

fair to say that there has been a response to this pressure. I expect to see Number 2 UNIVAC pass a more stringent acceptance test on the communication between the UNIVAC and the tapes.

**J. Belzer** (Battelle Institute): Mr. McPherson, I would like to know whether this equipment will at any time be available outside of the Census Bureau, or will the load of the Census Bureau still be great enough to keep it going, or perhaps do you feel you will need another UNIVAC?

**J. L. McPherson**: We certainly feel we have enough UNIVACS right now. We think that eventually we will have no trouble keeping three or four busy when we are in the relatively low phases of the 10-year cycle of census work. This I cannot document with statistics, however. We do not want another UNIVAC tomorrow certainly, because we are still learning how to make this one sit up and bark, and until we feel we know a good deal more about the one we have we will not be too anxious to get another.

We do have peaks and valleys in our use of the equipment. For example, as of right now the UNIVAC is short of work because we have had a rather unhappy two weeks most recently with the card-to-tape equipment. What the card-to-tape equipment has been turning out has been not acceptable; consequently, there is nothing for the UNIVAC to do. If somebody happens to

have a nice, big, important problem in his back pocket and it is all programmed, and he said to me this afternoon, "Will you do it," maybe I could do it for him. By tomorrow afternoon this golden opportunity may be gone.

**E. C. Carlson** (Mutual Life Insurance Company): Can you tell me just how much equipment, tabulating or otherwise, you are replacing with the UNIVAC?

**J. L. McPherson**: I think I have to just say no, I cannot. I am afraid I cannot elaborate much on that. The Census has a tremendous installation of tabulating equipment, and UNIVAC has taken a big load off that equipment, but we have a tremendous census, too, so that we did not cancel out any equipment. We have plenty of work for the UNIVAC and all the other equipment that we have.

It might be interesting and amusing and enlightening to sit down and try to estimate just how much different equipment we would use to do jobs that we plan to do with UNIVAC. The fact is that on the one hand, those of us who know UNIVAC, have been too busy just trying to make UNIVAC work, and those of us who know the other equipment have been too busy making that equipment work.

**B. V. Bowden** (Ferranti, Ltd., England): Are you going to use the same equipment for the census of production as well as the census of population? Are you going to use

the same equipment for doing other censuses, such as the census of production, the census of distribution, and the census of the retail trade and that kind of thing as well as the census of population?

**J. L. McPherson**: We are in the process of trying to answer that question ourselves. My own answer is yes, I would like to think that we will have a complete large-scale electronic computer processing of the so-called economic census. However, this is by no means certain.

If I predict, I will guess that we will do part of it using punch card equipment and part of it using the UNIVAC.

In the long run, we think the censuses will be tabulated through the use of the electronic equipment. At the Census we do a tremendous amount of what we call current survey work, much of which is based on small samples, and it is my own opinion that never will punch card equipment be replaced by this kind of equipment for the processing of some of the smaller samples. But the censuses of population, agriculture, retail trade, and manufacturing will in time be processed on this kind of equipment. The next economic censuses are for the fiscal year ending in 1953, I believe, which means that we get into the processing of those some time in the summer of 1954.

We hope, by then, to have techniques worked out for using the UNIVAC for those censuses.

## The Burroughs Laboratory Computer

G. G. HOBERG

**I**N EARLY 1950 the Research Division of the Burroughs Adding Machine Company developed a need for a computing installation of moderate size which would, among other objectives:

1. Serve as a proving ground for new ideas and devices.
2. Provide data on large-scale-computer reliability.
3. Offer a means for indoctrinating a large number of inexperienced people in the various phases of realizing and operating a digital computer.
4. Produce useful solutions of engineering problems associated with a research program.
5. Solve business problems in a manner which would simulate their handling by contemplated smaller and relatively special-purpose commercial machines.

At this time Burroughs had already developed a line of unit-packaged com-

puter-type electronic pulse circuits to facilitate research and development work on computer components, circuits, and systems. Known as pulse-control units, these system building blocks were based on similar ones in use at Project Whirlwind at the Massachusetts Institute of Technology, where the idea for this type of equipment originated in 1947. Large-scale use of such units to simulate the control and storage portions of the Whirlwind I computer, when only its arithmetic element had been constructed, established the intriguing possibility of their exploitation in the synthesis of directly useful high-speed digital-computer systems.

### ENGINEERING APPROACH

Although the already designed pulse-control units were thought to be some-

what too versatile and too bulky for use as mere low-level logical components throughout a complete computer, they offered what seemed to be a very reasonable solution to the problem of obtaining a flexible computing installation economically and in a short time. In May 1950, a decision was made to design and construct a computer which was to utilize pulse-control units wherever feasible.

In addition to pulse-control units, components which were considered at its inception to be suitable for the Burroughs Laboratory Computer were standard teletype equipment and a magnetic drum. Both of these were purchased.

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Particularly important contributions to the realization of the Burroughs Laboratory Computer were made by Edward W. Veitch, who was responsible for the logical design, and whose intimate knowledge of the logic resulted in the 48-hour checkout of the machine; Harry Kenosian, who designed the standard pulse-control units; and Joseph Chedaker, who assisted in the over-all physical design and who supervised all installation and construction work.

Credit also is due to the many other members of the Research Division without whose efforts and co-operation this project could not have succeeded.

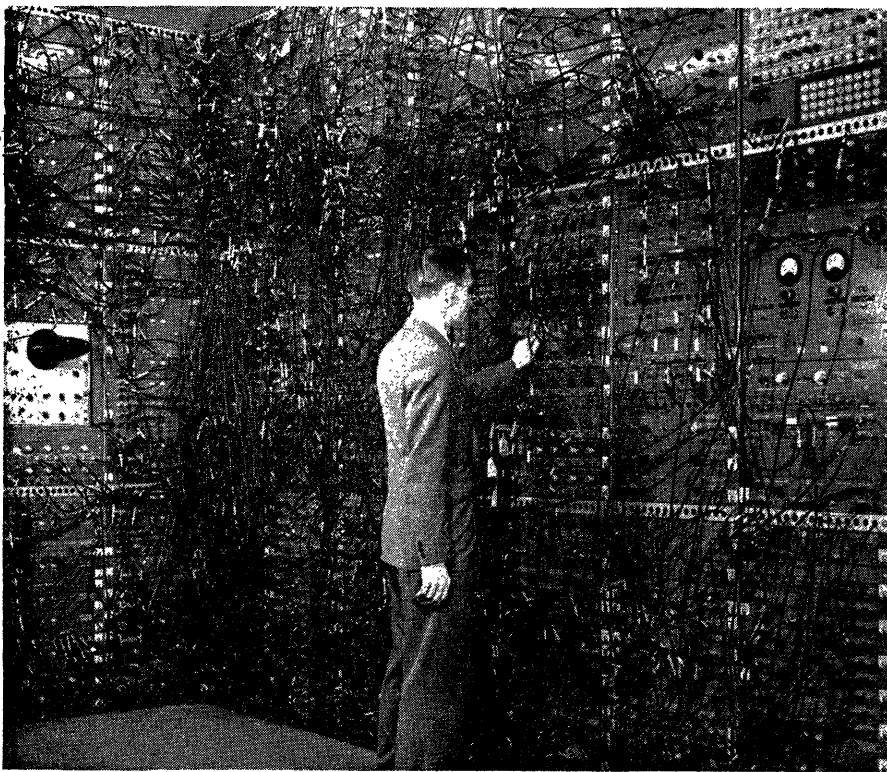


Figure 1. Right half of computer. Racks contain automatic and manual control systems

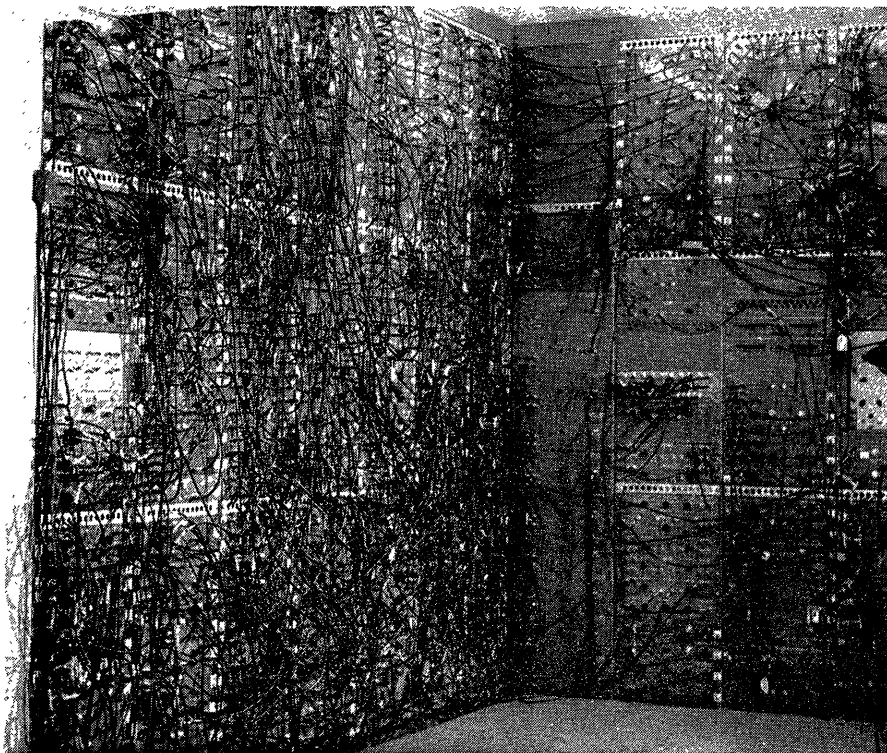


Figure 2. Left half of computer. Racks contain input-output control, manipulator, and portion of storage system

Engineering Research Associates of St. Paul, Minn., supplied the drum, together with much helpful advice and information on its use.

The availability of static magnetic registers of the type developed at the

Harvard Computation Laboratory was not assured until a few months before completion of the computer. These registers, designed for another Burroughs project, offered the possibility of saving about 40 pulse-control units in the

Laboratory Computer as then envisioned. The logical design was therefore changed to accommodate them. This adaptation, which did not at all affect the physical design of the computer, was the first concrete proof of the flexibility provided by the unitized approach.

Throughout the work of logical design, which represented the part-time effort of one individual, readily available equipment was the independent variable. Departures from this rule were made in only a few cases, such as that of a code-conversion function switch associated with the input-output equipment, where a minor custom-design task offered substantial opportunity to simplify the machine and to reduce its size.

#### ACCOMPLISHMENTS

Despite occasional hulls in the effort caused by procurement difficulties and the pressure of other tasks, the Burroughs Laboratory Computer was completely operative in its initial form on February 19, 1951, just 9 months after the decision to design and build it. At this time it was turned over to programmers and logical designers for their indoctrination and use. After the mounting and interconnection of the units, the entire computer was completely checked out within 48 working hours, which time included that required to check and test the power system and its controls.

In light of the unusually short realization and checkout times, and the demonstrated adaptability of the machine to changes in logical design, misgivings about inordinate bulk and versatility in the units have been forgotten. Because all objectives were so readily achieved, the particular form of unitization employed proved to be an auspicious choice for the task at hand.

This computer is obviously not a neatly packaged commercial machine, (see Figures 1 and 2). Rather, it is a laboratory device which has been demonstrated to be a substantial asset to the research and development program of the Burroughs Adding Machine Company and should be evaluated on the basis of its performance in this role.

#### Systems Design

##### GENERAL DESCRIPTION

Although a number of changes have been made in the Laboratory Computer since its completion, the over-all arrangement of its principal component systems, indicated in Figure 3, has not changed. In all the variations which have existed up to this writing the computer has

been a general-purpose device capable of solving a wide variety of problems by appropriate programming. Changes in plug-in interconnections of the many building blocks are not required for each new problem solution.

As indicated in Figure 3, bulk storage of information is achieved by means of a magnetic drum. Standard teletype equipment provides input and output facilities. Static magnetic shift registers are used in the data-manipulating section of the machine. Except for transducer circuitry associated with these elements, almost all electronic portions of the computer are made up of pulse-control units.

Both the instructions and the data upon which the instructions operate enter the machine via the teletype equipment, usually from previously prepared punched paper tapes. Normally the instructions, which are modifiable by arithmetic processes, are stored on the drum before a computation begins and are executed one after another in a sequence which can be contingent upon previously calculated results. Operands are called forth either from the drum or directly from one of a number of tapes.

The current instruction repertoire is listed in Table I. Actual execution of most instructions requires less than 700 microseconds, but each access to the magnetic-drum memory may require up to about 17 milliseconds, the time for one drum revolution. Addition thus requires a maximum of 17 milliseconds. Multiplication and division require an average of 50 milliseconds.

Although the machine originally used only single-address instructions, a recent modification which was carried out in less than an hour provided for a programmable choice between 1- and 2-address operation, (see Two address, Table I). The 2-address system requires more storage space for the program, but with it careful programming can result in appreciably faster computation by reducing the effective average access time to the drum memory.

Table II shows the teletype-printer representation for the standard operand and instruction words used in the Laboratory Computer. Each decimal digit is represented in the computer by four binary digits in the excess-three code. Conversion between the standard 5-hole teletype code and the excess-three code is accomplished by means of crystal-rectifier function switches. The check digit, which can have only three values, is a modulo-three count of all binary

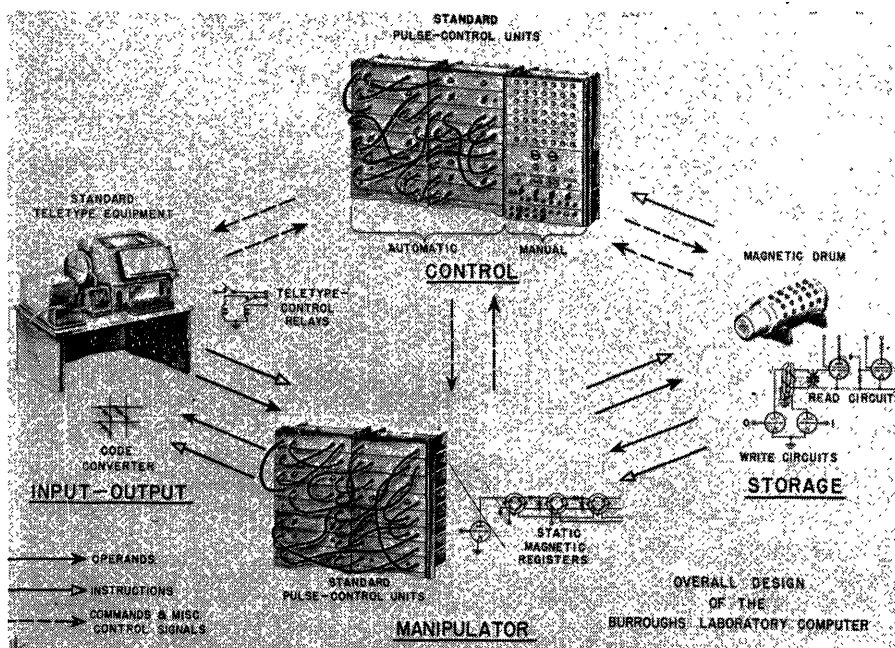


Figure 3. Over-all organization of computer systems

digits having the value 1 in an entire word. Within the computer the check digit is combined with the sign digit to make one 4-binary-digit group, so that the standard computer word length is 40 binary digits.

#### INPUT-OUTPUT SYSTEM

In its initial form the input-output system consisted of standard teletype equipment (see Figure 4), which included a page printer, a keyboard, a tape transmitter-distributor, and an automatic reperforator. Operating speed of this standard equipment is about six characters per second. Although it provided all necessary functions, the original system was no paragon of speed, flexibility, or convenience.

Additional standard teletype equipment was therefore added to increase the terminal data-handling facilities of the machine. At this writing the teletype system is made up of the following standard units:

1. Two page printers, for recording both input and output data.
2. Two keyboards, with tape punches, for manual preparation of tapes.
3. Two reperforators, one typing, one non-typing, for automatic preparation of new tapes, especially from computer results.
4. Three transmitter-distributors for reading from tapes.

Units may be selected both manually and automatically.

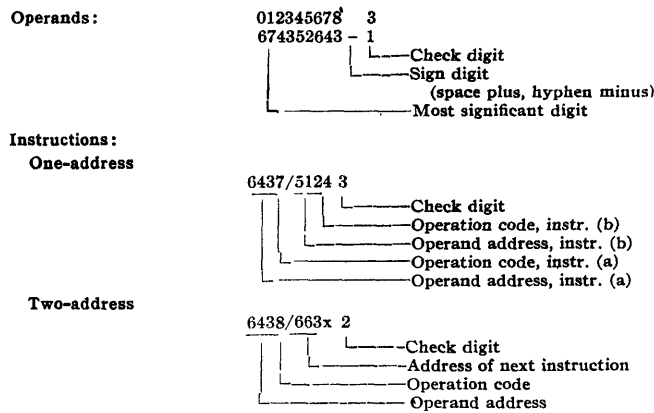
The most recent enhancement of the terminal facilities is an experimental photoelectric punched-tape reader built for the Laboratory Computer on a

Table I. Laboratory Computer Instruction Repertoire

(November 1, 1951)

| Address     | Operation Code                                                                                                            |  |
|-------------|---------------------------------------------------------------------------------------------------------------------------|--|
| (x)..... (  | ....Shift (SH). Shift accumulator right x places                                                                          |  |
| (m)..... /  | ....Unconditional transfer (UT). Obtain next instruction from first half of m                                             |  |
| (m)..... 1  | ....Conditional transfer (CT). Continue normally if accumulator contents are negative; otherwise, proceed as in UT        |  |
| (x)..... 0  | ....Halt (H). If x is 0 halt unconditionally. If x is 1 or 5, halt if appropriate switches are closed                     |  |
| (m)..... 1  | ....Add (AD). Add contents of m to contents of accumulator                                                                |  |
| (m)..... 2  | ....Subtract (SU). Subtract contents of m from contents of accumulator                                                    |  |
| (m)..... 3  | ....Read drum (RD). Clear accumulator and insert contents of m                                                            |  |
| (m)..... 4  | ....Extract (EX). Replace odd integers in accumulator with integers in corresponding digit positions of m                 |  |
| (m)..... 5  | ....Multiply (M). Multiply contents of accumulator by contents of m                                                       |  |
| (m)..... 6  | ....Divide (D). Divide contents of m by contents of accumulator                                                           |  |
| (x)..... 7  | ....Tape (T). Perform input or output operation designated by (x)                                                         |  |
| (m)..... 8  | ....Photoread (PR). Read from photoelectric reader into m, m+1, ... until tape marker or end of channel                   |  |
| (m)..... 9  | ....Write Drum (WD). Write contents of the accumulator in m                                                               |  |
| (m)..... Sp | ....C-A interchange (CA). Interchange contents of C register and accumulator                                              |  |
| (m)..... -  | ....Two address (2A). Change operation mode from one-address to two-address or vice versa; obtain next instruction from m |  |
| (x)..... )  | ....Switch band (SB). Switch to band x of storage system                                                                  |  |

(November 1, 1951)



of counters, registers, and local control systems which keep account of all information required for carrying out the various instructions of a program and the low-level commands within individual instructions. The techniques used are generally similar to those employed in other large-scale electronic digital computers.

Almost everything which can be done by the computer under the supervision of automatic control can be caused to happen in a step-by-step manner under the direction of the toggle switches and push buttons of the manual control system. Where the formally established manual controls prove inadequate, access to the individual pulse-control units of the automatic control and manipulator system can almost always be made to yield desired results. An important part of the manual-control system is the bank of indicator lights which repeat, in an ordered array, the information represented by the indicators on all the widely separated flip-flops in the machine.

## Engineering Features

### GENERAL DESCRIPTION

The over-all view of the Laboratory Computer presented in Figures 1 and 2 indicates that physically the machine resembles a huge plugboard. Most of the equipment is mounted in 19 relay racks which stand in rows along three walls of a room at a distance of about 4 feet from those walls. Each 10-foot rack can accommodate more than 30 pulse-control units. Ventilation is accomplished by exhausting the air from the U-shaped volume between the racks and walls, the latter being provided with filtered air ports. Almost all of the tubes in the machine are located within the ventilated region.

At this writing, the machine contains a total of about 3,700 vacuum tubes and 7,500 germanium-crystal rectifiers. Approximately 2,500 plug-in coaxial cables interconnect 800-odd discrete units. D-c dissipation is about 12 kw. Total demand from the a-c lines is about 35 kva.

Except for an oscilloscope used for test purposes, only two kinds of equipment are mounted in the racks:

1. Standard pulse-control units;
2. Custom-designed units intended solely for use in the Laboratory Computer, some of which, namely, the static magnetic memory units, serve a second purpose by demonstrating the operational feasibility of techniques under consideration for use in other Burroughs projects.

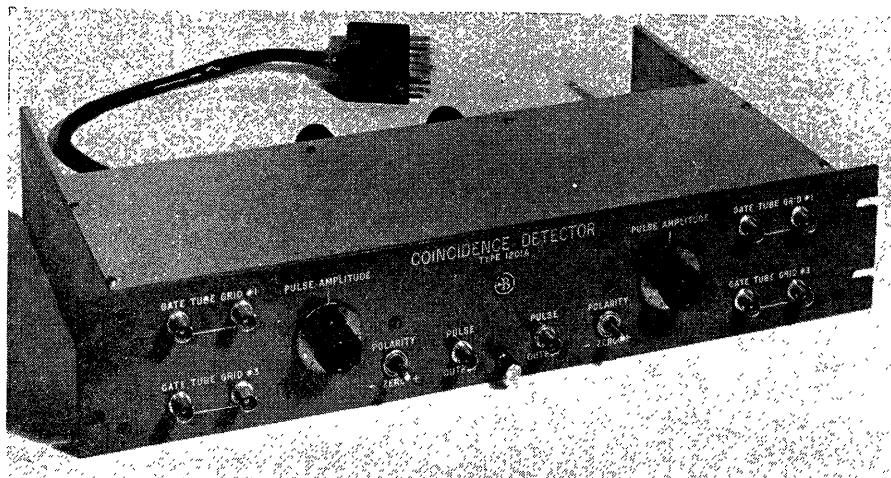


Figure 5. Typical pulse-control unit

Most of the 30-odd custom-designed units of about 15 different types are physically similar to the standard units. They account for fewer than 200 tubes, or about 5 per cent of the total tube count.

Four types of equipment are not mounted in the main racks:

1. The magnetic drum, which is located in the enclosure behind the racks, together with two small racks of auxiliary electronic equipment.
2. The standard teletype equipment, which is aligned along one wall of the room, adjacent to one row of racks.
3. The photoelectric punched-paper-tape reader, which is mounted on its own dolly.
4. Power transformers and the d-c power supplies, which are located in another room. The four identical general-purpose d-c supplies are in conformity with the over-all philosophy of unitization. They contain about 7 per cent of the total number of tubes in the machine.

Because the object was to realize only a laboratory device, and not a handsome and compact marketable machine, size and appearance were considered of little importance. Economy, convenience, and salvagability were stressed.

### PULSE-CONTROL UNITS

Pulse-control units contain electronic pulse circuits, for computer and similar applications, which are packaged at the flip-flop and gate level. Designed primarily for use in test setups which normally require only a half dozen or so units, the present line is satisfactory, but not optimum, for large-system applications.

A typical unit is shown in Figure 5. Pulse-control units are different from the plug-in units containing one or two vacuum tubes which are in widespread use at present because they contain both input and output buffer amplifiers, which make possible a high degree of interconnection flexibility. Signal con-

nections are made by means of the jacks on the front panel. Power connections are made by means of the power cable and connector with which each unit is equipped.

Only two kinds of signals are transmitted between units on the plug-in coaxial cables:

1. Standard pulses, each shaped roughly like a half-cycle of a sine wave, with baseline duration equal to 0.1 microsecond.
2. Two-valued control voltages supplied by flip-flop circuits whose switching time is about 0.2 microsecond.

Most units will operate at a pulse-repetition frequency of 2 megacycles.

Output impedance levels are low and input impedances high, so that one unit can drive many others. The load limit on a unit providing a control-voltage output is determined only by the required switching time. Each 2-foot length of unterminated output cable and each driven input terminal adds about 0.06 microsecond to the switching time. A flip-flop unit connected to five vacuum tube coincidence-detector inputs by means of 23 feet of coaxial cable gives an effective switching time of of approximately 1 microsecond.

Unlike control-voltage cables, pulse lines are terminated in their characteristic resistance by means of plug-in resistors. The 0.1-microsecond pulses are therefore not much affected by the length of cable driven. Eight driven units represent the usual working maximum load on pulse lines. Standardization of signals and incorporation of buffer amplifiers establishes independence of one pulse-control unit from another in three important categories:

1. *Logical.* Each unit is a logical entity which corresponds to a discrete box in the usual lowest-level block diagram.

Table III. Pulse-Control Units in the Laboratory Computer

(November 1, 1951)

| Unit Type                             | Function                                                 | Tubes<br>per<br>Unit | Units    | Total<br>Tubes |
|---------------------------------------|----------------------------------------------------------|----------------------|----------|----------------|
| Flip-flop, type 1101A.....            | Control, storage, counting.....                          | 7.....               | 160..... | 1,120          |
| Coincidence detector, type 1201A..... | Pulse gating.....                                        | 6.....               | 281*     | 1,686          |
| Coincidence detector, type 1202A..... | D-c gating.....                                          | 0.....               | 54*      | 0              |
| Pulse delay, type 1301B.....          | Unprecise delays, 1 to 80,000 micro-seconds.....         | 8.....               | 19.....  | 152            |
| Pulse delay, type 1302A.....          | Precise delays, 0.1 to 1.9 microsec-onds.....            | 5.....               | 14.....  | 70             |
| Channel selector, type 1401A.....     | Pulse distribution, manual control.....                  | 7.....               | 18.....  | 126            |
| Mixers, type 1601, 2A.....            | Pulse mixing.....                                        | 0.....               | 200..... | 0              |
| Other units of six types.....         | Counting, push button pulsing, relay switching, etc..... | .....                | 39.....  | 106            |
| Totals.....                           |                                                          |                      | 785..... | 3,260          |

\* Each unit contains two independent channels.

2. *Electronic.* Each unit is an electronic entity which can be connected to others without concern over electronic problems.

3. *Physical.* Each unit is a physical entity whose position in an array of equipment is substantially independent of the location of the source and destination of its signals.

Table III lists the types of pulse-control units and the number of each presently used in the computer, together with their salient logical features. These 785 units contain a total of 3,260 tubes, about 88 per cent of the total number in the computer. Note that some units contain no tubes, but only gating and mixing circuits comprising germanium-crystal rectifiers. These units are exceptions to the general rule in that they must be proximate to those which they feed, and are especially designed for this purpose.

#### RELIABILITY

Table IV presents the performance record of the Laboratory Computer. No particular effort has been expended to achieve impressive reliability figures. The totals shown began accumulating within a few days after final assembly of the machine.

Tube trouble was the cause of about 95 per cent of the large amount of down time, 145 hours, associated with pulse-control units. After 1,500 hours only 77 per cent of the 1,000 6AG7 pentodes and only 80 per cent of the 500 6AN5 beam-power amplifiers from the original installation had survived. The 6AG7's have suffered from cathode peeling, and are being replaced by the manufacturer as an admittedly defective lot of tubes. Difficulty with the 6AN5's has been cathode-current instability which is greatly aggravated if heater voltages drop only a few tenths below normal.

A flip-flop design which allows the plate potential to be lower than that of the

screen grid is believed to contribute to the 6AN5 trouble, although no ratings are exceeded. Close co-operation with the manufacturer is being maintained in an effort to solve the problem. More recent pulse-control unit flip-flops use 6AG7's with good results. The 6AN5's perform well in pulse circuits and JAN d-c tests.

Experience with other tube types has been satisfactory on the whole. Gradual application and removal of heater voltage over 5-minute periods is believed largely responsible for the fact that no heater failures have occurred since the initial checkout of the machine. None of the tubes installed originally were preburned, but because facilities have become available most tubes to be used in the future will have been preburned.

Only five germanium-crystal rectifiers of about 7,500 in use are known to have failed.

#### EVALUATION OF ENGINEERING APPROACH

##### Advantages

Creation of a substantial portion of the Laboratory Computer by merely mounting and interconnecting standard pulse-control units resulted in the following variety of significant advantages:

*Flexibility.* Changes in logical design have been readily effected. New major systems components have been integrated easily into the machine and others can be, provided they come equipped with necessary transducer circuitry.

*Salvagability.* At least 80 per cent of the bulk of the machine, including power supplies, is completely salvagable in terms of equipment in great demand on a number of different Research Division projects.

*Engineering.* The engineering effort devoted to this project was substantially

less than it would have been if any other design approach had been taken.

*Logical Design.* Logical design was conducted in parallel with, rather than previous to, electronic design and construction. Final details were not available until about 1 month before the computer was completed. Not the least advantage in this category was the fact that the logical design did not require thorough checking as is customary when it is relatively irrevocable. The few logical errors which were inevitable were uncovered and corrected during the short checkout period of the machine.

*Drafting.* In contrast with the very heavy drafting load usually associated with the design and construction of a machine of comparable size, this computer was built from negligibly few drawings, except for those on the individual unit types.

*Production.* The usual advantages accruing to the synthesis of a large equipment from small identical units applied here. Most of the construction was carried out with little regard for the logical design, since the only logical data necessary were estimates of units requirements.

*Trouble Location.* The easy replaceability of units is not the only major asset of the pulse-control units during fault-tracing periods. The on-off puls-switches and the pulse amplitude controls are very useful tools, but perhaps the greatest advantage is the ability of the trouble shooter to remove signal cables and note the effects either of just removing them, or of plugging them into spare units usually available for test

Table IV. Laboratory Computer Performance Record

(Feb. 19 to Nov. 1, 1951)

|                                                                                   | Hours    |
|-----------------------------------------------------------------------------------|----------|
| <b>Available Time</b>                                                             |          |
| Operating time.....                                                               | 1,102:42 |
| Down time due to faults in                                                        |          |
| Pulse-control units.....                                                          | 145:20   |
| Magnetic-drum equipment.....                                                      | 16:13    |
| Teletype equipment.....                                                           | 23:16    |
| Magnetic registers.....                                                           | 11:16    |
| Power system.....                                                                 | 24:23    |
| Undetermined.....                                                                 | 3:49     |
| Total down time.....                                                              | 224:17   |
| Total available time.....                                                         | 1,326:59 |
| % Efficiency = $\frac{\text{Operating time}}{\text{Available time}} \times 100\%$ |          |
| = $\frac{1,102}{1,326} \times 100\% = 83\%$                                       |          |
| <b>Unavailable Time</b>                                                           |          |
| Engineering changes.....                                                          | 202:28   |
| Preventive maintenance.....                                                       | 27:29    |
| Total unavailable time.....                                                       | 229:57   |

purposes. The level of manual access to the Laboratory Computer is such that an oscilloscope need rarely be used.

**Training.** Logical design personnel with little experience in electronics have been planning and carrying out physical changes in the machine with only technician assistance. Such experience is expected to have a valuable effect on the future output of these individuals.

#### *Disadvantages*

Following are listed some disadvantages attendant to the synthesis of the Laboratory Computer from pulse-control units:

**Size.** The machine is unquestionably bulkier than fundamentally necessary. Its tube count is of the order of 2.5 times greater than that which would be required in an efficient custom design for the same logic.

**Appearance.** See Figure 1. Some objections have been voiced to the appearance of a disordered array of cables on the fronts of the units, although the definition of front is a topic for discussion. These objections could be met by building a false front on the machine, but the matter has not been of sufficient importance to justify such expenditure of effort.

**Reliability.** The use of a greater number of tubes and other components than are basically required means that the fault probability is higher than the best possible figure. Also, since plug-in connections are inherently less reliable than soldered connections, the machine is more susceptible on this score than it would need to be. These facts have not yet resulted in appreciable difficulty.

**Power.** Dissipation is greater than necessary in the optimum custom design for two reasons:

1. The tube count is greater.
2. The circuits are all suitable for very high-speed operation, with consequent more lavish use of power than if they had only the required pass band in each individual case. A single high-speed flip-flop unit can dissipate as much as 50 watts.

**Convenience.** Because the units used in the computer had already been designed with only test-equipment applications in mind, removal and interchange of units is not quite so convenient as it might have been. On these units the cable connections are on the same side as that on which the units must be withdrawn from their mounting racks. A more recent mechanical design, which is a still unproved candidate

for future use, is such that the unit is removable to the side opposite that occupied by the maze of cables.

**Permanence.** The ability to change connections readily no doubt will result occasionally in their being changed unnecessarily. Amplitude controls and switches present the likelihood of temporary changes being forgotten and leading to trouble.

One or all of these disadvantages might have been prohibitive in some applications, but collectively they have presented no undue difficulties in the present computer in its use as a laboratory device.

#### **Applications**

Because the principal reason for its existence is not the achievement of volumes of computed results, the Laboratory Computer has not been faced with a demanding problem-solving schedule. Emphasis has been placed on use of the machine for training, and as a means for checking the feasibility of new methods. It has been operated only during the normal 40-hour week.

The normal operating staff consists of three programmers and one maintenance technician. However, many other people in Burroughs' Research Division have had opportunities to become acquainted with the machine, both by setting up problem solutions and by participating in the engineering changes which have been carried out.

Despite the lack of pressure, a variety of problems have been solved. Most solutions have been for test purposes only, but some practical problems have led to useful results. The more significant practical problems dealt with to date are listed below.

**Production Control.** Sales forecasts and production parts lists were used to determine sample optimum production scheduling for Burroughs' Detroit plant. This effort will be renewed to utilize the recent improvements in terminal facilities.

**Circuit Design.** Required resistor and voltage values were computed for complex networks involving large numbers of crystal-rectifier gates and mixers. Results disclosed necessary design changes in a large computing system.

**Logical Simulation.** Tentative computer-system logical designs were expressed in equations from which the computer was able to simulate the logical performance of the device under design.

**Cam Design.** A practical engineering problem involving the design of a cam surface was successfully handled.

Miscellaneous problems which have been run for test and training purposes include matrix manipulations, random-number and prime-number generation, solution of linear simultaneous equations, and autocorrelation-function calculation.

The recent expansions of storage capacity and terminal facilities, and the incorporation of multiplication and division as built-in operations, have opened up new areas in which the Laboratory Computer can operate as an effective computing device. Its potential usefulness for handling business problems has been greatly increased. However, plans for the near future continue to emphasize the use of the machine as a laboratory device to an extent which will inhibit its accomplishments as a computing instrument.

#### **Conclusions**

The Research Division of the Burroughs Adding Machine Company has built a large-scale digital computer which is unique in that the internal mechanization of computational steps can be changed merely by reconnection of plug-in cables, see Figure 1. Construction from already designed general-purpose building blocks known as pulse-control units resulted in an unusually short time, only 9 months, between the decision to design the computer and its realization.

As implied by its name, the Laboratory Computer is a laboratory device whose most important function is to assist in a long-range development program of wide scope by providing a versatile proving ground for the trial and evaluation of new ideas and components. It is a useful source of engineering performance data, and has proved valuable as a means for training personnel.

Although problem solution has been regarded as a subsidiary objective, useful results have been obtained from the machine.

Initially its computational ability was modest, but recent enhancements have substantially increased its potential. These alterations have not yet been exploited to any great degree.

Basic limitations on its performance as a computer are the rotational speed of the magnetic drum, the only internal memory medium, and the speed of standard teletype terminal facilities. If further improved storage and terminal equipment becomes available it can

readily be added to the system, after first being equipped with necessary transducer circuitry.

Plans for the future continue to subjugate problem solution to use of the machine as a development tool.

#### RECOMMENDATIONS

Because the Laboratory Computer has fulfilled all of its objectives to a satisfactory degree, the building-block approach upon which its success is based

appears worthy of consideration by others who have similar objectives or problems amenable to a similar design technique.

Although in all of its configurations to date the Laboratory Computer has been a programmable general-purpose computer, its engineering philosophy should be of particular interest to those who have need for smaller special-purpose and fixed-program machines, especially where the ability to change the

logical design would be a substantial asset.

The method also is recommended where the need for a machine is only temporary, and where systems principles should be demonstrated before the engineering of a permanent machine is begun. Indeed, an aggregate of units used to establish logical feasibility might also serve as test and simulation equipment during the engineering design and final integration of a finished machine.

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## Discussion

**W. P. Byrnes** (Teletype Corporation): Did I hear you say that the information is put into the magnetic storage drum sequentially, binary digit by binary digit?

**G. G. Hoberg:** Yes, but it first goes into the arithmetic registers of the computer which serve as buffer storage. It is not put directly from the teletype equipment into the drum but rather from the teletype equipment into the manipulator registers and thence into the drum.

**W. P. Byrnes:** Is it put in the drum on a simultaneous basis?

**G. G. Hoberg:** No. These magnetic registers consist of four parallel magnetic shift registers, but the information is taken out of them only bit by bit: that is, all four registers are shifted simultaneously, so that one decimal digit and four binary digits come out of the register, into flip-flops. Then this information is picked up bit by bit

and put into the drum at the proper time.

You see, it is fundamentally impossible here to read directly from teletype into the drum because they are both dynamic systems and it is difficult to synchronize them. You have to get information where it will be held for a while and then put it into the drum selectively at the proper time. This is done by the static magnetic register.

**W. P. Byrnes:** Your buffer registers, are they set up so they could accept the information from the teletype equipment on a simultaneous basis rather than a start-stop?

**G. G. Hoberg:** Yes. One word at a time is read from the teletype equipment normally, or there is at least a spacer between words. Digits are read essentially continuously, but in one word groups. All five binary digits are read from the teletype in parallel.

**J. C. Simons** (Westinghouse Electric Corporation): You have given us a good picture of what you have done. Would you give us a better indication of your plans for

the future? Do you plan to use this machine for your own work on problems, for your own development, and more particularly do you plan to develop this into another machine, a package machine which would be available commercially?

**G. G. Hoberg:** There will be no direct development of this machine into another machine; that is, this is not the first model of some series of machines, the last of which is to be a commercial product. It is not like that. This is a general purpose computing installation whose function will not in the future be primarily the solution of problems. It will be used mostly as a versatile proving ground, where we can, if we get a new kind of magnetic shift register, integrate it into the machine, or if we get a new arithmetic unit, integrate it into the machine. We may try out some solutions of business problems which will be handled in the same way they will be handled in contemplated commercial machines, but this machine is unlike anything that Burroughs hopes to sell in the future.