THE FRANKLIN INSTITUTE

COMMITTEE ON SCIENCE AND THE ARTS

No. 3168 *Subject* ELECTRONIC NUMERICAL INTEGRATOR AND COMPUTER ("ENIAC")

~~*Applicant*~~ XXXXXXXX

Address

~~Date of Application~~

Inventors Dr. John W. Mauchly and Mr. J. Presper Eckert, Jr.

Address Eckert-Mauchly Computer Corp., Broad & Spring Garden Sts., Philadelphia 23, Pennsylvania.

COMMITTEE:

Dr. Richard M. Sutton, *Chairman* (App'd. Nov. 13, 1946)	*MEETINGS:*
Dr. George S. Crampton	May 26, 1948
Comdr. William G. Ellis	October 1, 1948
Mr. Walter C. Wagner	
Dr. Winthrop R. Wright	

Report presented to General Committee:

November 10, 1948

Final Action:

December 8, 1948

roved by
d of Managers
December 15, 1948

Award Howard N. Potts Medals

Reports Medal, and Certificates presented ~~forwarded~~ *to* Medalists ~~XXXXXX~~

To John William Mauchly
J. Presper Eckert, Jr.

Medal Day, October 19, 1949.

THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA

FOR THE PROMOTION OF THE MECHANIC ARTS

Hall of the Institute,
Philadelphia, December 8, 1948.

Report No. 3168.

Investigating the Electronic

Numerical Integrator and Computer

("ENIAC").

Committee on Science and the Arts, The Franklin Institute

THE FRANKLIN INSTITUTE OF THE STATE OF PENNSYLVANIA

For the Promotion of the Mechanic Arts

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Hall of the Institute,

Philadelphia, December 8, 1948.

Committee on Science and
the Arts Case No. 3168.

The Franklin Institute of the State of Pennsylvania, acting through its Committee on Science and the Arts, investigating the Electronic Numerical Integrator and Computer ("ENIAC"), reports as follows:

From the time when men first began to use their fingers and toes, or piles of pebbles, to help them count, they have relied increasingly upon external aids in performing calculations; and as Mathematics has advanced, so has the complexity of computing increased, whereas the proficiency of computing machines has not kept step with the needs. In short, it is much easier to <u>formulate</u> mathematical problems than it is to <u>solve</u> them, and in many modern problems the numerical work has become prodigious. Several ingenious devices have already come to the aid of the computer, and more are on the way. Computing machines may be divided into two general classes: continuous variable, and discrete variable computers. The slide-rule is an example of the first kind, the ancient and honorable abacus an example of the second, as is also the adding machine so common and important in modern business.

To the group of digital or discrete variable machines has now been added the ENIAC, or "Electronic Numerical Integrator and Computer", devised by Dr. John W. Mauchly and his colleague, Mr. J. Presper Eckert, Jr., and developed in secrecy at the Moore School of Electrical Engineering at the University of Pennsylvania, under contract with the United States Army Department of Ordnance, between July, 1943, and the fall of 1945. In February, 1946, the first press accounts of the development were released. This is the first all-electronic computer of its kind, bringing to the field of digital computing the very high speeds of operation inherent in electronic circuits. The input and output of the machine are electromechanical business machines of the punch-card type, and it is the slowness of these machines and the difficulty of setting up problems in suitable programs that are now the factors that limit the speed. The input can be only about 960 digits per minute, and the output slightly less; but once a problem is set up and translated into suitable electric impulses, the process of computing is entirely electronic and amazingly swift. The machine is best suited to the solution of problems requiring a large amount of repetitious work, (Plate I), such as in the constructing of tables or the solution of certain differential equations with slowly varying parameters. It performs all the operations of common arithmetic: addition, subtraction, multiplication, division, and root taking, at speeds varying from 5000 times per second for simple addition or subtraction of two 10-digit numbers to one-fortieth of a second in the taking of the square root of a 20-digit number.

ENIAC is not an "electric brain", but it has been more aptly described as "like a desk calculating machine operated by a moron who cannot think,

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but who can be trusted to do exactly as he is told". Most of the time required for the solution of any problem suited to the ENIAC is spent in "telling the machine what to do", that is, in setting up the program of operation and feeding data to the machine. The solution time itself is very short in comparison.

The machine constructed for the Ordnance Department was an impressive array of stacks occupying a room in the basement of the Moore School (Plate II). It contained 18,000 electronic tubes, probably more than in any previous device. The power requirement was 150 kilowatts. The floor-plan is shown in Plate III which shows the Initiating Unit, the Cycling Unit, and the Master Programmer on the left, and then long racks of Accumulators, Function Tables, Multipliers, and movable Function Tables, terminating on the right in the Printer and I.B.M. Recorders. Plate IV shows the arrangement for solving the equation $\frac{dy}{dx} = y$.

The ENIAC "won its spurs" in the solution of an important differential equation relating to ballistics and the construction of firing tables. Whenever a new combination of shell, gun, and propellant is used by Ordnance, firing tables must be constructed. At times in the past, because of the prodigious work of computation involved in making such a table, this has been a serious bottleneck. The Army was quick to recognize the importance of Dr. Mauchly's suggestion of an electronic computer which was made to them in August, 1942. Mr. Eckert was associated with him almost from the first. A contract with the Moore School was executed, Dr. Mauchly was put in charge of fundamental developments; Mr. Eckert became the engineer in charge of engineering and design, and Captain H. H. Goldstine served efficiently as technical liaison officer. The machine was completed in about two years and was given nearly a year of use on Ordnance problems before it was disassembled and moved to the Aberdeen Proving Grounds where it has again been in satisfactory operation since July, 1947.

The basic elements of the ENIAC are in large measure not new, but the skillful adapting and coordinating of elementary circuits into an interlocking combination that could perform extensive computations accurately and swiftly was the valuable contribution of Messrs. Mauchly and Eckert. The former had for several years previously envisaged the possibilities of electronic computers to handle long problems arising in meteorology, -- problems which took so long to solve that the weather being "forecast" was already past history when the prediction based upon observable quantities was turned out! Two of the important circuit elements in ENIAC are the counting circuits and the "gate" circuits. The counting circuits are of the flip-flop type, first proposed in 1919 and now commonly used in nuclear physics researches for counting purposes. The flip-flop circuit (Plate V) is an inherently stable circuit. By the cross-connection of grids and plates of two triodes, only one tube can be conductive at a time, and the conducting tube cannot be changed by any signal applied to *its* grid. If, however, a positive pulse is applied to the grid of the *other* tube, the first is rendered non-conducting and the second becomes conducting. The combination therefore acts very much like an on-off switch or relay.

The actual circuit used in the ENIAC is somewhat more complex, as shown in Plate VI, but the function of this circuit is the same as the simpler circuit just shown. It includes two twin-triodes (Type 6SN7), one to trigger the other. This circuit can count as rapidly as 300,000 times per second, but its normal operation is at 100,000 per second.

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By arranging a series of these flip-flop circuits to form a scale-of-ten counter, and by properly inter-connecting one decade counter with the next, an electronic adding machine is possible. Plate VII shows the arrangement of flip-flop tubes to form a single decade. Whether or not digits are "carried forward" from one decade to the next during addition is determined by the gate tubes. Plate VIII shows the circuit of a pentode employed as a gate tube.

Operation of all parts of the machine is synchronous, that is, successive operations take place in successive cycles of time determined by the <u>cycling unit</u> which sends out periodic patterns of signal pulses every 200 micro-seconds. This period of one five-thousandth of a second is called the "addition time" within which a single addition or subtraction of two numbers up to ten digits each can be performed and the circuits cleared for the next operation. The cycling unit sends out a sequence of pulses divided as shown in Plate IX. Each pulse, except for a long "gate pulse", is of 2 microseconds duration, and the separation of pulses is 10 microseconds. The addition of nine two-digit numbers, even like 123456789 and 987654321, involving as many as nine "carriers" can be performed in one addition time, or 200 microseconds. The cycling unit also sends a program pulse that clears all circuits for their next operation. Thus every part of the ENIAC is prepared for a new operation of addition or sub-traction 5000 times per second.

Besides counting accurately, a large machine of this kind must have a prodigious "memory" for numbers. That is, it should be capable of storing numbers for long or short periods of time and be ready to deliver them when needed. Each of the 20 accumulator banks of the ENIAC can store a number; the three Function Tables will likewise store many special numbers, but beyond this, it is necessary to delegate storage to punched cards that can be printed at the output end of the machine and reintroduced when needed at the input end, a process that is unavoidably slow. ENIAC is deficient in "electrical memory", a lack which was early recognized and has since been corrected by Mauchly and Eckert, and by others. However, as these new memory circuits are part of EDVAC and other later machines, it is not our purpose to describe them here. Suffice it to say that ENIAC can retain a limited amount of information, but not as much as experience soon showed to be desirable. A machine of this kind should be capable of storing between one and five <u>thousand</u> numbers instead of the few hundred for which it was designed. A special part of the machine was allocated for multiplying so as to make this process faster than mere successive additions would allow. An "electronic multiplication table" was designed by which the multiplication of two 10-digit numbers could be performed in 14 addition times (about 0.003 seconds). Division and square-root taking are more laborious and may require nearly ten times as long, or nearly 0.03 second. This is still rather fast compared with any other method available!

The electronic engineering of the ENIAC is noteworthy. No previous device has employed so many tubes, yet tube troubles are kept at a low level by operating all tubes at only a fraction of their rated values of voltage and current. The circuits employed allow wide tolerance in this respect, as operation depends more upon the presence or absence of a signal than upon its actual value. Tests of the equipment may be made at any time by "single-cycling" of the addition time, or by supplying to the machine certain problems whose solutions are known. In many cases, successive runs of a problem were made to allow comparison of results. In case of failure, it is possible to locate the trouble promptly, either in a single

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tube or in half a dozen. In one of the first tests publicized, ENIAC solved in two weeks a problem which reputedly would take a skilled computer one hundred years to solve, and on which one hundred computers, working concurrently for one year, could not succeed because of the sequential operations involved. However, most of those two weeks were spent in setting up the problem so that the machine could handle it. The machine actually operated only two hours to perform the computation. Such high rates of computing are of value not only in solving problems of Ordnance, but in solving differential equations in aerodynamics, meteorology, atomic physics, and problems of the census, in short, any problem which can be stated in the calculus of finite differences. As the machine is built throughout to handle 10-digit numbers, it is capable of greater accuracy than the well-known mechanical differential analyzer, designed by Dr. Vannevar Bush more than twenty years ago. This latter machine, of the continuous variable type, is capable of only four- or five-figure accuracy.

So far, no patents have been granted, but applications were made by Army Ordnance in behalf of Messrs. Mauchly and Eckert in June, 1947, and applications have also been filed in England.

John William Mauchly was born in Cincinnati, Ohio, August 30, 1907. He was granted his Ph.D. in physics at Johns Hopkins University in 1932 and for eight years thereafter was head of the department of physics at Ursinus College. In 1941 he joined the staff of the Moore School where he remained for five years, during which time he was engaged in the design and construction of the ENIAC. In 1946, he and Mr. Eckert formed a partnership and are at present engaged in perfecting other electronic computers, principally the EDVAC and the UNIVAC. He is a member of the American Physical Society, American Meteorological Society, American

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Geophysical Union, Phi Beta Kappa, Sigma Xi, and The Franklin Institute.

J. Presper Eckert, Jr. was born in Philadelphia in 1919. He attended the William Penn Charter School, and in 1941 took his Bachelor's degree in Electrical Engineering at the University of Pennsylvania. For the next year or two, he was engaged in further study, and in instruction in electronics, together with consulting work in that field. He received his Master's degree in Electrical Engineering from the Moore School in 1943, and thereafter became chief engineer for the ENIAC project. He was in charge of all technical phases of the work. He is a member of the Institute of Radio Engineers, and of Sigma Xi.

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In recognition of their design and construction of the ENIAC, the first large-scale, general purpose, digital electronic computer, a machine of great accuracy which makes feasible the application of mathematics to problems which hitherto had either to be ignored or else solved in a much more laborious way, THE FRANKLIN INSTITUTE awards its HOWARD N. POTTS MEDAL each to J. PRESPER ECKERT, JR., of Philadelphia, Pennsylvania, and JOHN WILLIAM MAUCHLY, of Philadelphia, Pennsylvania.

Richard T. Nalle
President.

Henry B. Allen
Secretary.

... W. Hill
Chairman of the Committee on Science and the Arts.

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It is well known[1] that the path of a projectile motion is described by

$$y'' = -Ey' - g$$
$$x'' = -Ex'$$

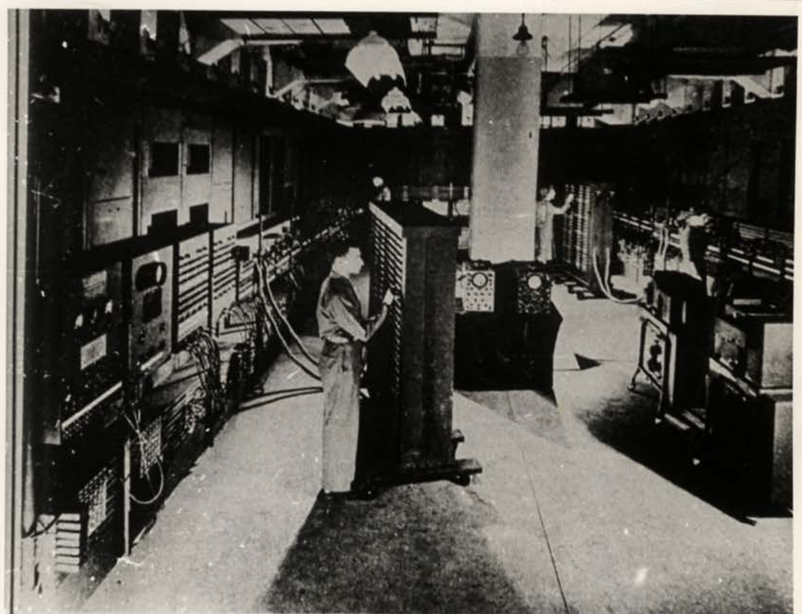
where

$$E = \frac{\epsilon^{-hy}G(v)}{C}, \quad (v = \sqrt{(x')^2 + (y')^2}),$$

g and h are fixed constants, C is a constant for a giv shell, and $G(v)$, the ballistic drag function, expresses t resistance of the air to the shell as a function of i velocity. The equations are thus easy to state, but sin

S. & A. Case No. 3168, ENIAC. Plate I.

Plate I.



S. & A. Case No. 3168, ENIAC. Plate II.

Plate II.

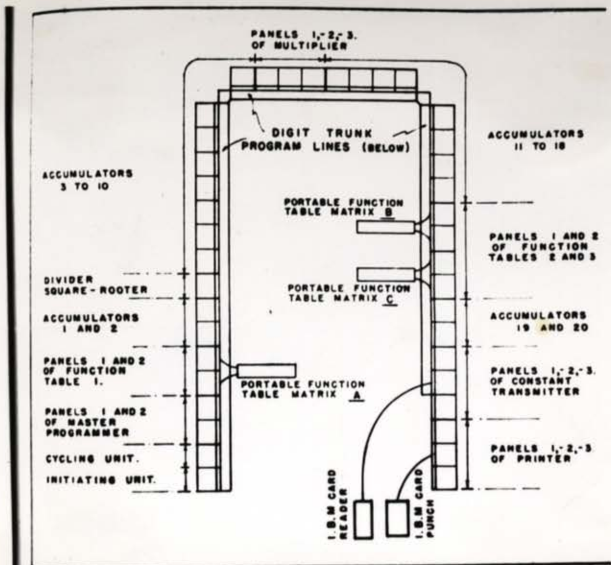


Fig. 1—Layout of the various parts of the ENIAC from initiating unit to printer as in general vi[e]

S. & A. Case No. 3168, ENIAC. Plate III.

Plate III.

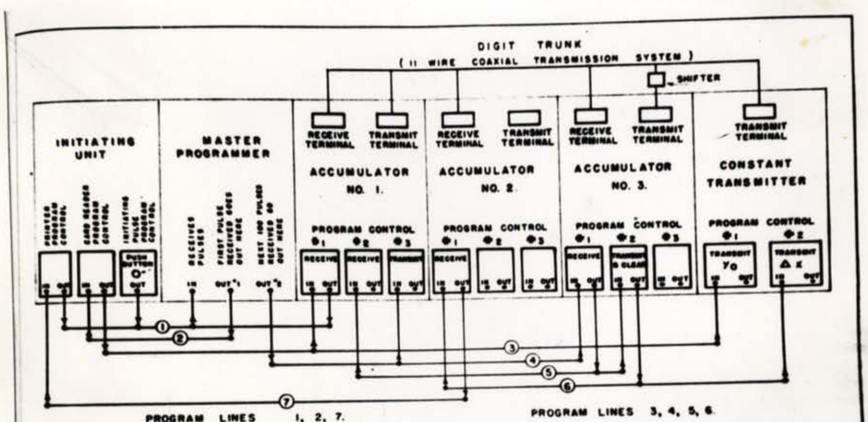


Fig. 3—Interconnection of units required to solve the differential equation $\frac{dy}{dx} = y$. This uses only a very small part of the ENIAC

S. & A. Case No. 3168. ENIAC. Plate IV

Plate IV.

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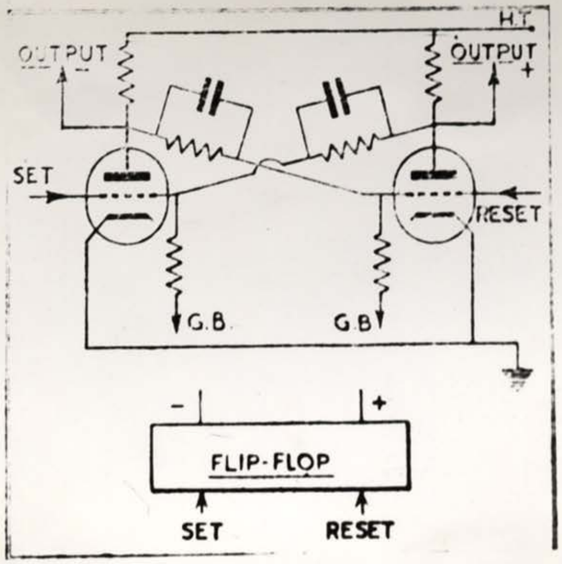
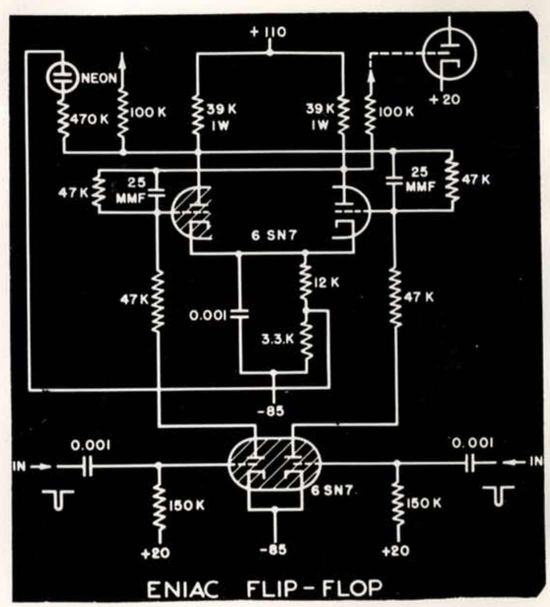


S. & A. Case No. 3168,
ENIAC. Plate V.

Plate V.



S. & A. Case No. 3168. Plate VI.

PLATE VI.

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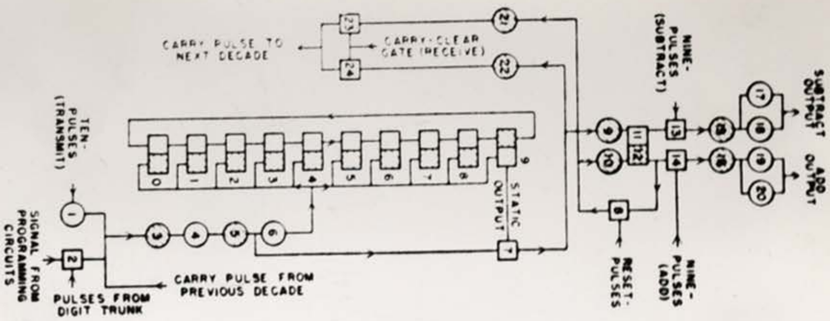

S. & A. Case No. 3168, ENIAC. Plate VII.

Plate VII.

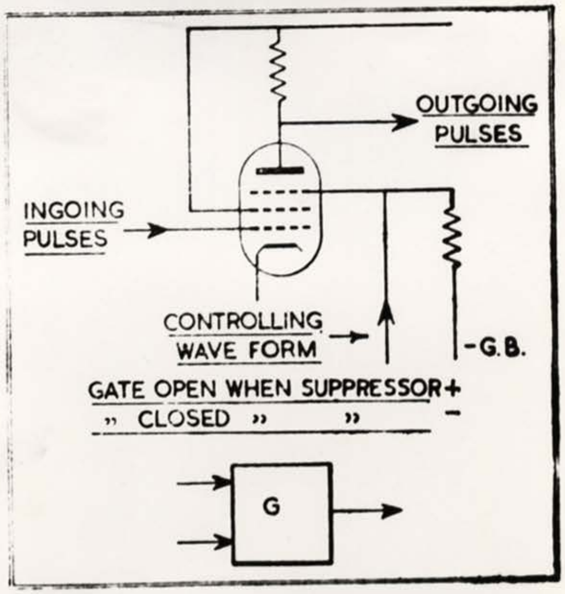

Fig. 4. Use of pentode as a "gate" tube.

S. & A. Case No. 3168, ENIAC. Plate VIII.

Plate VIII.

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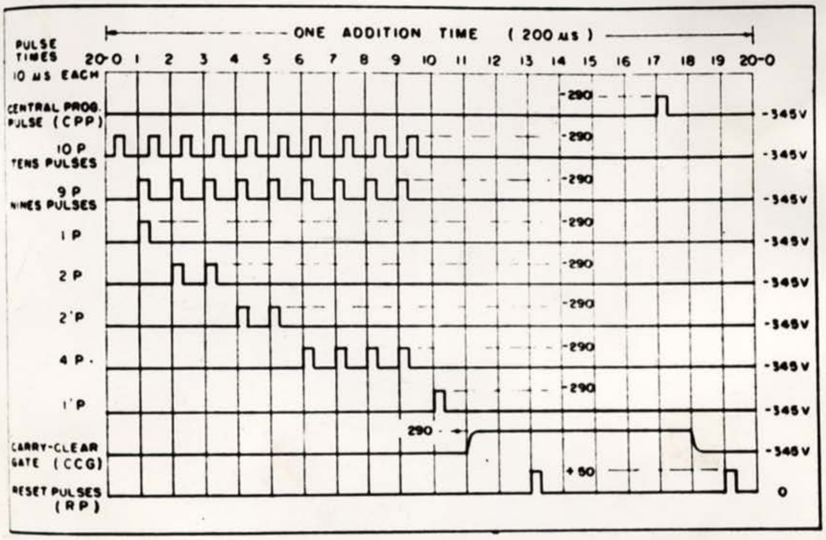

S. & A. Case No. 3168, ENIAC. Plate IX.

Plate IX.