The IBM 650 RAMAC System Disk Storage Operation

DAVID ROYSE†

Disk Storage Operation

THE IBM 650 RAMAC System combines the computing flexibility of the Type 650 magnetic drum data processing machine with the quick random-access large-scale memory which may be assembled from several of the Type 355 disk storage units. The combination may be programmed to perform rapid sophisticated jobs of in-line (single-step) data processing. Briefly, this means that the punched-card or taped record of each event is in turn completely processed against all of the records, inventories, or summaries which it affects. The various physical units which may comprise the system are shown in Figs. 1-3.

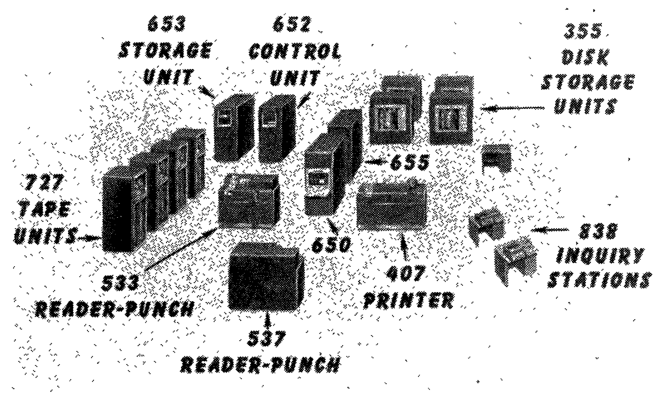

Fig. 1—IBM 650 RAMAC.

Basic Computer

The basic computer consists of the elements shown in Fig. 2: from one to three of the three card inputs; card or printer output units may be had in any combination, each with or without alphabet. The 655 unit contains the power supply for itself and for the 650 console unit. It also contains input-output translating, and any associated alphabetic equipment. The 650 console unit contains the magnetic drum main memory and the principal arithmetic, logical, and timing elements; it has the display console. (See Fig. 4, next page.) The 650 is the nerve center of any of the expanded 650 systems which may be assembled.

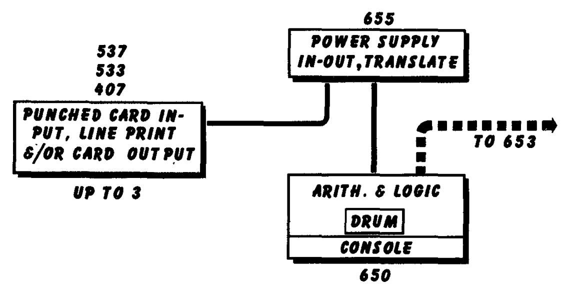

Fig. 2—The basic 650.

The basic computer is a stored program, single address, intermediate speed machine. It is a serial by digit parallel by bit machine with 125-kilocycle clock rate. It has a main memory capacity of 2000 ten-digit words, a very comprehensive list of commands (including automatic table-look-up), and it is very easily programmed.[1] Circuit design is conservative and the machine is thoroughly self-checked.

653 Storage Unit

The next unit in the system is the 653 storage unit, which may contain automatic floating decimal arithmetic, index registers, immediate access (core) storage, or any combination of the three. (See Fig. 3.)

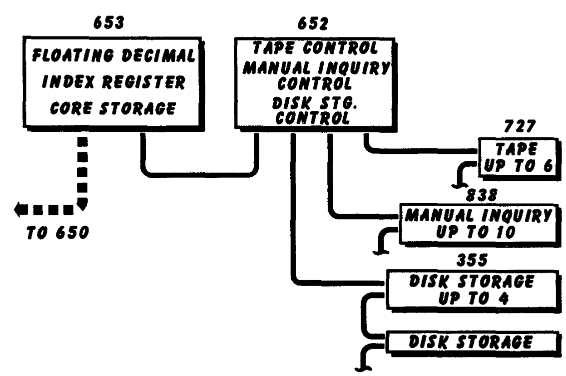

Fig. 3—650 RAMAC (basic 650 not shown).

"Immediate access (core) storage" is a necessary part of any system which includes tape or disk storage. The core storage array has a capacity of 60 ten-digit words (plus their signs). It is directly addressable from the 650. Single-word access to transfer to or from the 650 requires the minimum execution time of any 650 instruction, which is two 96-microsecond word time. Block transfers may be made directly between the core storage and the 650 drum in increments of ten and 50 words. Table look-up may be made directly on core storage, the same as on the drum.

In addition to serving as quick access storage for the 650, the 60-word block of core storage serves as a static

† Internatl. Business Machines Corp., Endicott, N. Y.

[1] E. S. Hughes, Jr., "The IBM magnetic drum calculator type 650, engineering and design considerations," *1954 Proc. Western Joint Computer Conference.*

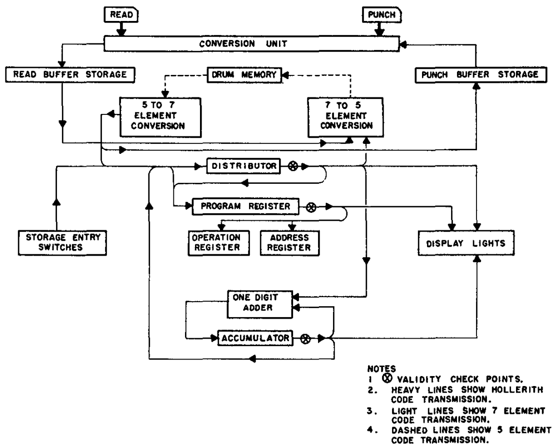

Fig. 4—Flow of instructions and data in basic 650.

buffer for information transferred between the computer and tape, between computer and disk storage or between tape and disk storage under computer control.

652 Control Unit

The 652 control unit, next in line, Fig. 3, may contain electronic controls for tape; it may contain electronic controls and a thyratron address buffer for disk storage, and it may contain equipment necessary with the manual inquiry feature described in a companion paper.[2] A discussion of tape operation is not included here, except to say that tape units are extremely useful in the application of the 650 RAMAC to in-line processing.

355 Disk Storage

The remaining element in the system is the 355 disk storage unit. (See Fig. 5.) Each disk storage unit has a capacity of six million numeric digits plus six hundred thousand signs, or three million alphabetic and special characters. Information is stored magnetically on both surfaces of each of 50 oxide coated disks. The disks are stacked and rotated on a common vertical axis at 1200 rpm. A description of the prototype disk array and access mechanism has been given.[3] Capacity of each surface is 100 concentric tracks; capacity of each track, as used in the 355, is 600 numeric digits, plus 60 signs, organized into 60, 650-sized, ten-digit words. (See Fig. 6).

There are three independently and simultaneously moveable access arms in each storage unit. (See Fig. 7.) Each arm is forked to straddle a disk and contains a spring-retracted air-extendable read-write head recessed into the end of each "tine" for access to opposite faces of the same disk. (See Fig. 8.)

[2] H. A. Reitfort, "The IBM 650 RAMAC inquiry station operation," this issue, pp. 49–51.
[3] W. E. Dickinson and T. Noyes, "Engineering design of a magnetic-disk-random-access-memory," *1956 Proc. Western Joint Computer Conference*, pp. 42–44.

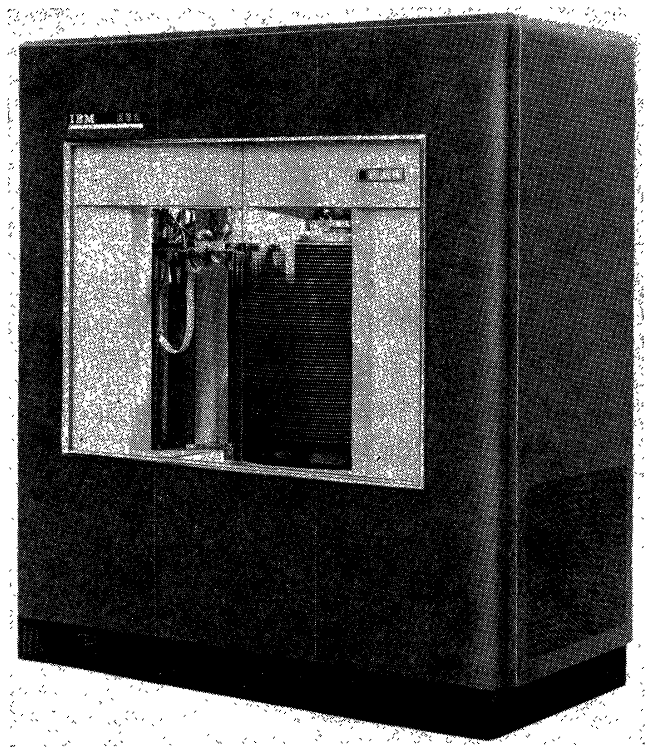

Fig. 5—355 disk storage unit.

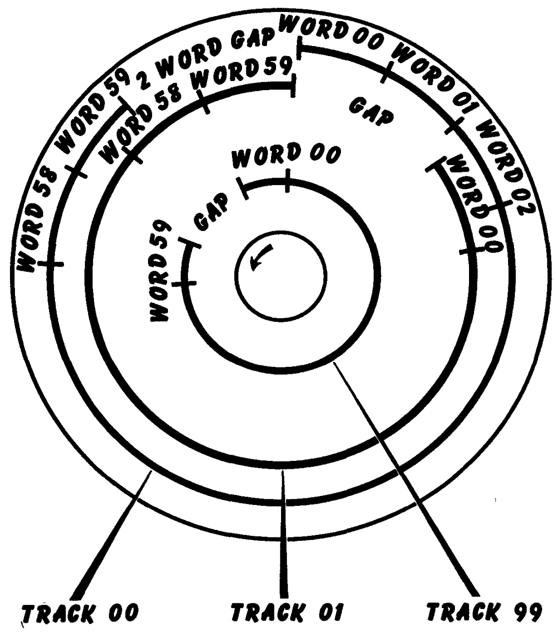

Fig. 6—Track and word arrangement on a disk face.

Disk storage operation is controlled from the computer-stored program by only three commands and a six-digit disk-storage address. The commands are as follows.

OP Code	*Command*
85	seek
86	read
87	write.

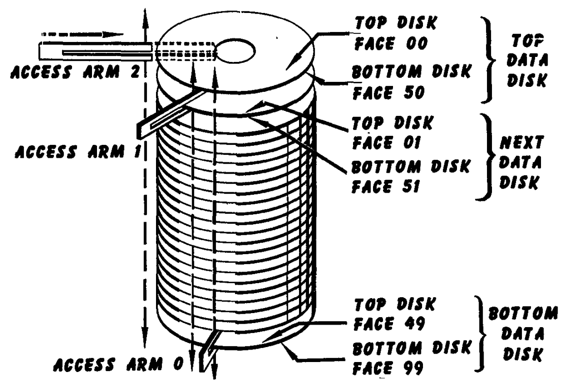

Fig. 7—Arrangement of arms and disks.

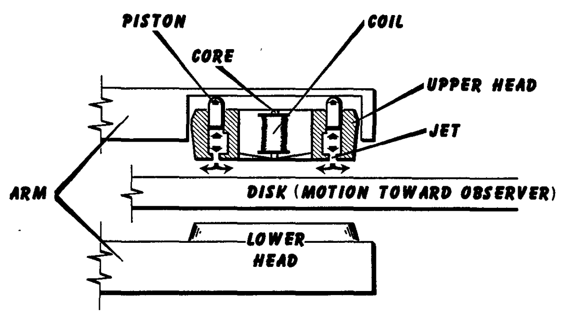

Fig. 8—Air-head arrangement.

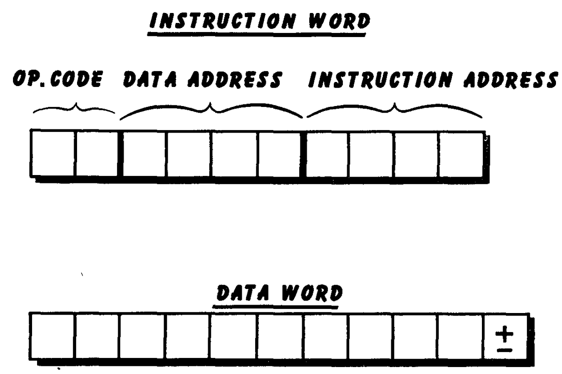

Fig. 9—650 word-arrangement.

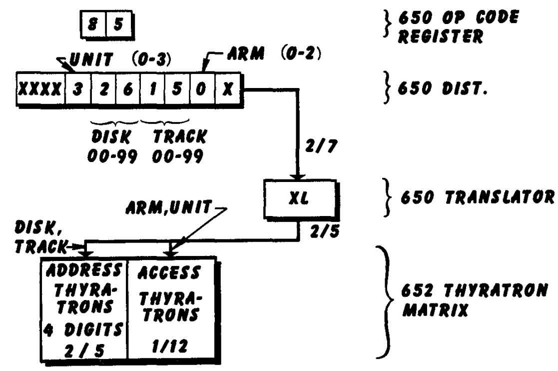

Fig. 10—Seek: transfer disk—memory address from 650 to 652.

In each case the six digit disk-storage address is programmed into the six low-order positions of the 650 distributor, (Figs. 4 and 9), in a program step just preceding any of the three commands. This departure from the usual placement of the data address in the 650 address register is made necessary by the fact that only four places are available in either the instruction word or the address register.

Seek Operation

Seek is one of very few commands issued by the 650 which sets up access to a memory, but which does not make the data transfer in the same step.

At the cost of a few more program steps, the speed of the system is greatly increased by permitting movements of the access arms to be overlapped with each other and with read or write operations in other arms.

Appearance of the 85 in the OP code register sets up seek-mode controls in the 652; thereafter, the seek command is executed in four steps.

1) Transfer of seek address from distributor to thyratron matrix. Information is read out serial by digit, parallel by bit, translated from 2/7 biquinary code to 2/5 code and sent to the 652, where the unit and arm digits are time sampled and cause one of the 12 access thyratrons to fire. The four disk and track digits are time-sampled and stored in a thyratron matrix in a 2/5 code. (See Fig. 10.)

After the two word times required to initiate this much of the seek operation, the 650 finds its next instruction and proceeds with its program.

2) Transfer of the disk and track address from the thyratron matrix to a set of address relays corresponding to the proper arm is made via the contacts of one of the 12 access relays. The address relays are then held through their own contacts. (See Fig. 11, next page.)

A two out of five validity check is made on the address, a bit-for-bit comparison made between thyratrons and address relays, and a one-and-only check made on all the access relays. Satisfaction of these checks extinguishes the 652 thyratron matrix and resets the seek mode controls. The 652 is then ready to accept a read or write command or another seek command. This takes about 30 ms from the initiation of the seek command.

3) Arm servoaction. The information contained in the address relays is translated into a corresponding arm position by action of the servo shown much simplified in Figs. 12,[3] 13,[3] and 14.

Power for both up-down and in-out arm motions is provided by a $\frac{1}{3}$ hp motor. Magnitude and direction of the driving force are controlled by a pair of counter-rotating magnetic clutches. The force is transmitted to the arm by a single steel cable.

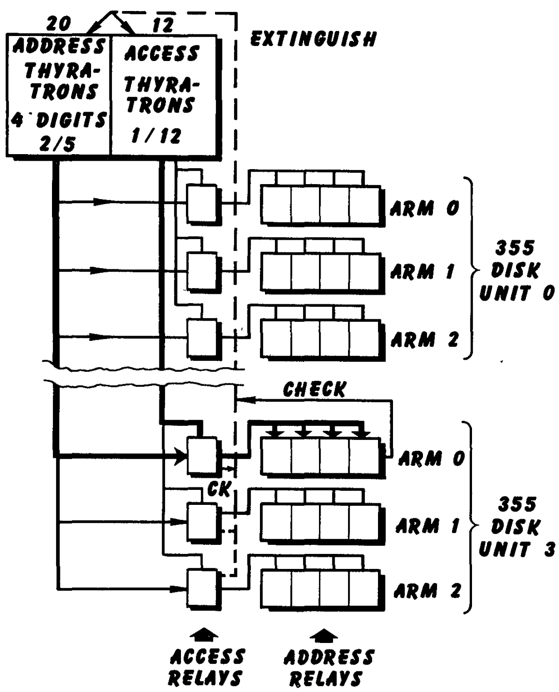

Fig. 11—Seek: Transfer address from 652 to 355 address relays.

When new disk and track addresses are entered into the address relays, new taps are grounded on both disk and track potentiometers through trees of contacts on the address relays; see Fig. 14. The disk error signal causes the arm to be extracted radially clear of the disks, locking the arm in its outermost radial position and unlocking it for vertical motion. The disk wiper error signal then causes the arm to seek and find the new disk null point. The vertical position is then digitalized and locked opposite the proper disk by an air driven "disk detent," unlocking the arm for radial motion and transferring servocontrol to the track potentiometer and wiper. The arm is then moved radially to the track null position. There it is digitalized and locked in place by a "track detent."

4) Final step in the execution of a seek command is to verify that the location of the arm corresponds to the new address.

The arm location is brush-sensed directly in the 2/5 code from a pair of rhodium-plated printed circuit strips. One strip is attached to the top of the arm, the other is attached to the vertical way. A successful bit-for-bit comparison on all four disk and track address digits signals completion of the seek for that arm and prepares it for reading, writing, or another seek.

Failure to get a proper comparison results in movement of the arm to another location, after which it is redirected to the true address and the position check is repeated. Possible random servoerror is thus corrected with a minimum of delay and no special programming.

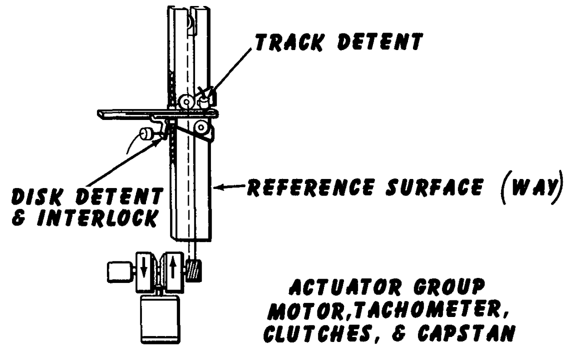

Fig. 12—Mechanical portions of arm-servo.

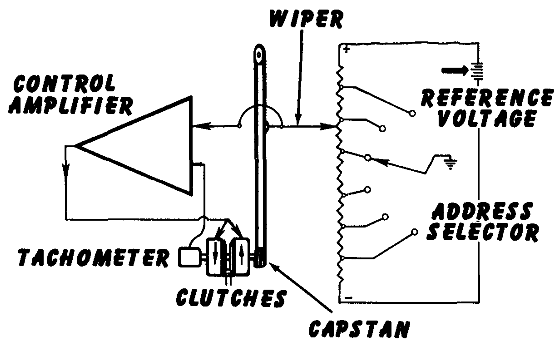

Fig. 13—Electrical portion of arm-servo (simplified).

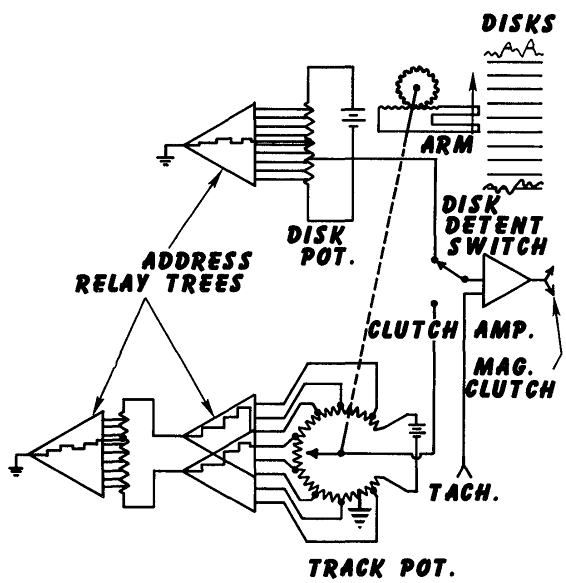

Fig. 14—Electrical portion of arm-servo including disk and track address trees.

Total time for completion of a single seek varies, depending on how far the arm is required to move. Minimum time consumed (for seeking from track to track on the same disk) is about 150 ms.

Maximum, for movement from inside track, top disk, to inside track, bottom disk, is about 800 ms. The statistical mean seek time based on random addressing is a little over one-half second.

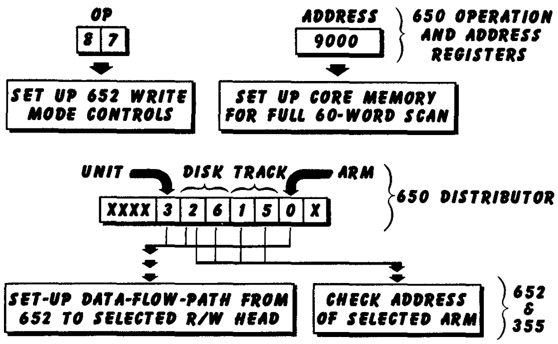

Fig. 15—Write flow path setup and address-check.

Write

The function of the write command is to cause the full 60-word content of immediate access (core) storage to be stored on a disk-storage track. The information is written there by a particular read-write head which was placed over the correct track in a preceding seek operation.

Presence of an 87 in the 650 OP code register (Fig. 15), initiates the disk-storage write command, which is also executed in four steps.

1) The six-digit disk-storage address is again transferred from the 650 distributor to the 652 thyratron matrix. The 650 then proceeds with its program.
2) The address information stored in the thyratron matrix is then used for two purposes (Fig. 15): To establish a data flow path from the 652 by means of access relay points to the proper read-write head, and to check that the selected arm is in the proper location. (This is a check on the program to insure that the arm was not inadvertently re-seeked between the intended seek and write instructions for that arm.)
3) Writing begins at whatever point on the track happens to fall under the head at the time the address check is completed. Writing on the track and clocking of core read-out and regeneration are controlled by an 83-kc LC oscillator in the 652.

First, a three-word gap is written, erasing any old information. (See Fig. 16.) Then one digit at a time, core memory is read out and regenerated. Core information is at the same time placed parallel-by-bit into a one-digit buffer, which is scanned out serial-by-digit, serial-by-bit into the read-buss line. (See Fig. 17.)

Information is written on the track in a modified non-return-to-zero form. Presence of a bit is indicated by a transition between the opposite remanent states. (See Fig. 18.)

Writing is terminated upon run-out of the core timing rings. Nominally the last $1\frac{1}{4}$ words of written information overlap the first portion of the written gap. This allows $\pm 1\frac{1}{4}$ word variation (in 63 words) between oscillator frequency and disk speed and at the same time insures the half-word of gap needed by the read circuits to detect the start of a record. It also insures that all of the previous record is erased.

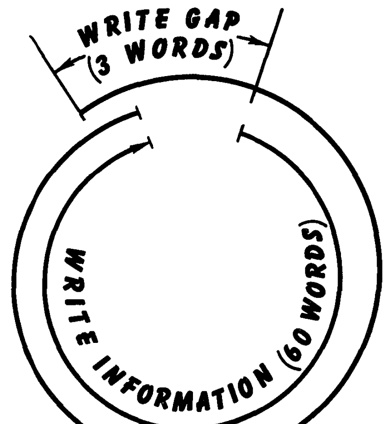

Fig. 16—Track writing overlap.

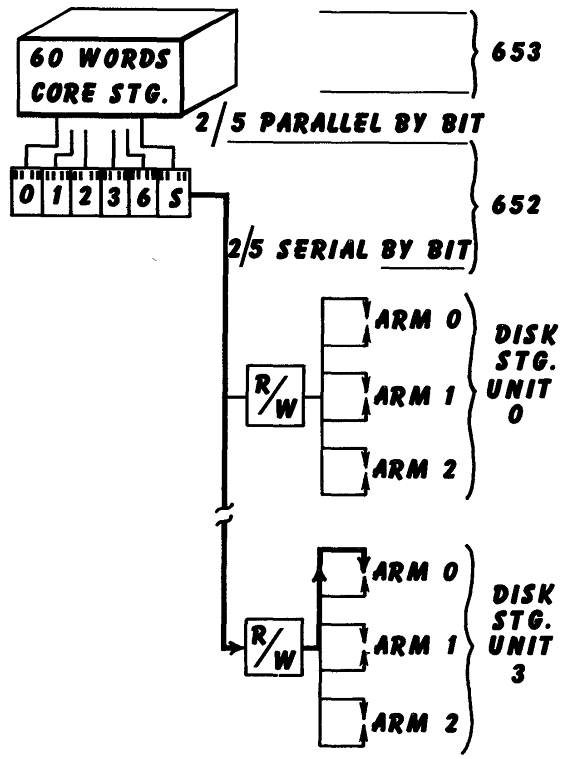

Fig. 17—Write data flow.

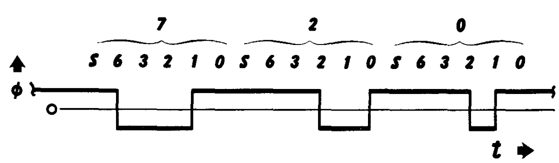

Fig. 18—Modified NRZ recording.

4) To insure that correct, readable information was written, the track is read on the following disk revolution as core memory is again read out and regenerated.

Track information is converted from serial by bit to parallel by bit in the 652, validity checked and compared digit by digit with that from core storage. Satisfaction of this check completes the write operation. Otherwise the operation is repeated from the writing of the gap until the check is satisfied or until the operator intervenes.

Write execution, from initiation by the 650 to completion of the check, requires approximately 30-ms set-up time plus two disk revolutions, a total of 130 ms.

Read

The purpose of the read command is to transfer the 60-word contents of a track into core memory. Execution is very similar to that of the write command.

Flow path set-up and address check are identical.

The beginning of the record is found by sensing the gap. Reading and core timing are clocked by a pair of 83-kc LC oscillators in the 652, (one of which was used for writing). When reading, each bit sensed turns one oscillator off and the other one on, rephasing the clock with the information twice every digit time. Information is scanned serially into a one-digit buffer in the 652 during 6, 3, 2, 1, and 0 bit times, then validity checked and read into core memory parallel by bit during "S" bit time. (Fig. 18.) Satisfaction of the validity check by all digits read signals completion of the read operation. If the check is not satisfied the operation is repeated from the sensing of the gap on. Total time for a read operation varies depending on how long the head must wait for the gap. Average time is about 30 ms for set-up and address check, 25 ms wait for gap, 50 ms for one disk revolution, a total of 105 ms.

Conclusion

Disk-storage operation is controlled by three commands from the computer, seek, read, and write. Average times required are 565 ms for seek, 105 ms for read, and 130 ms for write.

Although access to this disk storage is inherently fast compared to that for other comparable random access memories, speed of the system is materially improved by permitting arm servo actions to be overlapped with each other and with other disk-storage operations.

Independent computer operation is permitted during the execution of any disk-storage command.

All operations are thoroughly self-checked with respect to addressing, valid data transmission, and completion.

Automatic recycling features, which are provided for arm servo, read and write, prevent unnecessary downtime for random errors, without complicating the program.

Discussion

David Zeheb (General Electric): Is the density of recording on a disk variable and if not, does the number of words increase with the distance from the center?

Mr. Royse: The density of recording is variable. It is about a hundred bits to the inch on an individual track and about fifty bits to the inch on an outside track. Because we use just one half of the total radius, the distance is two feet in diameter, and we use practically five inches of the outer area of the disk. We also have sixty words recorded in each track.

N. M. Blachman (Sylvania EDI): Why is the RAMAC clock not recorded on a 51st disk?

Mr. Royse: It was less expensive to do it the way we did.

C. O. Carlson (National Cash Register): What was the reason for three access arms rather than more or less?

Mr. Royse: This seemed to give us an overlap with three access arms, and we could overlap seek operations so that the total seek time, assuming a percentage overlap, was of the order of two-hundred milliseconds.

W. C. Carter (Datamatic): Does the 653 have either floating decimal or index registers or core storage, or some combination of these?

Mr. Royse: You can get any combination. You may have one, two, or three of these features.

G. Barclay (General Electric): Would stationary arms for each disk decrease the access time and make the memory system more economical?

Mr. Royse: They would decrease the access time, but it is our belief that they would increase the cost of the memory system.

C. H. Richards (Convair): What is the function of the "seek" command, if address in information is given when reading and writing?

Mr. Royse: By separating a seek command from a read or write, we are able to send seeks out ahead. We are able to cause seeks ahead of our need for the read or write operation, and because we have multiple arms for each disk, we are able to overlap. We need not wait for the commencing of the seek if we are able to send seeks out ahead.

Mr. Richards: Well then, what function does the address information contain in the read or write? Just a check?

Mr. Royse: It is a check principally on the program and upon the operator. Even in the in-line processing system, there are times when you shut down for maintenance operations. At that point, we lose the information from the address relation in the 355 units and after the maintenance operation is done, we must fire the system up and get valid information back into these address relations before we can proceed. The nature of the system is that it must have valid information back into these address relations in order to get another seek command into the seek operation. Now, to take care of the situation, we have a button on the 652 which is reset, which puts the arm over the zero track on the zero disk. Now, suppose that the system had stopped between the seek which was not an all zero seek, but some other locations in the memory, and the next operation to come up was a read or write command. If we did not have this check on the address, the system might think the arm was correctly in position and we might ruin some valid information in the file. Another reason is that we have to have part of that information in order to prepare the proper data flow pattern between a head and the core memory.

D. L. Shell (General Electric): How long does it take an arm to seek the same track as present location, and how long to seek the same track number on the opposite side of the same disk?

Mr. Royse: We have found that whenever we resend, it takes a little less time than we thought it would originally and this time is in the order of one hundred milliseconds for the complete search of the surface. In other words, in answer to the second part of the question, you have already seeked the track and you have forgotten about it and you try to seek the same location. This takes of the order of fifty milliseconds to accomplish. We must go through all the checking procedures. In seeking the same track number on the opposite side of the same disk is approximately the same time, five milliseconds.

C. F. Summer (RCA Missile Test Project): Would it be possible to address individually any word on any disk? Further, how far apart physically are the channels on each disk?

Mr. Royse: In answer to the first part of the question, no, not directly. The way we handle this is to read an entire track into the core memory and there we have very powerful editing ability. We can make a block transfer of ten or fifty words. From core memory, we can make block transfers in any amount, which includes words which are successive words between core memory and the drum. In addition, we can pull out one word and we can do the reverse. So, what we do to change one word is to read out a track into the core memory, alter the one word, and rewrite the contents of the core memory on the same track. To the last part of your question in regard to how far apart physically are the channels on each disk, they are five thousandths apart.

W. L. Martin (Marchant Research): Does 838 typewriter have a mechanical matrix for automatic typing or are the keys each activated by individual solenoids?

Mr. Reitfort: They are activated by individual solenoids.

A. A. Cohen (Remington Rand UNIVAC): Please expand on how rotation is controlled in servicing waiting inquiry stations.

Mr. Reitfort: As each increase station makes a request, information is stored in relays. Once this station has completed its inquiry and released the typewriter, then we look to see what next station has a request for.

The IBM 650 RAMAC Inquiry Station Operation

HENRY A. REITFORT†

Quick Access Via Inquiry Station Typewriter

A FEATURE of the IBM 650 RAMAC important to "in-line" processing is the facility for quick access to the data processing system from remote locations without interfering with the daily routine. This interrogation of the RAMAC is done through the IBM 838 inquiry station typewriter from locations up to 500 feet from the computer. (See Fig. 1.)

The inquiry station typewriter provides transmission of data to the 650 system and automatic typing of data replies from the system. Up to 10 inquiry stations are available, arranged in one control or in two controls. Each control independently communicates with the 650 system through its own inquiry station synchronizer. Thus, by having two controls, up to twice the volume of inquiries can be handled. By proper programming of the two controls, inquiries and replies can be functioning from both controls at the same time.

Several operating keys and lights are located at each inquiry station which allow the operator to control the various functions of the machine. The unit also contains a regulated power supply and a small relay gate.

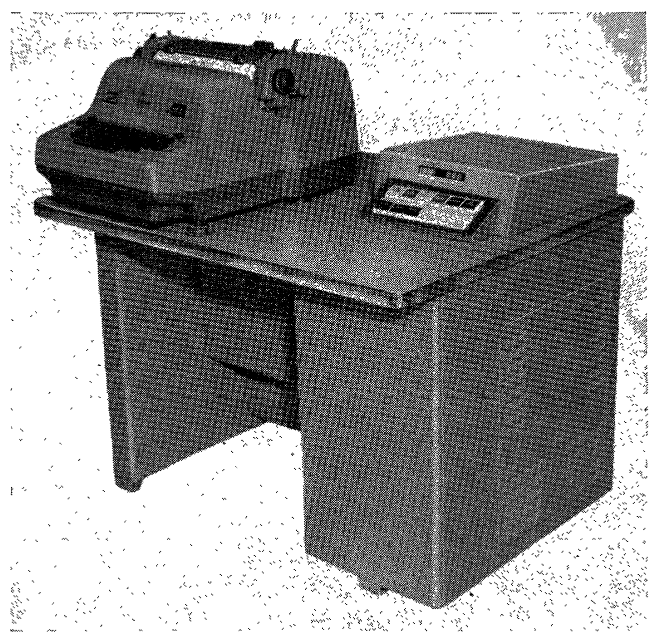

Fig. 1—838 inquiry station.

Flexibility of Inquiry Stations

The inquiry stations are completely flexible since they can inquire into any record in the 650 system. By means of the typewriter keyboard, data and instructions can be provided to the system. Automatic typing of replies to inquiries, miscellaneous messages, or productive output printing can be accomplished.

Each typewriter is addressable from the 650 program, thus an inquiry received from one station can reply at a different station, if desired. A program tape on each inquiry station provides for format arrangement of the inquiry and reply. The program tape also contains a control word that identifies the station and specifies the 650 program routine to be followed for the particular inquiry.

The inquiry stations are connected by multiconduc-

† Internatl. Business Machines Corp., Endicott, N. Y.