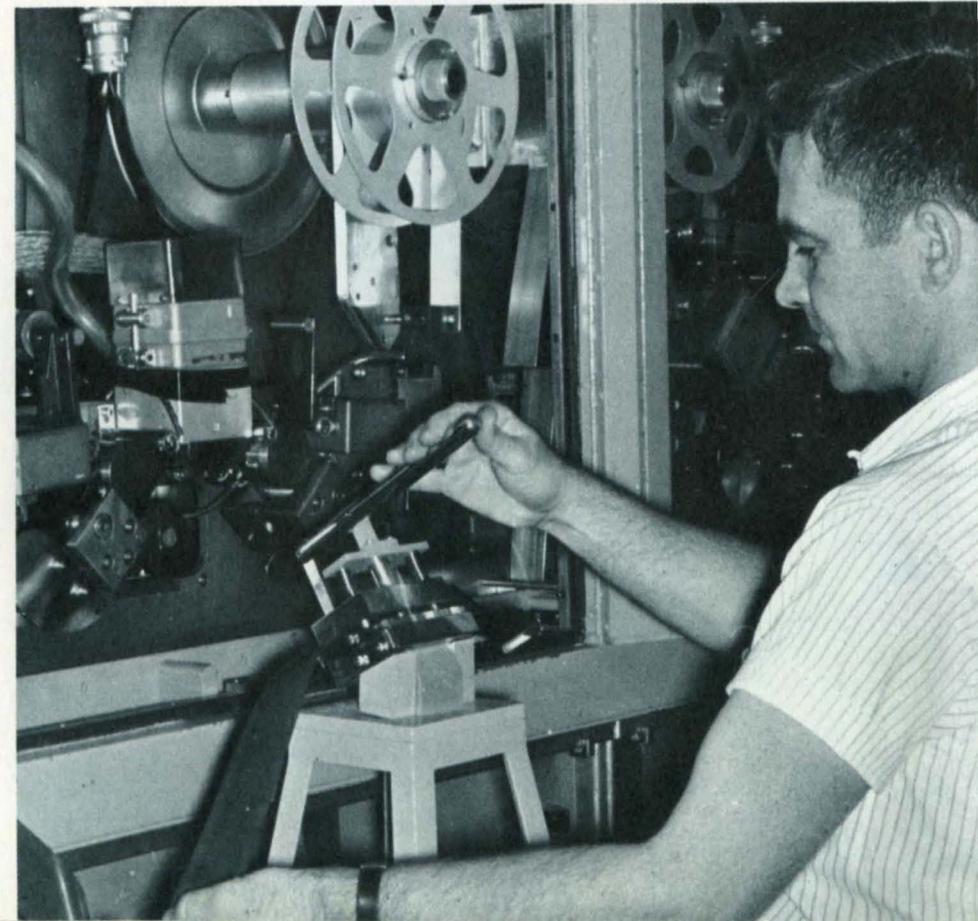
## Magnetic-Tape Units

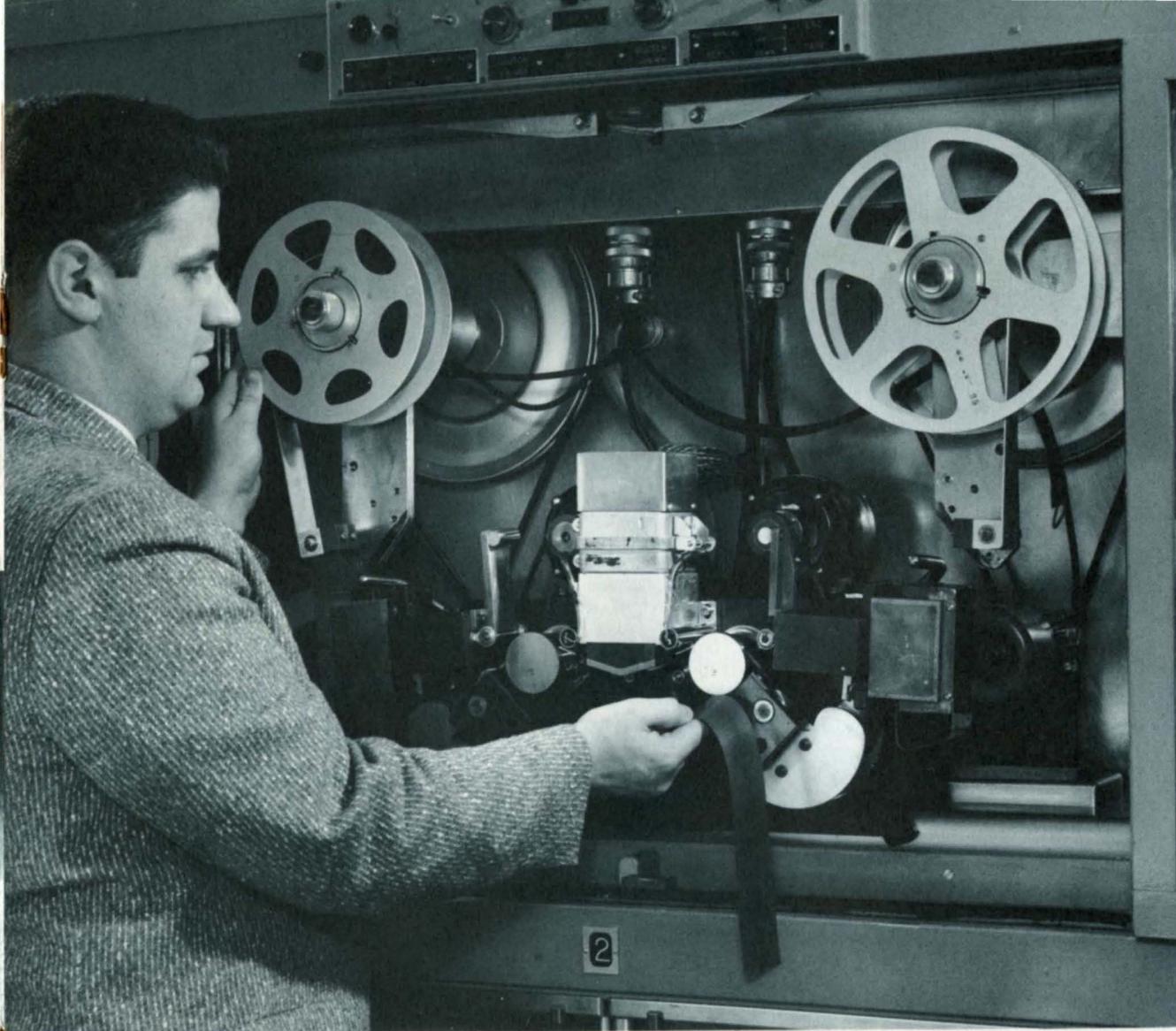
Like most other large computers, the Oracle has magnetic tape storage which supplements its high-speed internal storage. This auxiliary memory consists of four tape drives, each holding 1000 feet of 2-inch magnetic tape.

One of the striking features of this equipment is the unusual tape width which Oracle designers pioneered. Most computers use tape less than 1 inch wide. With this additional width, more information can be stored in a unit length. Also, less actual motion of the tapes across the reading heads is required to transfer numbers to and from the computer's internal storage. The result is considerably faster operation.

All tape numbers are automatically recorded twice, and both copies are automatically compared when read. This dual recording system reduces considerably the number of errors. The Oracle stops operating when one of its checking devices detects an error.

An Instrument technician checks a magnetic tape for flaws. A bad block of tape can be marked so that the Oracle will not use it.

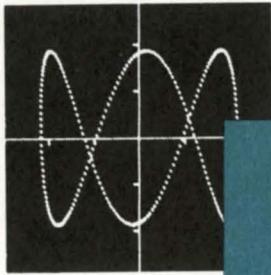




Four magnetic-tape units, utilizing tape 2 inches wide, give the Oracle large secondary storage capacity to supplement the high-speed cathode-ray-tube memory.

Tape is divided into "blocks" by regularly spaced perforations which the Oracle can sense and count. This permits positioning of tape on each drive to any block specified in code, allowing the user to re-record a specific block or blocks without disturbing any other. This is one method of allocating storage space on tape. Each block stores 128 Oracle words.

Five milliseconds are required to start or stop the motion of a tape which travels across reading heads at 47 inches per second. Packing density is 180 characters per inch, one character consisting of 20 binary digits stored twice, two characters being one Oracle word. Each block is 2.41 inches in length, including unused space between consecutive blocks. The tape is specially manufactured of Mylar plastic 0.003 inch thick and with an oxide coating 0.001 inch thick.



## Curve Plotter

The Oracle's most efficient output medium is its Photographic Curve Plotter and Digital Output Device, commonly called the Curve Plotter. This equipment permits high-speed, automatic plotting of graphs, as well as of alphabetical and numerical characters, sometimes more important for computing work.

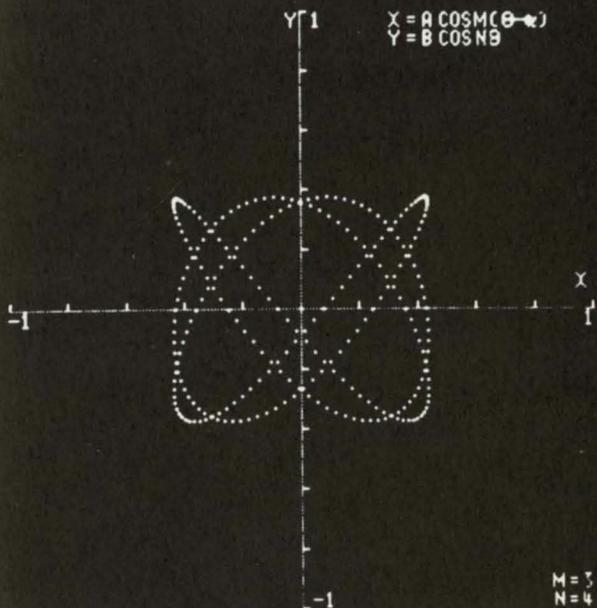
One component of the system is a cathode-ray tube whose face can be brightened momentarily at a large number of points in sequence. Horizontal and vertical coordinates, which can be specified in Oracle code, are associated with these points, 1024 in each of the two directions. Brightening is done by an electron beam scanning the face of the tube. A camera, located in front of the tube and with its shutter open, records graphs and characters as they are traced. Kodak 35-mm Linograph Ortho film is used for this purpose. A second cathode-ray tube, visible at the console, monitors all Curve Plotter operations.

Character plotting is facilitated by a special instruction. In this operation, the electron beam is forced by control circuitry to sweep through a 5 x 8 point rectangle for each character. In so doing, it brightens a specified character pattern. This unique feature of automatic character plotting was not available on other computers as of early 1959.

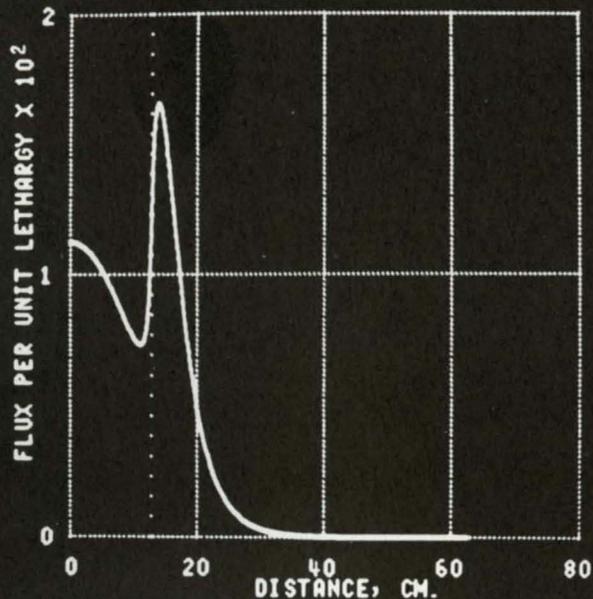
Speed is the chief advantage the Curve Plotter affords as an output medium. Characters can be plotted several times faster than they can be written on the magnetic or paper tapes. Approximately 40 microseconds are required to plot a single point, and about 400 microseconds are needed to plot an entire character. The film advance order is executed in approximately 1 second.

The Curve Plotter, designed and built at the Laboratory, was installed in the Oracle in April, 1956.

Character plotting and curve tracing are often combined in curve plotter use.



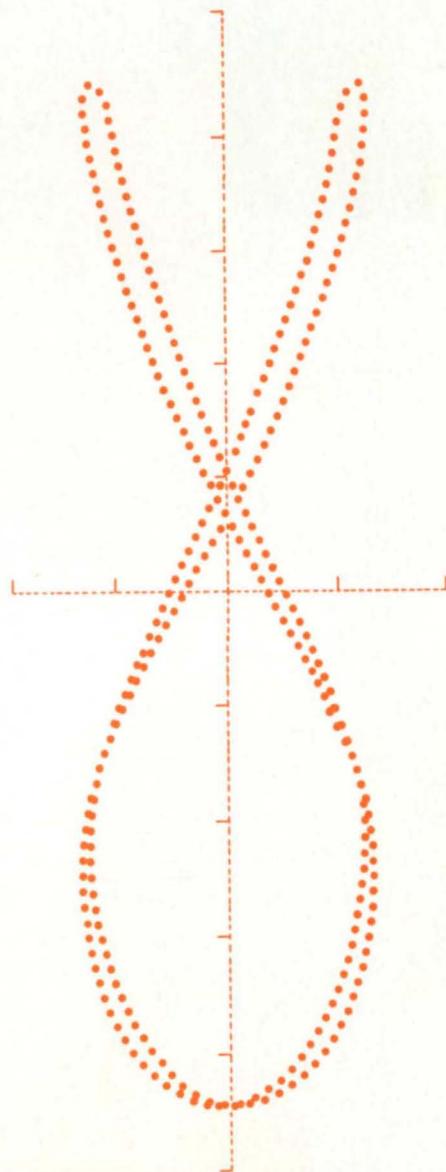
Automatic character plotting is a unique feature of the Oracle curve plotter.

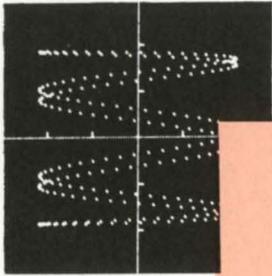


A Lissajous curve traced on the curve plotter.

Emily Levi Cooper - Mathematics Panel 1/30/59  
Inverse Matrix - Second System of Equations - Fike

|   |              |              |
|---|--------------|--------------|
| 1 | 1.810928818  | -0.119532511 |
|   | -0.068603216 | 0.728810403  |
|   | -0.218423254 | -0.399466951 |
|   | 0.007646275  |              |
| 2 | -0.119532511 | 1.763492676  |
|   | -0.033166772 | -0.791723670 |
|   | -0.002167952 | -0.820278689 |
|   | -0.018171694 |              |
| 3 | -0.068603216 | -0.033166772 |
|   | 1.499593069  | -0.152040318 |
|   | -0.462645232 | 0.141235980  |
|   | 0.233585994  |              |
| 4 | 0.728810403  | -0.791723670 |
|   | -0.152040318 | 7.329515067  |
|   | -1.670234065 | -0.742018615 |
|   | 0.098048364  |              |
| 5 | -0.218423255 | -0.002167952 |
|   | -0.462645232 | -1.670234064 |
|   | 5.480985408  | 0.383553766  |
|   | -0.072571384 |              |
| 6 | -0.399466951 | -0.820278689 |
|   | 0.141235981  | -0.742018614 |
|   | 0.383553766  | 7.910484176  |
|   | -1.704744399 |              |





## Engineering of the ORACLE

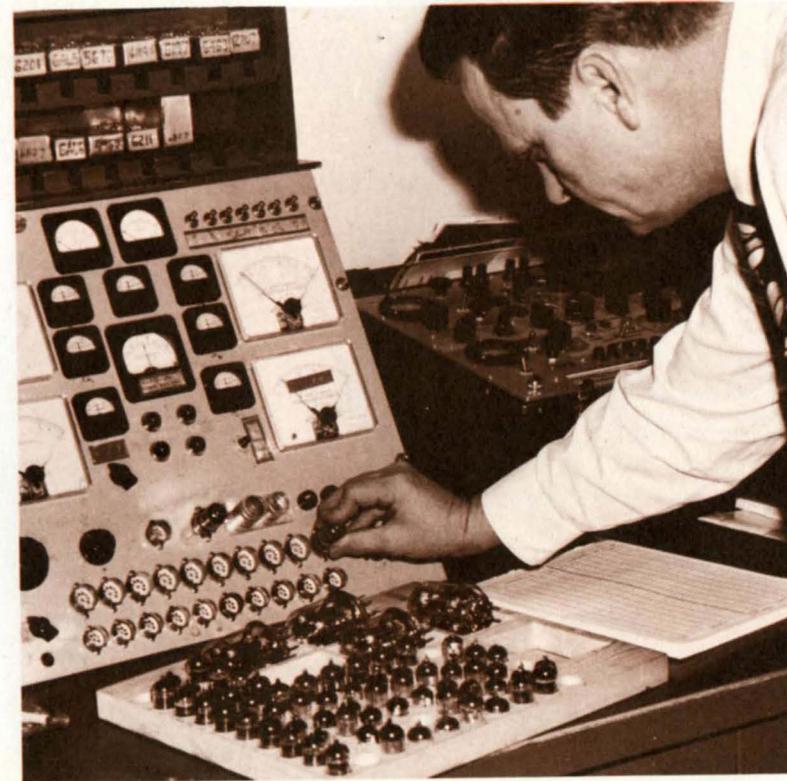
The Oracle consists of seven main units: the arithmetic unit, electrostatic memory unit, magnetic-tape memory unit, the control, input-output, power supply, and the console. All units are integrated into a system permitting good access for maintenance, adequate cooling, efficient power, orderly signal distribution, and ease of operation.

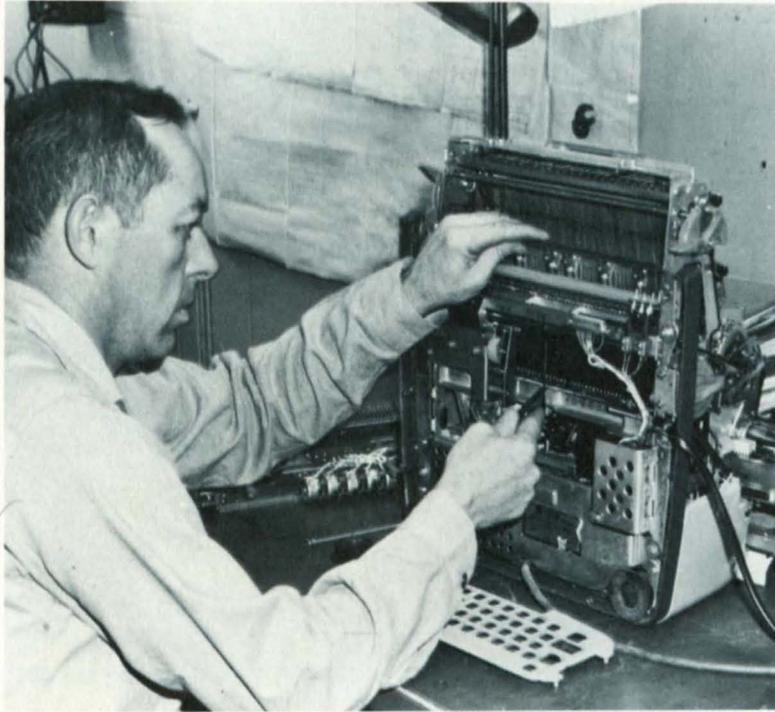
Maintenance access is provided by locating the circuitry for each unit in separate cabinets with adequate space for test equipment. The fast-memory unit has unitized construction allowing accessibility and interchangeability of memory stages.

A closed air-conditioning system maintains close control over temperature and humidity within the machine. More than 6000 cubic feet of air per minute flow through the system to cool approximately 75 kilowatts of heat load. Incoming air is maintained at approximately 50° F and 50% relative humidity.

All power leads are in special troughs beneath units, with separate troughs for different classes of power leads. Similarly, all signal leads are in separate troughs.

Oracle tubes must meet high standards and are all carefully checked before use.





Oracle printers must be kept in good condition. Each typewriter usually types several hundred thousand characters daily.

Computer operation is conducted from the console, surrounded by the input-output media. The console also monitors, continuously, the status of the computer. The console is centrally located in front of other computer units so that all are constantly under surveillance.

The arithmetic unit consists of three storage registers, a parallel logical adder, an *M-to-Q* selector, and four driver chassis. Two of the registers, *A* and *Q*, are shifting regis-

ters. Each register contains two banks of 40 flip-flops, with transfer gates between the flip-flop banks.

Shifting registers use the asymmetrical flip-flop, together with a system of clear and transfer so that a shifting operation can occur in 2.5 to 3 microseconds. In all operations, flip-flops are cleared to zero with an overlap timewise of the transfer pulse and clear pulse. Shifting registers also have an overflow feature which allows easier programming of scaling operations and floating-point routines. The third storage register holds the instructions and one of the operands, which can be transferred as a number or the complement of the number.

The parallel logical adder is the voltage type, consisting of gates that follow the logical-adder scheme. Each adder stage contains seven double triodes and two double thermionic diodes. The carry time per adder stage is 0.1 microsecond. The total carry time for 40 stages is 4 microseconds.

The *M-to-Q* selector serves as a fast-switching and -dispatching medium for transfers between the memory and the arithmetic unit. It permits partial substitution from the storage registers and is a direct transfer not requiring a pulse routine of the arithmetic unit.

Drivers for the registers operate the clear and transfer lines and provide a regulated pulse amplitude for all gating signals to ensure greater reliability of operation.

The electrostatic memory consists of 43 plug-in memory stages (41 in service and 2 in warmup), deflection adders, and the memory monitor or slave scope. The Williams-type store is used with a slide-slide storage technique. Eighty-two 6571 cathode-ray tubes are used, with two cathode-ray tubes per stage. A raster of 1024 digits on each of the 82 tubes provides a 2048-word memory. The stability of

# Engineering of the ORACLE

the system is greatly increased by using automatic beam-current stabilization, which compensates for drifts that change the amplitude of the 1's signal. The memory cycle is 18 microseconds, and at least one regeneration occurs after each memory reference by the arithmetic unit.

The magnetic-tape auxiliary memory consists of four reversible tape transports each containing 1000 feet of 2-inch-wide tape. Each transport includes a 42-channel read-write head and operates at a packing density of 180 pulses per inch, and a tape speed of 47 inches per second. Oracle words (40 bits) are divided into two 20-bit characters, each of which is recorded twice across the tape so that a best-of-two selection may be employed on reading back.

The total storage capacity with 1000-foot reels is 2,560,000 words or 107,520,000 bits.

The automatic control of computer operations is accomplished by four control sections: fast memory (electrostatic), arithmetic, auxiliary memory (magnetic tape), and input-output. These control sections, all properly synchronized, allow a minimum of dead-time operation of each unit consistent with the design capabilities of the circuitry of the computer. The arithmetic unit, auxiliary memory unit, and the input-output unit have asynchronous controls permitting each unit to proceed independently on certain machine operations. The fast-memory control is synchronous so as to provide continuous regeneration of information stored on the cathode-ray tubes. Other units of the computer are allowed to interrupt the memory cycle so as to read or write information.

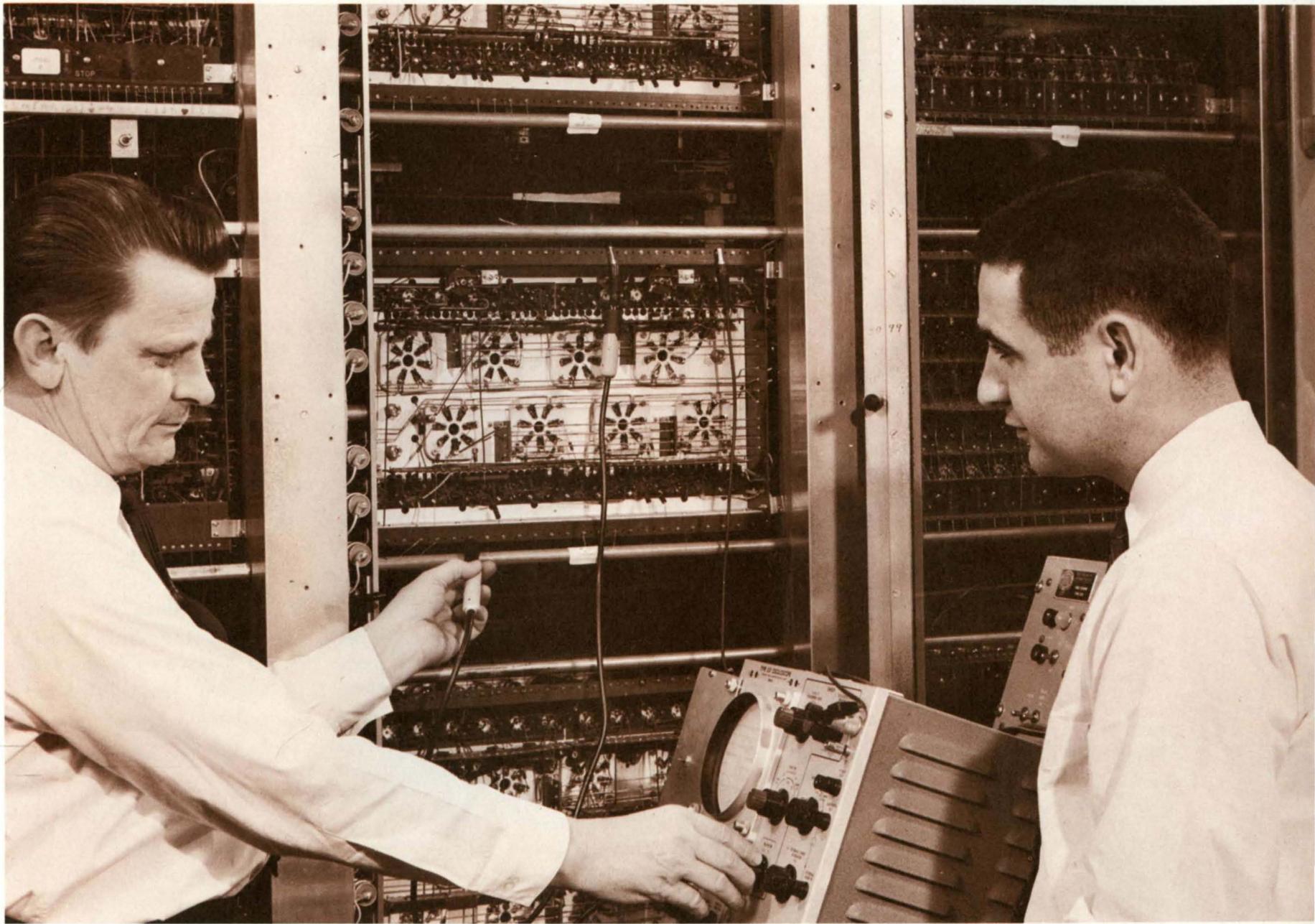
The dispatch counter, pulsers, and mixer make up the fast-memory control. The dispatch counter locates the deflection system of the memory at the position specified by the address of the order. It automatically sequences the order pairs and controls the regeneration of the memory.

The dynamic programmer, static programmer, and shift counter make up the arithmetic control. The dynamic programmer generates a pulse routine to transfer information in the arithmetic unit after the static programmer decodes the order and sets up the transfer gates. The shift counter is a six-stage, scaler-type, binary counter that keeps track of each arithmetic step and generates a recognition signal at the end of an operation sequence.

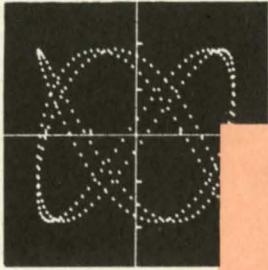
The input-output unit consists of paper-tape-handling equipment, magnetic-tape-handling equipment, and a cathode-ray-tube photographic-output device. The paper-tape reader is a Ferranti photoelectric reader, and the output device is a fast paper-tape punch. Fast read-out is accomplished on  $\frac{3}{8}$ -inch magnetic tape. The photographic output plots curves directly from the computer and also provides automatic character plotting.

Power requirements of the computer are adequately served by a 75-kilowatt system. Direct-current power is provided by seven Power Equipment Company rectifiers which represent the seven basic machine voltages. Power control and interlocks, together with voltage regulators, are housed in seven relay-rack cabinets from which all machine power is distributed. Fire protection is provided by a smoke detector and automatic alarm system.

The console contains operational switches, engineering test switches, register monitors, a fast-memory CRT monitor, a console typewriter, and a keyboard for special order and code changing.



Instrument technicians maintain and modernize equipment of the Oracle, which was installed in 1953.



## Technical Facts about the ORACLE

Built at Argonne National Laboratory by Argonne and ORNL engineers and installed in Oak Ridge in 1953.

Cathode-ray tube memory of 2048 40-binary-digit words.

Parallel operation.

Fixed-point, binary arithmetic.

Memory cycle of 18 microseconds.

Two instructions per word—eight digits for each order, twelve for each address.

Add time (including access) of 70 microseconds.

Multiply time (including access) of 370-590 microseconds.

Divide time (including access) of 590 microseconds.

Four 2-inch magnetic-tape units which read and write at 2500 words per second.

Seven-channel paper-tape input at 200 characters per second.

Seven-channel paper-tape output at 60 characters per second.

$\frac{7}{8}$ -inch magnetic-tape output at 840 characters per second.

Console typewriter output at 8 characters per second.

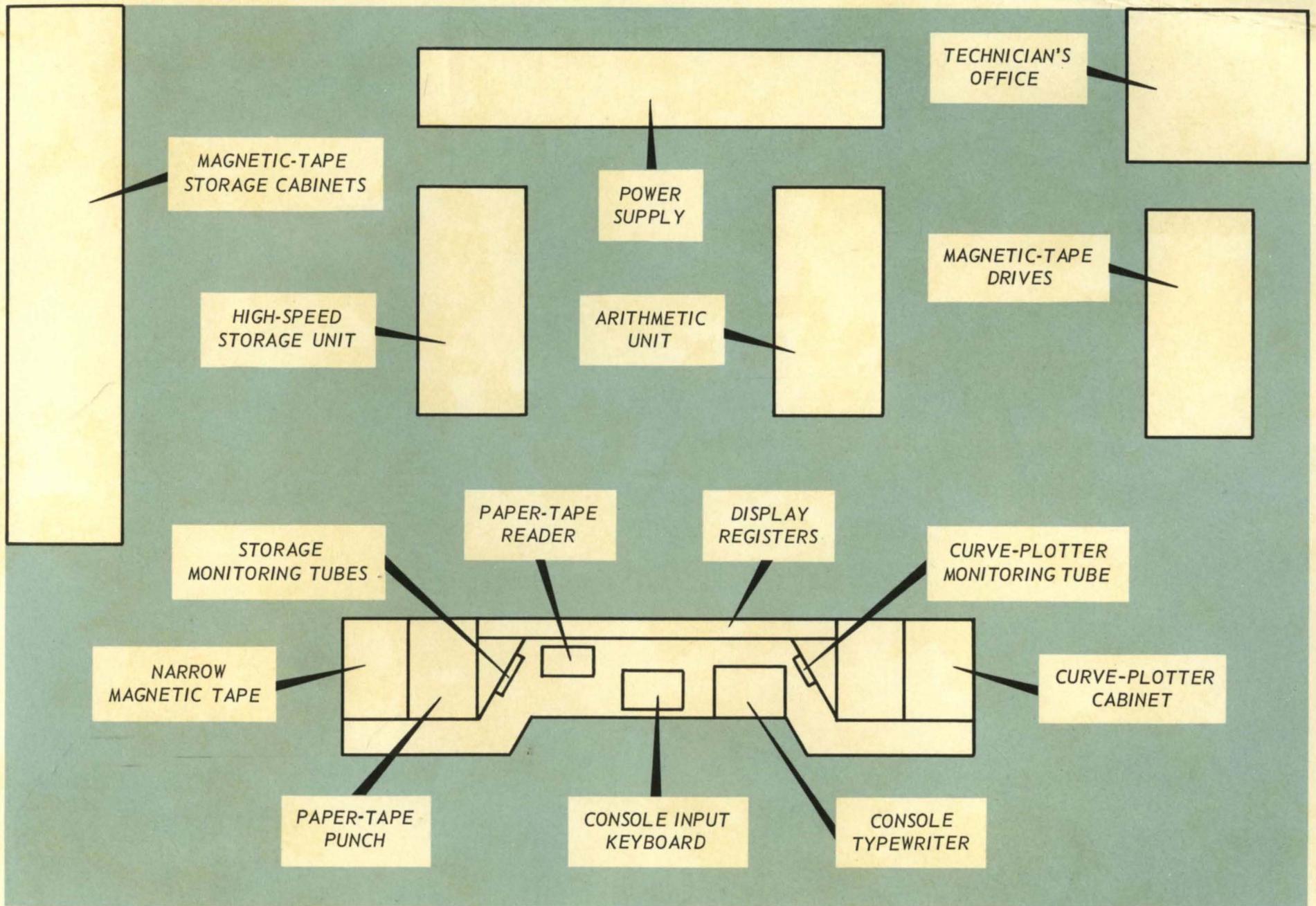
Photographic (Curve Plotter) output including automatic character plotting equipment.

Console facilities include displays of all the primary registers and counters, cathode-ray-tube monitors of the memory and of Curve-Plotter output, and an audio monitor of the computer operations.

75-kilowatt power supply.

40-ton air conditioning system.

Total of 5000 vacuum tubes.



Floor plan of the computer room, showing the location of primary Oracle components. Paper tape preparation and printing machines are in an adjoining room.

