

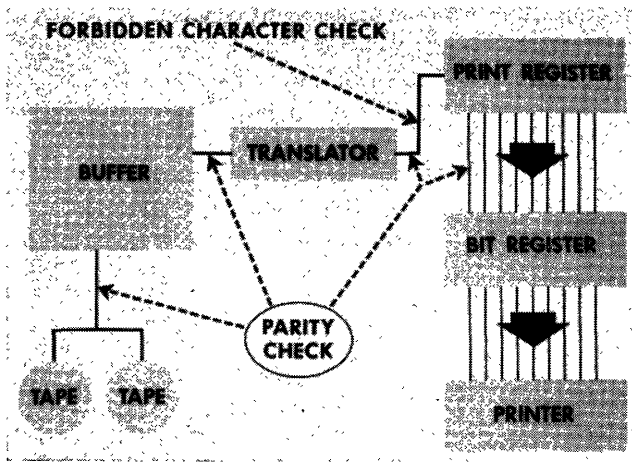


Fig. 14—System checking.

compared with the row counter when the latter's value is at zero. If the two are out of synchronization, the system automatically halts.

This is the only checking feature which cannot be ignored; the print check alarm is not available on the plugboard.

All error checking alarms that are available on the plugboard can be used to cause retries or brute-force operation which can be flagged on the printed page. Thus, in every case but one, the programmer, not the machine, decides whether an operation is to be halted or not. Oftentimes, the programmer will want to wire automatic restart procedures on the plugboard.

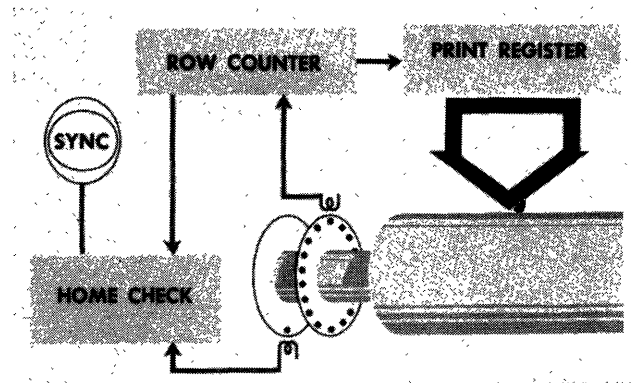


Fig. 15—Synchronization check.

Because of the versatility of the Burroughs 220 High-Speed Printer System, all operations must be programmed or wired. The operator effectively provides his own logical operations by wiring.

#### CONCLUSION

To summarize, the Burroughs 220 High-Speed Printer System offers a maximum of editing versatility with minimum plugboard wiring. More important, it allows swift, simple but complete rearrangement of buffer information—and eliminates the necessity for complex and time-consuming data shifting within the computer or the preparation of special print tapes.

Because of this flexibility and power, the printing problems of a wide range of applications can be solved with ease.

## The ACRE Computer—A Digital Computer for a Missile Checkout System

RICHARD I. TANAKA†

#### INTRODUCTION

THE effectiveness of a missile system is directly dependent upon the proper assembly and subsequent reliability of its various subsystems. A supporting checkout system which enables rapid, consistent, and thorough testing of subsystems is an essential item in insuring the over-all operational success of a complex missile.

This paper describes a digital computer which is used as the central controller in an automatic checkout system. The system itself is called ACRE, for Automatic Checkout and Readiness Equipment; the computer is

referred to as the ACRE computer. The ACRE computer is, essentially, a general-purpose, stored-program digital computer; particular capabilities, however, have been emphasized to enable efficient operation of the checkout processes.

The computer and associated system are required to perform functions which can conveniently be grouped as follows:

- 1) Monitor key quantities which indicate the existence of conditions hazardous to the missile or to associated personnel.
- 2) Perform detailed checkout on a newly manufactured missile system to inspect for proper operation or to diagnose possible causes of malfunction.

† Lockheed Missiles and Space Div., Palo Alto, Calif.

- 3) Perform tests on a standby missile system at periodic intervals, to verify tactical readiness. Again, if a malfunction is detected, a diagnosis is required.
- 4) Execute, rapidly, the test sequence required prior to firing. For possibly marginal systems, a quantitative measure of operational success probability is desirable.

It is possible, of course, to meet the above requirements by utilizing manual methods or special-purpose test devices. There are obvious disadvantages, however, to both of these procedures. The described digital computer enables efficient operation in all of the modes described above and affords the following salient advantages.

#### *Adaptability*

The system can easily adapt to changes in the missile, in the test procedures, or in the criteria used for evaluating results. If required, the system can be used to test differing kinds of missiles.

#### *Reproducibility of Test*

Once a test sequence has been established, there are no unwanted variations in the test procedure thereafter. The operational advantages of a special-purpose checkout device are obtained.

#### *Versatility*

In the event that particular test results indicate a system malfunction, the computer program enables a wide variety of alternate procedures to be followed. Some factors for determining alternatives are:

- 1) the importance of the malfunctioning subsystem;
- 2) the extent of the malfunction;
- 3) the particular test mode in progress (*i.e.*, a system in the process of standby check offers alternatives not available for a system which is being checked in preparation for firing).

Possible reactions to an indicated system malfunction might include a retest against less stringent test limits, halt of the test sequence, or automatic switching to standby system components.

#### *Automatic Sequencing*

By using a stored program which includes the procedures to be followed if a malfunction is detected, the test sequences become completely automatic in their execution. This feature is particularly valuable during countdown; the test times are accurately known, and human operator errors (which could easily occur during the stress of tactical countdown) are eliminated.

#### *Self-Diagnosis Possibilities*

As a corollary to the above, the computer also can be programmed to execute routines intended to monitor the operation of the checkout system itself. The rou-

tines can be commanded to occur at periodic intervals, or may be the first step following an indicated system malfunction (to verify that the missile system, not the checkout system, is at fault).

### GENERAL SYSTEM OPERATION

Fig. 1 illustrates the functional requirements for a general checkout system. The following operations are required.

#### *Select and Control Test Stimulus*

If a signal source is required as input to a subsystem or system, the appropriate signal generators are selected and adjusted to provide the proper levels.

#### *Select Input to Missile*

The test stimulus is then channeled to the proper input terminal of the system under test.

#### *Obtain and Convert Results*

The resulting output from the system (the test value) is converted, if necessary, from analog to digital form.

#### *Perform Comparison*

The test value is compared against previously established test limits.

#### *Evaluation of Test*

If the test value falls within the test limits, a "Go" result is obtained; if the test value falls outside the allowable limits, a "No-Go" result is obtained. These two possibilities determine the choice between two paths: a successful test or "Go" result causes the normal test sequence to continue; a "No-Go" result causes execution of evaluation modes as previously described.

#### *Documentation*

For later diagnostic purposes, it is extremely important that a detailed and accurate record be kept. Furthermore, the documentation process should be as completely automatic as possible.

#### *Display*

For supervisory purposes, a display panel of suitable information (test number, results, etc.) is required.

### GENERAL CHARACTERISTICS OF THE ACRE COMPUTER

The ACRE computer is designed to meet the functional requirements outlined above; further, since the checkout system must operate under tactical as well as laboratory conditions, requirements of reliability, maintainability and environmental suitability are also involved. In a very general sense, the machine satisfies the latter requirements with conceptually straightforward logical organization and carefully designed, conservatively operated circuits.

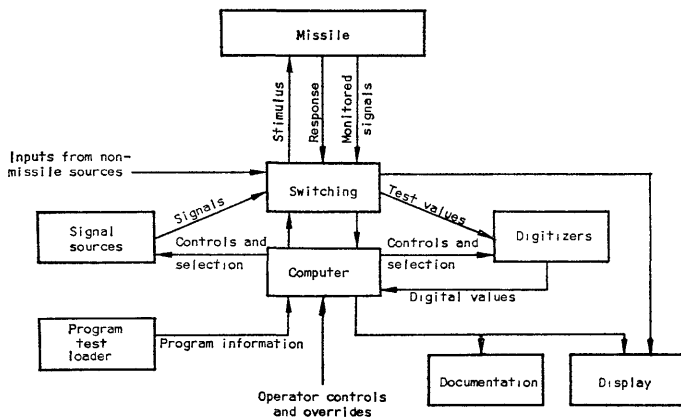


Fig. 1—Generalized checkout system.

### Physical Characteristics

The specifications on physical volume enable an overall assembly oriented toward accessibility and ease of maintenance. The computer circuits, on plug-in etched card assemblies 6×6 inches in size, are arranged in horizontal chassis in groups of 25. The chassis are wired into assemblies termed "pages"; two pages, forming a "book," comprise the computer.

The front of a page is shown in Fig. 2; the interconnection wiring is on the back of each page.

Fig. 3 illustrates the flip-flop card, which contains three transistorized flip-flop circuits. Diode logic gates are fabricated on similar cards.

The computer requires approximately 40 flip-flops, and operates at 100-kc clock rate. Physical dimensions are 20×20×56 inches high.

To aid in the maintenance of the computer, a special maintenance panel is attached, which includes: 1) a tester for the various circuit cards; 2) a memory simulator which allows static test of the computer with the magnetic memory disconnected; 3) controls which allow single clock operation and manual setting of flip-flops; 4) indicators attached to the individual flip-flops; and 5) voltage level switches for marginal checking.

Depending upon external system requirements (*i.e.*, tie-in with missile subsystems, various converters, etc.), as many as 30 additional flip-flops may be required. This quantity varies directly with the desired system performance requirements.

### Memory

The ACRE computer utilizes a rotating magnetic memory with an addressable capacity of 3904 words, 24 bits in length. These are organized into 60 channels, each with 64 words, and four faster access channels of 16 words each.

The memory also contains a nonaddressable 64-word channel which is used for automatic storage and output tape buffering for the later described documentation capability. Further, the clock pulses, sector reference information, and the various one-word registers are supplied by the magnetic memory.

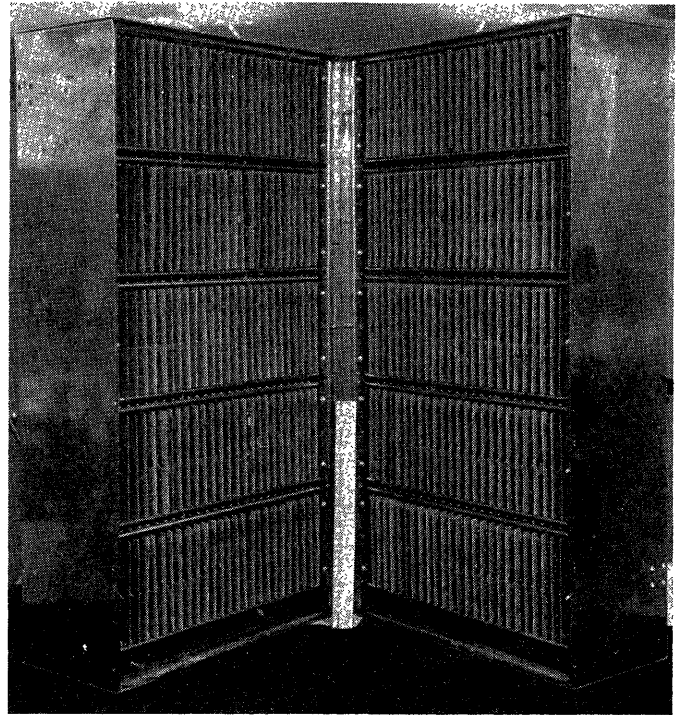


Fig. 2—ACRE book: front view.

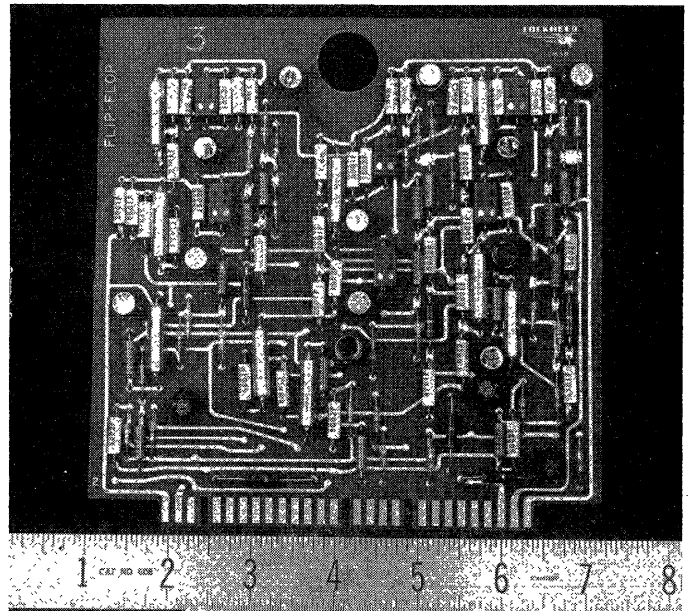


Fig. 3—ACRE flip-flop board.

The six 24-bit registers on the memory are: 1) the *A* register, the main arithmetic register in the machine; 2) the *D* register, an auxiliary arithmetic register; 3) the *B* register (Index register), used both for address modification and for tallying purposes; 4) the Order Counter, which specifies the address location of the next order to be executed; 5) the Address register, which stores the address portion of an order obtained from memory; and 6) the Documentation or *X* register, which receives information either from selected arithmetic registers or from an external keyboard, for eventual storage on magnetic tape.

### *Logical Organization*

An Order Counter is used to specify the normal program sequence; the order structure is single address. An order word contains a 5-bit command code, a 12-bit address (designated as *m*), and single bits each for parity, *B*-reference, documentation, and spacer.

Numerical information is represented as sign and magnitude (fractional binary), with single bits for parity and spacer.

The machine has a total of 25 commands; these can be categorized loosely as 5 arithmetic commands, 9 internal transfer commands, 6 control commands (jump to location *m* for various conditions), and 5 special commands which relate directly to the checkout requirements. (The latter 5 are included in the later description of special commands.)

### SPECIAL COMPUTER FEATURES

Miscellaneous features, which define some of the capabilities of the ACRE computer, are described below.

#### *Parity*

To detect malfunctions in the transfer and retention of information, word contents undergo automatic parity check during transfer. If a word is modified by arithmetic processes, a new parity bit is generated and inserted in the word. Parity error causes the computer to halt; the operator is notified by a suitable alarm indicator.

#### *Switching Matrix*

The ACRE system incorporates a switching matrix which is directly controllable by the computer. At present, a relay switching matrix is used, since the speed of the relay network is sufficient to meet existing system requirements. (Also, relays enable convenient handling of a wide range and class of test variables without elaborate preprocessing.) If desired, a solid-state switching network can easily be substituted.

#### *B Register*

As previously mentioned, an Index register is provided for automatic address modification and for tally uses. A one-bit in the *B*-reference position of an order word causes the contents of *B* to be added to the address portion of the order prior to execution.

For tally purposes, commands which increase or decrease the contents of *B* are provided. The decrease *B* command allows branching on the sign of *B*. The logic allows this command to be used either for branching each time until the final traversal of a loop, or for the opposite case of not branching until the final traversal.

Because of the similarity of many of the test sequences, the *B* register enables a significant saving in storage required. Since, for tactical operation, the program and all associated parameters are stored permanently on the memory, the inclusion of a *B* register (at a

cost of two flip-flops, associated logic, one read and one write amplifier) contributes much more than programming convenience alone.

### *Documentation*

The documentation feature enables automatic recording of all information pertinent to the checkout processes. Normally, the information to be stored on the output tape is specified by the program and hence is documented automatically; however, to enable the operator to insert additional information, input from a keyboard can be documented during intervals when the computer is idling.

During computation, a one-bit in the documentation code position of an order word causes information appropriate to the command to be documented (two examples: the sum for an addition command; the word transferred, for any of the various transfer commands).

This information progresses from the one-word *X* register into the 64-word special storage channel. When the channel is filled, the entire channel contents are transferred automatically to an output magnetic tape.

The output tape recorder uses magnetic tape 1 inch wide, on 8-inch reels, each with a total capacity of 5 million words of storage (each word 24 bits long). Cross-channel and longitudinal parity are automatically generated and recorded.

### *Display*

The progress of each test sequence is indicated by a panel of display lights. The display lights are addressable through the switching matrix; the operator receives a direct indication of the sequence in progress, and of test results obtained.

## INPUT-OUTPUT

### *Program Test Loader*

The magnetic memory is filled by the Program Test Loader, a demountable input device using seven-channel, punched paper tape. The Loader uses channel parity and cross-channel parity to check information pickup; as a further safeguard, the memory contents are automatically read back and verified.

For laboratory use, the Loader can be used as a normal input reader.

For tactical operation (where the test sequences presumably have been generated, tested, and then stored in their entirety in the memory), the Loader is disconnected. Disconnecting the Loader insures that no inadvertent modification of memory contents can occur. The stored routines are so designed that the operator is required only to monitor the results, or, in a few instances, to initiate sequences by push button control.

### *External Controls*

The operator is provided with a minimal selection of controls. These include Start, Stop, the documentation

keyboard, and Test Selectors. The latter are individual buttons which set the Order Counter to preselected configurations, enabling convenient manual selection of particular tests.

For maintenance purposes, controls affecting physical conditions, *e.g.*, single clock, marginal checking voltages, drum simulator levels, flip-flop set and reset switches, are provided. Further, a Function Switch enables selection among three modes of operation: Normal Operation, Single-Order Execute, and Breakpoint Operation (the last-named causes halt after execution of each command accompanied by a breakpoint code-bit).

#### *Output Display*

A numerical display device can selectively display the contents of the Order Counter, the *A* register, or the Documentation Register. The Order Counter display consists of four octal digits; the other two registers appear as sign and four decimal digits.

As previously mentioned, test indicators, primarily controlled by the switch matrix, are provided. These indicate, for example, status of various missiles, test in progress, subsystem under test, test results, etc.

#### DISCUSSION OF COMMANDS

The commands available in the ACRE computer have been mentioned in the description of logical organization. Seven of the 25 commands directly related to the checkout process are discussed in detail below.

#### *Compare (cpr)*

The contents of the *A* register are compared with the contents of *D*; if *A* is greater than *D*, the computer will transfer control to the order found in memory position *m*. Both registers remain unchanged. The comparison process is basic to the operation of the checkout system, and is required frequently. Hence, although the comparison, and transfer of control, can be performed by a subroutine, it is convenient to have the process available as a command.

#### *Switch (swc)*

Twenty bits in position *m* are transferred into the Switching Address Register. At the end of the transfer process, a signal to initiate switching is generated. The switching matrix proceeds to establish the connections specified by the 20 bits; the computer is free to proceed with the program. An interlock is provided, so that if switching is still in progress when a new switch operation is commanded, the computer will idle until the previous operation has been completed.

#### *Select (slt)*

The four least significant digits in the address code *m* are used to set the four flip-flops of the Select Register. The register contents then determine which item of external equipment is to be affected by subsequent commands.

#### *Conditional Adjust Test Equipment (caj)*

An item of test equipment, designated by the Select Register, receives the 12 bits of the address *m*. The bits are made available only after any previously commanded switching operation has been completed.

The selected equipment could be a signal generator whose output is adjusted by the 12 bits; it also could be an analog-digital converter, whose scale adjustments or whose turn-on signal is derived from the 12 bits. The switch interlock insures that switch connections pertinent to the operation of the selected equipment have been made before the equipment is activated.

#### *Unconditional Adjust Test Equipment (uaj)*

This command is similar to "caj" above, except that no interlocks with the switch operation are provided. This command is used when the desired connections are known to be made. The unconditional aspect insures that a simultaneous switching operation related to another test cannot inhibit an operation initiated by this command.

#### *Bring Test Equipment Output (bte)*

The output from an item of test equipment, designated by the Select Register, is read into *D* and also into position *m*. This command is used, for example, to obtain the output of an analog-digital converter for subsequent comparison against programmed limits.

#### *Halt (hlt)*

The Halt command causes the computer to idle. Simultaneously with the Halt, the Select Register receives the four least digits of the address code *m*. The machine will start automatically when one of the 16 signal sources, selected by the contents of the Select Register, turns on. This allows the checkout system to wait for the establishment of various conditions in the missile before proceeding with a test.

#### CONCLUSIONS

The ACRE system has demonstrated the feasibility of assigning to a digital device of the stored program class all of the central control requirements for a missile checkout system. The advantages inherent to a stored program have contributed significantly to the derivation and application of test sequences at all levels of missile operation, from manufacturing to field readiness to prelaunch countdown. The tests, in turn, are of paramount importance in insuring the highest possible degree of successful missile operation.

#### ACKNOWLEDGMENT

The writer wishes to acknowledge contributions by B. D. Leitner, P. W. Cheney, and L. D. Healy to the computer logical design. Circuit design and computer assembly were the responsibility of various members of the Lockheed Computer Research Department.