Maintenance and Reliability

The function of the AN/FST-2 has been described in simplified "block diagram" form. The actual design and operation of the machine is quite complex, as might be indicated by the size of the equipment and by noting that the radar PRF, the antenna rotation, and the telephone bit rate are asynchronous. This tends to make troubleshooting and signal tracing somewhat difficult.

The AN/FST-2 was designed using the "worst-case" philosophy to achieve reliability. In this approach, all circuit components are assumed to be at their "end-of-life" values simultaneously, in the worst direction for design purposes. For example, a 1 per cent resistor is assigned a design value 5 per cent from nominal in the direction which will make performance most marginal. This approach, combined with the use of the best available tubes, diodes, and other components, is expected to provide the optimum in equipment reliability attainable in the art today.

To facilitate machine checking and preventive maintenance, the AN/FST-2 incorporates a marginal-checking system and an extensive variety of internal check and test circuits. Many of the checks are continuous during normal on-line operation. In addition, a test simulator is provided. The simulator generates complex repetitive target patterns which completely exercise all parts of the AN/FST-2. At the maintenance man's discretion, it can also force the synchronization of the simulated radar trigger, azimuth, and telephone-pulse repetition rates.

Two displays are provided as part of the AN/FST-2 to permit on-line monitoring and to aid in maintenance. A PPI monitor can display various quantized video and detected target signals near the front end of the machine. A digital B Scope permits detailed examination of the range and azimuth coordinates of each target that is transmitted to the direction center. A random-access PPI (RAPPI) and associated word printer are also located at the radar site for output monitoring and recording. It is recognized that no matter how careful the design, good machine performance requires good maintenance, and considerable thought was, and is, being devoted to improving the maintainability and maintenance procedures for the AN/FST-2.

Conclusion

The AN/FST-2 Coordinate Data Transmitting Set is a vital link in the SAGE system for the air defense of the continental United States. Its function of "filtering" raw radar data and providing accurate target information to the SAGE Direction Center represents an important application of digital data processing equipment to the solution of real-time problems. Many units of the AN/FST-2 equipment have been produced and installed in the field. Their performance to date has been up to expectations.

Acknowledgment

The FGD and SAH/F functions for SAGE were conceived and initially developed at Lincoln Laboratory, Massachusetts Institute of Technology. Particular credit is due Group 24 of Lincoln Laboratory which was instrumental in the early program and provided the essential transfer of know-how which resulted in the production equipment.

The authors are also indebted to the many people of the Burroughs Corporation who made significant contributions to the successful development of the AN/FST-2.

Operation of the SAGE Duplex Computers*

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Introduction

LARGE SCALE digital computers perform the routine control and data-processing functions of SAGE direction centers. For practical air defense, the SAGE direction centers must operate around the clock, a goal not yet achieved by present-day computing equipment. In order to achieve 24-hour-per-day operation, two identical computers are provided at each center. One computer (the active computer) operates the direction-center program. The other computer (the stand-by computer) is available for preventive maintenance and a limited amount of routine data processing. The functions of the two machines are interchanged by switching the direction-center inputs and outputs from one machine to the other. Thus, if the active computer fails, the task of operating the direction-center program can be transferred to the stand-by

* The research reported in this paper was supported jointly by the U. S. Army, Navy, and Air Force under contract with Mass. Inst. Tech. and the IBM Corp., Kingston, N.Y.

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machine, and as far as the direction center is concerned, computer "down time" is reduced to those periods when both machines are simultaneously inoperative.

Unique to the duplex installation are the equipment design features that accomplish switching direction-center inputs and outputs, and those that provide communication between the two computers. The duplex switch (which is manually operated) transfers external input and output communication lines, inputs from direction center operators, and control of the display equipment from one computer to the other. The switching facilities are shown in Fig. 1. Each computer can read or write upon its own intercommunication drum, and can read from the other computer's intercommunication drum. These drums permit the transfer of large amounts of data from one computer to the other. The intercommunication lines terminate in sense units (flip-flops) whose conditions (0 or 1) are controlled by one computer and sensed by the other. Thus the intercommunication lines enable the program operating in one computer to determine that a given event has occurred in the other. These lines are primarily used to synchronize the programs operating in the individual computers. The alarm lines, like the intercommunication lines, terminate in sense units. Thus an overflow, memory parity, or drum-parity alarm occurring in one computer can be detected by the program operating in the other. The alarm signals from one computer can also be utilized to interrupt the operation of the other. The settings of certain switches, located on the operating console, determine whether an alarm signal originating in one computer will be ignored by the other, or will cause the other to stop or branch to test memory. The intercommunication facilities are shown in Fig. 2.

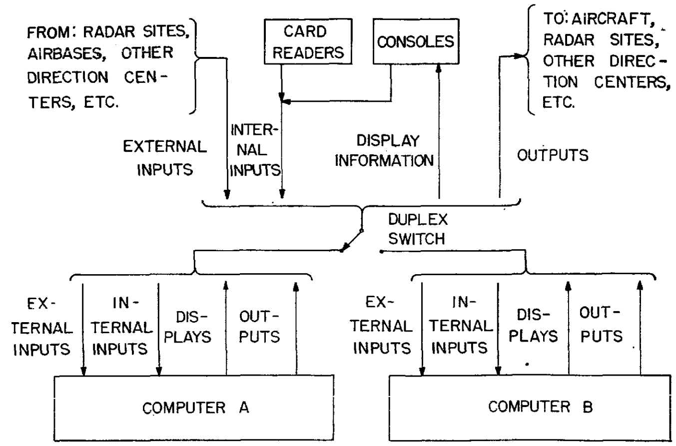

Fig. 1—Switching facilities.

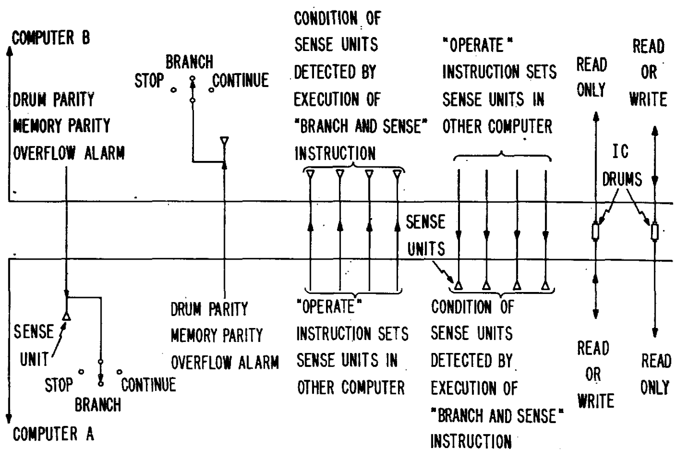

Fig. 2—Intercommunication facilities.

The primary task assigned to the active computer is the operation of the direction-center program, and that assigned to the stand-by computer is the operation of maintenance programs. These are the so-called simplex functions of the active and standby machines. In addition, each machine performs certain functions unique to a duplex installation. These functions are directed toward insuring minimum interruption of direction-center operation, should an interchange of computers (switchover) be required. The remainder of this paper is devoted to a discussion of the duplex functions performed by each computer, and to a discussion of the switchover process itself.

Duplex Functions of the Active Computer

Continuity of direction-center operation can be retained after switchover if data representative of the current air situation can be made available to the newly active computer. Part of these data, generated by the previously active computer and stored upon the magnetic-drum fields of that computer, represents a myriad of decisions and manual actions made by the Air Force personnel who operate the direction center. Loss of these data during switchover would necessitate repetition of these decisions and actions, resulting in a transient degradation of direction-center operation. The duration of the transient would depend upon the complexity of the air situation at the time of switchover. This transient period is minimized by maintaining certain key data upon the drum fields of both the active and stand-by computers. Thus, an up-to-date summary of the air situation is available to the direction-center program immediately after switchover.

The summary air-defense data stored in the stand-by computer are periodically assembled by the direction-center program operating in the active computer, and transmitted to storage in the stand-by computer via the intercommunication-drum system. The amount of data transferred is limited by the program operating time available in the active computer, and the drum storage available in the stand-by computer. Operating time is a critical factor because the direction-center program is part of a real-time control system, and any increase in operating time degrades over-all system response. The drum storage available in the stand-by computer is limited by the storage requirements of the stand-by programs.

The nature of the summary air-defense data can best be discussed in terms of the types of data tables used and generated by the direction-center program. There are four broad categories of data tables: input, output, display, and central.

Input tables contain data awaiting processing by the direction-center program. These data are generated at external sources (*e.g.*, radar data), and by the Air Force personnel within the direction center. Output tables and display tables contain data awaiting sequential transmission to locations outside the direction center (*e.g.*, air bases), or display to direction-center operators. No portions of the input, output, or display tables are transmitted to the standby computer for storage as summary air-defense data. The net result is loss of direction-center operation during the switchover period. If this period is short, the effect is not serious, because the input data are accumulated again after switchover, and the display and output tables are regenerated by the direction-center program itself. The central tables, on the other hand, are the heart of the air-defense program. In a broad sense they represent a mathematical model of the air situation on which the operation of the direction center is based. It is the central tables, or more specifically, the key portions of the central tables that are transferred to the stand-by computer as summary data.

The only other duplex function of the active computer is that of monitoring the intercommunication lines to determine if a scheduled switchover is to take place. The program operating time required to accomplish this monitoring function is negligible. The switchover process itself will be discussed later.

Duplex Functions of the Standby Computer

The stand-by computer must operate maintenance programs, and at the same time be readily available for operation of the direction-center program. Certain duplex functions, then, must be performed by the stand-by computer:

1) Monitor active-computer alarms,
2) Maintain the direction-center program on the stand-by computer drum fields,
3) Transfer and store summary air-defense data assembled by the active computer,
4) Monitor operator-inserted switch requests controlling standby operations,
5) Prepare digital displays indicative of the status of standby computer operation.

Only the first of these functions (alarm monitoring) is an equipment function; the others are programming functions.

Memory parity, drum parity, or arithmetic overflow alarms that occur in the active computer cause an automatic branch of program control to test memory in the stand-by computer. The sequence of instructions in test memory initiate preparation of the standby computer for switchover. Preparation for switchover includes erasure of all maintenance programs and tables from core and drum storage, restoration of the direction-center program upon the stand-by drum fields (if necessary), and a final transfer of the summary data from the active machine. Having completed preparations for switchover, the stand-by computer simply waits for switchover to occur, or for a manual intervention to restore normal stand-by status.

Maintenance of the direction-center program on the standby computer's drum fields permits rapid recovery of direction-center operation after switchover. The fact that the direction-center program is properly stored is verified by reading each program drum field into core memory, computing the sum of the binary numbers stored on the drum field, and comparing the result with the correct sum (also stored on the drum field). If the computed sum is incorrect, the offending drum field is reloaded from magnetic tape. The process of checking and loading the program drum fields occurs automatically whenever a maintenance program has destroyed the contents of a program field, or whenever preparation for switchover is initiated by an active computer alarm. It can also be requested by a manual switch action.

The duplex functions of transferring summary air-defense data, monitoring operator switch actions, and the preparation of digital displays are executed periodically. The frequency with which these functions are performed depends upon the mode of operation of the stand-by computer. One of three modes may be selected. Each provides a different frequency of execution of the periodic duplex functions, in the range of once every few seconds to once every few minutes. This requirement for interleaving simplex and duplex operations imposes stringent requirements for manual and automatic control of the maintenance programs. Control of the sequence of operation of maintenance programs, and selection of the mode of stand-by operation is accomplished by manually-inserted operator-switch actions. The running time of each maintenance program is known to the stand-by control program, and either manual or automatic selection of long running maintenance programs is automatically prevented if the selected mode of stand-by operation requires frequent execution of the periodic duplex functions. In order to relieve this running-time restriction on the selection of maintenance programs, the programs are designed as a collection of program units to permit operation of long running maintenance programs by operating them one program unit at a time.

Switchover

Switchover requires transfer of direction-center inputs and outputs from the active to the stand-by computer, and activation of the direction-center program in the stand-by computer. Preparation of the stand-by machine for switchover is initiated automatically by an active computer alarm, or manually by an operator switch action. After the stand-by computer has completed its preparations for switchover, and after the duplex switch has been operated, control of the stand-by computer is transferred from the stand-by control program to the startover program. The startover program performs the function of activating the direction-center program in the standby computer, and thereby completes the transition of that machine from standby to active operation.

Two modes of switchover have been provided. The emergency switchover mode is used when switchover occurs after the active computer has become inoperative. The scheduled switchover mode is used when both machines are in operating condition at the time of switchover. The major difference between these two modes is in the amount of air-defense data that is made available to the stand-by computer. Normally, only summary air-defense data are available upon the drum fields of the stand-by computer. As was mentioned before, these data are transferred to the stand-by computer periodically, and the amount of data that can be transferred is limited by the computing time and storage-space restrictions imposed upon a periodic operation. In short, program operating time is not available to transfer a voluminous amount of data during each cycle of the direction-center program. If, however, switchover is scheduled when both computers are operating, more complete data can be transferred as a "one-shot" process during switchover. This wholesale transfer of data is accomplished by interrupting operation of the direction-center program just prior to switchover, and transferring the contents of the central tables and display tables from the drum fields of the active computer to the corresponding drum fields of the stand-by computer. Proper timing of successive drum transfers is achieved by signals transmitted between computers via the intercommunication lines.

The following conditions describe the status of the stand-by computer at the time that control is transferred to the startover program.

1) The direction-center program is properly stored upon the drum fields of the stand-by computer.
2) The summary air-defense data are stored upon one stand-by drum field.
3) All traces of stand-by program operation have been erased from core and drum storage.
4) In the case of emergency switchover, all program tables are cleared.
5) In the case of scheduled switchover, the air-defense information transferred from the active computer is stored on the proper table drum fields.

Completion of the switchover process requires that the startover program process the air-defense data stored in the stand-by computer to make it usable by the direction-center program. The startover program then transfers the control portion of the direction-center program into the core memory of the stand-by computer, and transfers computer control to the direction-center program.

Sorting and extrapolation of air-defense data are performed by the startover program. In the case of emergency switchover, only summary data are available to the stand-by computer. These data, which were gathered from several central tables, occupying different drum fields in the active computer, are packed together upon one drum field in the stand-by computer. The startover program sorts these data and distributes them among the appropriate stand-by table drum fields. In the case of scheduled switchover, the air-defense data are already stored upon the proper standby drum fields, and the sorting process is unnecessary. The extrapolation process performed by the startover program adjusts the air-defense data to compensate for the program operating time lost during switchover. The process is primarily a matter of extrapolating the position of aircraft tracks along their last known velocity vectors.

Future Developments

The duplex problem is that of determining how best to utilize two computers to enhance direction-center reliability. A secondary consideration is that of determining how to make efficient use of the stand-by computer without jeopardizing the primary requirement that it be readily available to perform air defense. When more information has been gathered regarding maintenance requirements, and when maintenance techniques have been perfected, it may be possible to utilize the stand-by computer for a limited amount of data processing, or for simulation of battle conditions during training exercises. Such applications must, of course, be designed within the ground rules established by the primary requirements of adequate stand-by computer maintenance, and availability for rapid switchover.