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A RELIABLE SYSTEM FOR SWITCHING CIRCUITS BETWEEN ON-LINE AND OFF-LINE SWITCHING COMPUTERS

Kenneth D. Beach, et al.

Goddard Space Flight Center
Greenbelt, Maryland

June 1967

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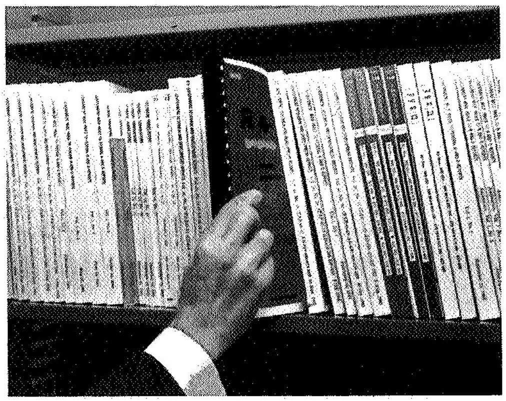

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A RELIABLE SYSTEM FOR SWITCHING CIRCUITS BETWEEN ON-LINE AND OFF-LINE SWITCHING COMPUTERS

Kenneth D. Beach
Vaughn E. Turner
Communications Engineering Branch

June 1967

GODDARD SPACE FLIGHT CENTER
Greenbelt, Maryland

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A RELIABLE SYSTEM FOR SWITCHING CIRCUITS BETWEEN ON-LINE AND OFF-LINE SWITCHING COMPUTERS

INTRODUCTION

The National Aeronautics and Space Administration's (NASA) communications network (NASCOM) provides operational communications lines and facilities for transmitting mission-related information on NASA programs and projects. The basic NASCOM arrangement provides all NASA mission control, technical control, and computation centers with access to the remote tracking, data-acquisition, and command stations. Access for launch, insertion, orbital flight, deep-space flight, and recovery operations is provided by communications channels between the primary NASCOM switching center at the Goddard Space Flight Center (GSFC) and remote NASCOM switching centers. The primary switching center provides central communications operations and control and, with the remote switching centers, primary circuit-sharing of costly overseas circuit facilities to the maximum degree consistent with requirements of the various NASA missions.

NASCOM originated in early 1958 when point-to-point teletypewriter services were established in Africa, South America, and Australia to support Project Vanguard. In early 1961, the Mercury network of radar tracking, telemetry, and command stations was set up with central communications-control facilities at GSFC. This network included full-period leased point-to-point teletypewriter and voice circuits which interconnected the tracking stations with the control and computation centers.

In 1964, NASCOM was established as an entity to provide unified communications management and control of all operational ground communications systems which support the satellite tracking and data-acquisition network (STADAN), the deep space network (DSN), and the manned space flight network (MSFN). These three networks support manned spacecraft as well as unmanned scientific satellites which orbit in space between the earth and the moon or perform missions to or near other planets in the solar system.

The nature of existing programs and future programs and missions requires frequent additions, modifications, and improvements to the NASCOM network; the introduction of central spacecraft command and control requires reliable communications services. Economic considerations and the high-reliability requirement created a compelling need for sharing the communications facilities of STADAN, DSN, and MSFN. This led to the concept of a primary switching center which would permit optimum circuit-sharing and flexibility, making total NASCOM communications resources available if isolated circuit malfunctions occur.

The global NASCOM network now contains over one million miles of services operating on a full-period basis, including:

- 400,000 circuit miles of teletype facilities
- 140,000 circuit miles of voice-only telephone facilities
- 450,000 circuit miles of alternate voice/data telephone facilities
- 10,000 circuit miles of data-only telephone facilities
- 10,000 circuit miles of wideband facilities

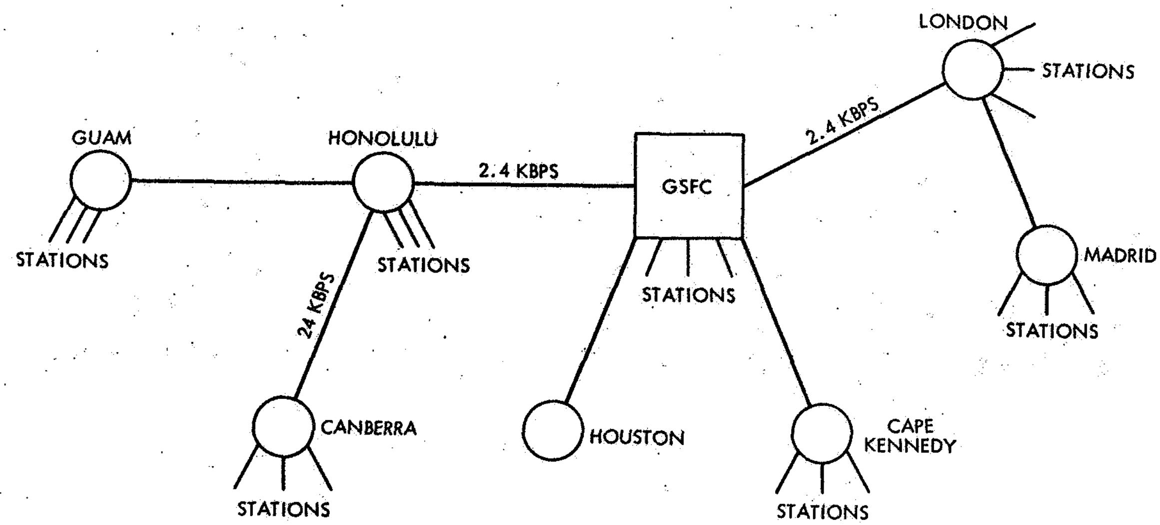
More than 100 locations throughout the world use various combinations of these services in support of NASA activities.

Initially, the communications network used a central torn-tape (manual tape relay) system (Western Union 111B) along with its associated technical control facility. Therefore, communications support was not in real time; messages were delayed an average of 5 to 10 minutes, with some delays as long as an hour or more. For Project Mercury, the torn-tape system was supplemented by a system (Western Electric 83B2) which used tape store-and-forward on an automatic basis and which used torn-tape for nonstandard messages. Although it contained more automatic features, the new system still did not provide real-time support of all NASA activities. Messages were delayed from seconds on the average to several minutes.

In 1964 more sophisticated equipment was installed at GSFC,* London,** and Canberra** (Figure 1) to accommodate increased real-time requirements of the satellite tracking networks.

The new fast store-and-forward systems, using dual redundancy to meet reliability requirements, permit as near-real-time support of NASA communications activities as is possible.

*Univac 490-494 system
**Univac 418 system



NOTE: THE 2.4 KBPS INTERCENTER TIES ARE TIES BETWEEN GSFC COMPUTERS AND ANCILLARY COMPUTERS AT THE VARIOUS CENTERS.

Figure 1. NASCOM Prime and Ancillary Switching Centers

GENERAL SYSTEM DESIGN PROBLEM

The fact that each center has two sets of computers and peripherals resulted in a decision to treat each main-frame computer and its peripherals as either on-line or off-line. The on-line computer is the computer which is actually communicating with the network; e.g., both input and output functioning normally. The off-line computer is the computer which is not outputting to the network although it is receiving from the network. During nonmission periods, the off-line computer may also do debug routines, or may undergo maintenance checks or service. The off-line computer in normal monitoring service has a complete set of peripherals with the same capacity as the on-line computer peripherals.

An internal transfer arrangement can transfer any peripheral from one of the dual computers to the other. Although the internal transfer provided for component failure within the computer complex, it could not transfer the entire on-line/off-line system if either system failed or if maintenance was required. A transfer arrangement external to the computer system was therefore necessary to perform this function.

An attempt was made to integrate this function into the computer programs. However, this scheme was unreliable; if one computer failed, it would not necessarily be able to tell the other computer to take over the operation and might even cause the second computer to fail.

As an interim solution, a system of transferring by circuit patching was implemented and used for nearly a year before it was discontinued. This patching system required four patching operations on any circuit in the network in order to transfer that circuit between the on-line and off-line computers. At that time, the NASCOM teletype network consisted of approximately 100 full-duplex circuits; a single transfer therefore required approximately 400 patching operations. These operations required up to 5 minutes for the three technical controllers on duty during normal working hours. The time required to perform an external transfer under this system was incompatible with the real-time concept of NASCOM when the on-line computer complex failed. Besides the loss of real-time response to emergency conditions, the number of required patching operations made the transfer system prone to errors and thus undesirable. It was then decided that a new, more nearly automatic transfer system should be designed.

SYSTEM DESIGN APPROACH

The systems design was approached from the view that, at any given time at each of the switching centers, either the A complex or the B complex will be on-line and its alternate will be off-line. It is not necessary that the on-line system consist entirely of the A system or the B system; internal transfer switches within the computer complex may be in effect because of equipment failure or other reasons.

An on-line computer system will be actively switching data on a network whose configuration may vary from minute to minute. An off-line system at any given time may be: (1) receiving traffic from the circuits but inhibited from outputting, (2) inoperative and receiving maintenance, or (3) testing new programs which may require patching in a different configuration from that of the on-line system.

For these reasons, two groups of jacks were added to the technical control facilities which support the computer complexes. One field of jacks was to be used with the on-line system at all times, regardless of which computer complex (A or B) was on-line (Figure 2). The second group of jacks was assigned to the off-line system. One jack of each group was assigned to the transmit side of a given line and one was assigned to the receive side.

A system for transferring the A and B computer complexes was added to the on-line/off-line jack groups. The transfer system had to be as simple as possible to operate, essentially instantaneous, and more reliable than the total computer complex. The transfer-system connections to the computer were

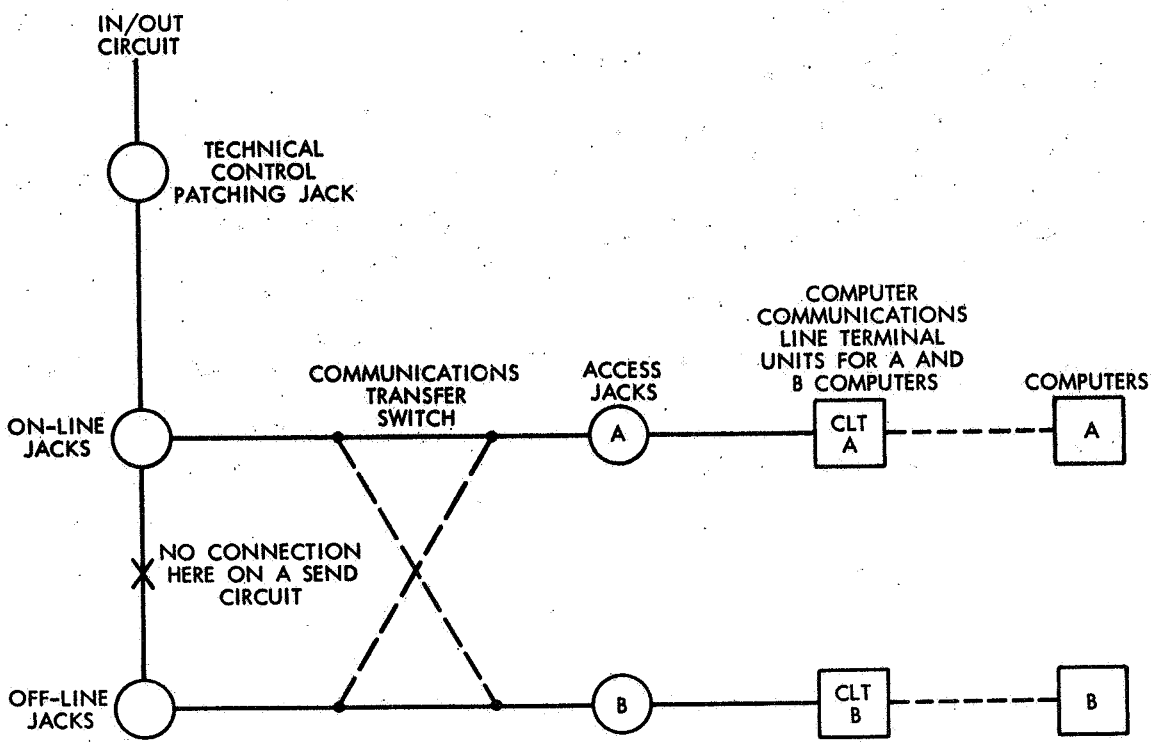


Figure 2. Transfer System for an Individual Simplex Circuit

wired back to the technical control jack fields where two additional groups of jack fields were assigned: one for direct access of the communications line terminals (CLT) on the A complex and the other for direct access of the B complex CLT's.

The access jacks permit testing of the CLT's when necessary, manual bypassing of the transfer system should a catastrophic failure of the entire system occur, or bypassing of a single circuit if it fails to transfer with the other circuits in its group. The transfer switch is bypassed by a manual patch.

Control of the transfer system was based on the possible operating configurations for the computer complexes. The CLT's connected to each line are time-shared with the other 31 CLT's onto one of the central processor computer I/O channels in a multiplexer group. The control system permits the entire group of 8 multiplexers to be transferred at any one time by the operation of a single control button, thus transferring an entire system from on-line to off-line or vice versa. Also provided is the capability of transferring an individual multiplexed group of CLT's in the event of an internal computer transfer of any multiplexer from on-line to off-line or vice versa. If necessary, a single circuit can be transferred by the operation of a control button which controls only its associated transfer device. The reliability of the system was improved by the use of redundant fusing and powering and by the capability of manually bypassing any failed component in the system.

TELETYPE-TRANSFER SYSTEM

The teletype-transfer switch is entirely electromechanical, using class E telephone relays. The teletype system at all the switching centers is a ground-isolated 60-milliampere 120-volt interface. All equipment except for the battery plant must therefore have its signal input and output leads isolated from ground. The ground-isolation requirements were the reason for avoiding the use of a more advanced solid-state technique whose cost could become prohibitive. The ground-isolation requirement also means that all transfer devices must be on a two-wire rather than a single-wire basis in the transfer system.

The transfer system for the teletype network at GSFC has a maximum capability without modification of transferring 256 full-duplex circuits at one time, or transferring 32 at a time (the quantity of CLT's on a multiplexer). This teletype-transfer system was designed so that no single failure could completely incapacitate it and so that, with the worst-case common equipment failure, the longest time to complete corrective action would be a few minutes. During total loss of power, the system will revert to a preselected computer complex on-line.

The on-line and off-line jack configurations, which are standard for teletype applications, are assigned to both the send and the receive sides of the full-duplex circuits (Figure 3). The equipment terminals of the jacks are then wired to the on-line and off-line terminals of the transfer switch relay associated with the circuit to which the jacks are assigned. All jacks are series-wired. Besides connecting the transfer relays to the circuits, this jack arrangement provides the capability of patching CLT's to different circuits when desired.

The design of the transfer switch uses standard plug-in telephone relays for the transfer device. The transfer switch uses one of these relays for each circuit, a single relay handling both the send and the receive side of its assigned circuit. The relay connects the on-line jacks to the A system and the off-line jacks to the B system or vice versa. Power for each of the 256 transfer relays is supplied by dual 24-volt power supplies which in turn are powered by dual 208-volt, 3-phase, 60-hz primary power sources.

The large quantity of relays used required special considerations as to the contact current-driving capability of the driving source (Figure 4): this problem

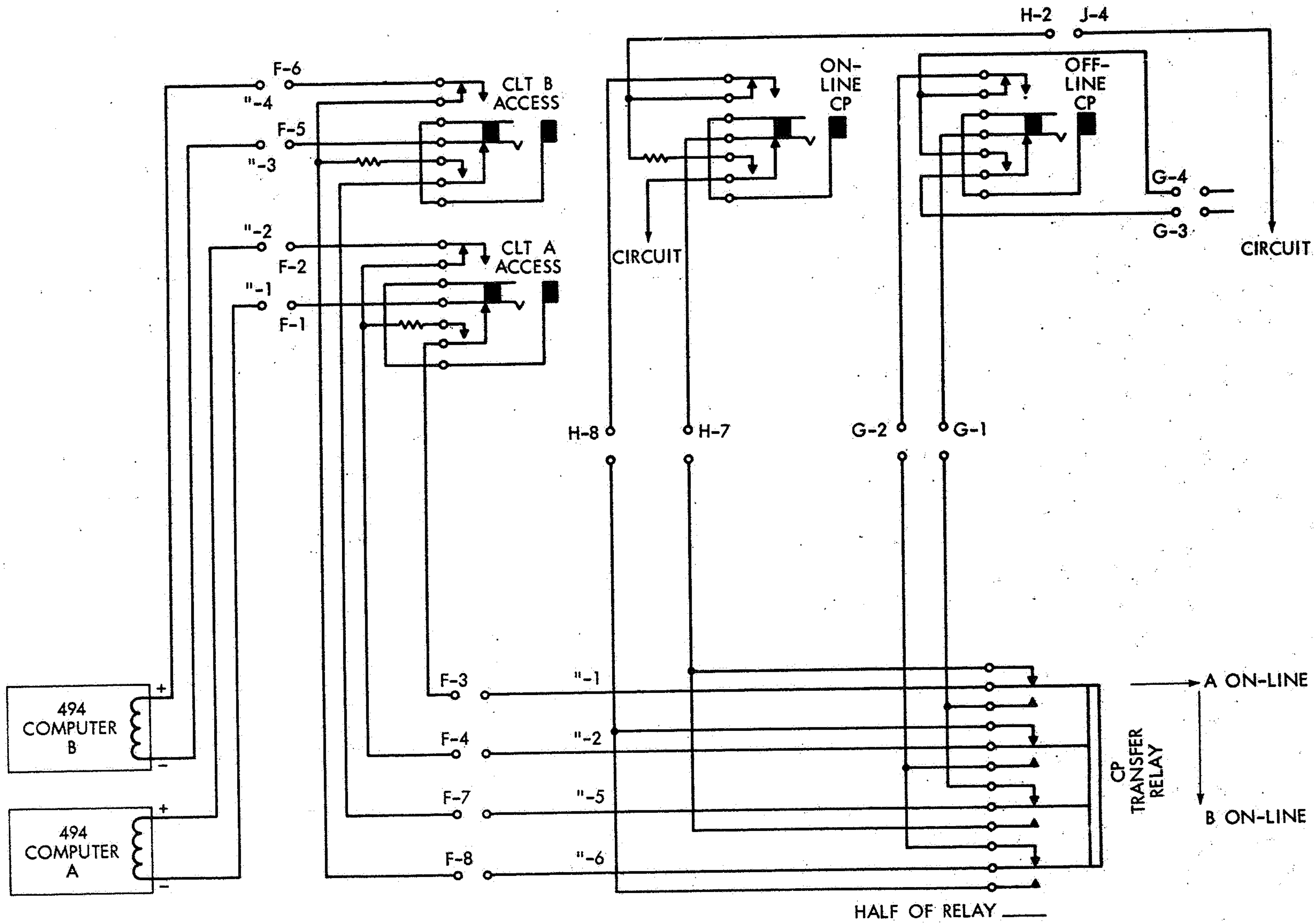
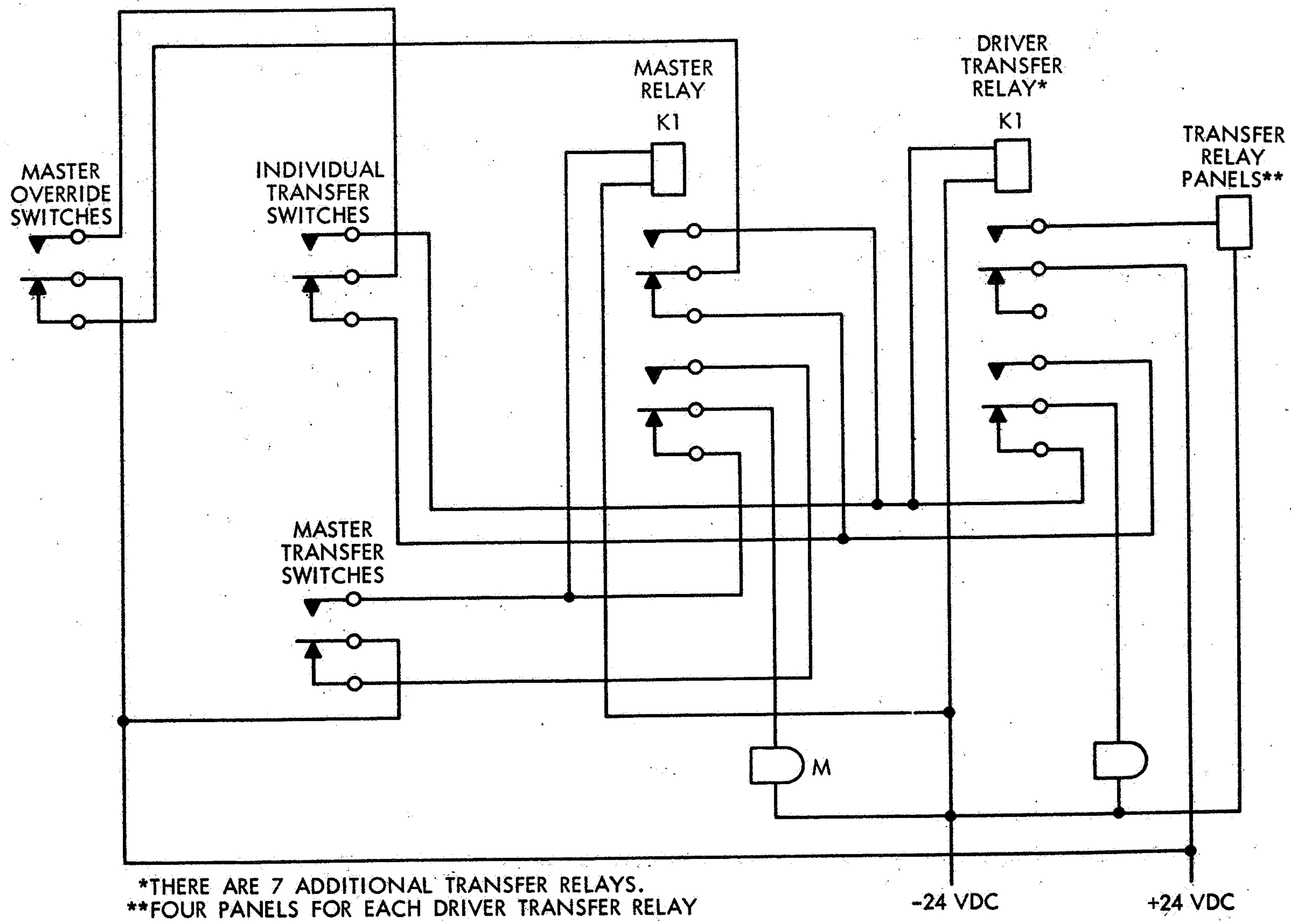


Figure 3. Teletype-Transfer System, Schematic Diagram



*THERE ARE 7 ADDITIONAL TRANSFER RELAYS.
**FOUR PANELS FOR EACH DRIVER TRANSFER RELAY

Figure 4. Transfer System, Schematic Diagram

was solved by using a tree structure in the control system for operating the relays. The control system also supplies the necessary logic for driving the relays, which will be described later in more detail. Leads of the transfer relays connecting to the computer complexes are applied to the access jacks, which are also arranged in a standard configuration. The transfer relay output leads are applied directly to the line side of the jacks, and the computer CLT leads are applied to the equipment side of the jacks, thus providing a direct access to the computer CLT's.

The transfer switch control system gives and indicates commands to the transfer relays and provides the drive capability for the individual transfer relays. The transfer control system uses Automatic Electric class E plug-in relays identical to those in the transfer system. Each panel contains eight transfer relays and has an associated fuse in the power supply system so that loss of an individual fuse will affect the transfer capability of only eight circuits. Each panel of relays also has its own source of drive current from the control system so that contact failure in the driving circuit will affect only eight circuits.

Each driver relay controls only four panels of transfer relays; if a driver relay fails, the maximum number of circuits affected is 32. There are 32 corresponding teletype circuits per multiplexer. An individual switch at the driver relay controls the transfer of an individual multiplexer. A total of eight driver relays controls all 256 transfer switch relays of the 256 teletype circuits.

Each driver relay can be optionally driven by a contact on one of the two master control relays. This option, provided by a switch on the control console, permits the master relays to be overridden if one of them fails or if an individual multiplexer transfer is required. The master relays have a contact for each driver relay so that failure of a master control relay contact will affect only one multiplexer group of 32 relays. A single switch, which permits all 256 teletype circuits to be transferred at once from the on-line to the off-line computer complex, drives the master control relays. For additional assurance, when a command is sent to the transfer control system, the transfer control system confirms completion of the command to the operator at the control console by means of indicator lights. An alarm system (a bell and alarm lights at various critical locations) is activated when an order is not completed.

DATA-TRANSFER SYSTEM

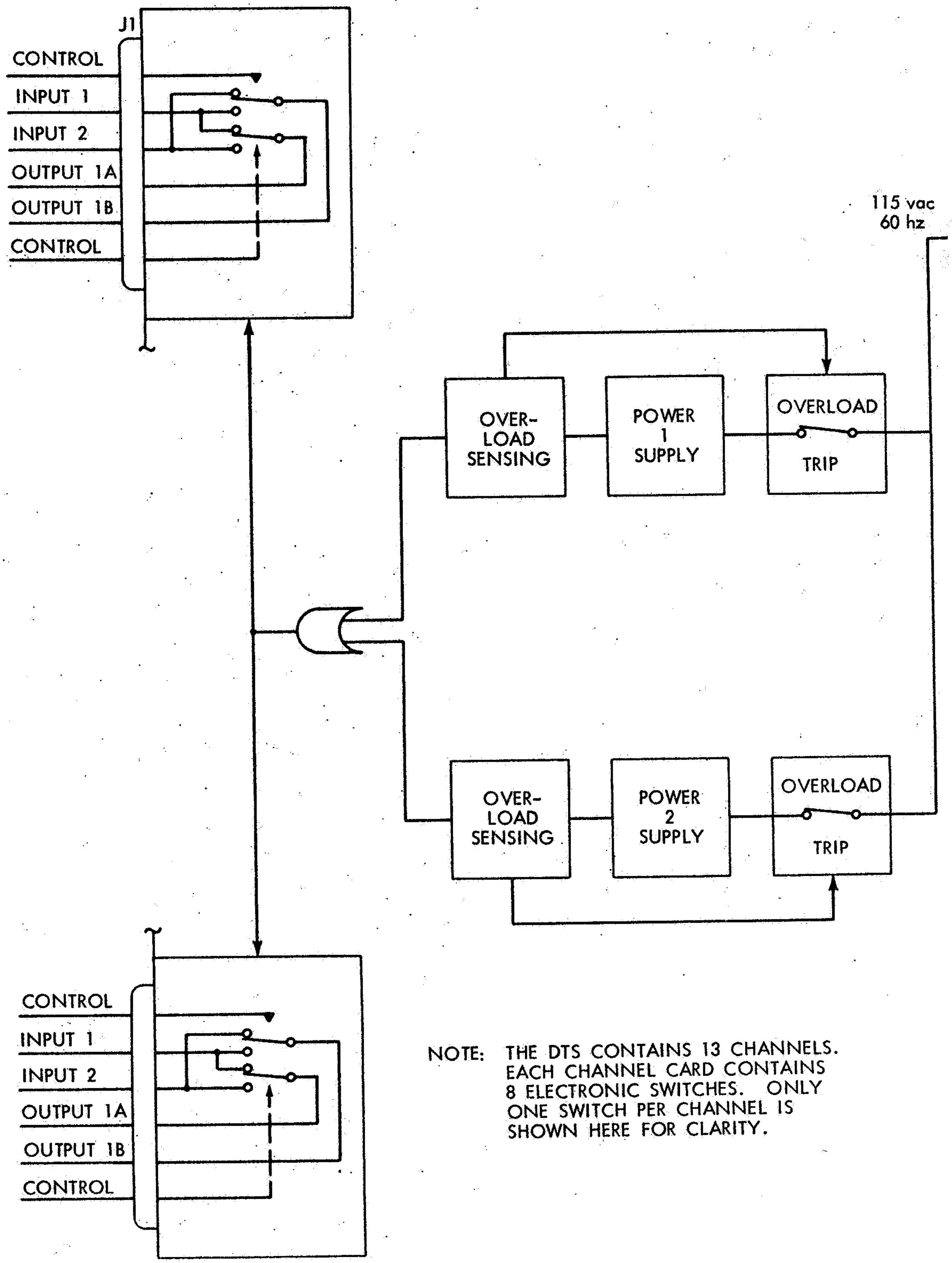
The system used for switching 600-, 1200-, and 2400-bit-per-second data circuits is called a data-transfer switch (DTS). The DTS permits switching the data modem dc interface signals to either of two multiplexers, and connects the other multiplexer to a set of off-line jacks. This permits selection of circuits from one multiplexer to the other and use of the off-line multiplexer for tests.

The DTS is a solid-state device containing individual switch circuits for eight signals which must be switched in a full-duplex data modem interface. Of the eight switches (Table 1), four are Electronic Industries Association RS-232B interface circuits, and the other four are compatible with Military Communications System Technical Standards MIL-STD-188-B. A ninth line is provided for signal ground. Each group of eight switch circuits is controlled by the polarity of a control voltage from the master control console. Each DTS contains 13 sets of eight switching circuits; each set of eight switches is a plug-in module. Two power supplies are provided for fail-safe redundancy; should one supply fail, the other will instantly take over, thereby minimizing data loss. Input and output connections to the DTS are 13 connectors mounted on the rear of the unit.

Figure 5 is a functional block diagram of the DTS. The inputs from two CLT sources are applied to each of 13 channel cards. (Figure 5 shows cards for channels 1 and 13 only.) In order to handle all the interface circuits, each card contains eight electronic switches similar to the one shown. Each switch is made up of two AND gates, one OR gate, a voltage amplifier, and a driver stage with overload protection. Two signals generated by the master control

Table 1
Design Specifications for Signal Leads

Signal Name	Design Specification
Send data	MIL-STD-188B
Receive data	MIL-STD-188B
Send clock	MIL-STD-188B
Receive clock	MIL-STD-188B
Request to send	RS-232B
Clear to send	RS-232B
Data set ready	RS-232B
Spare	RS-232B



NOTE: THE DTS CONTAINS 13 CHANNELS. EACH CHANNEL CARD CONTAINS 8 ELECTRONIC SWITCHES. ONLY ONE SWITCH PER CHANNEL IS SHOWN HERE FOR CLARITY.

Figure 5. Data-Transfer Switch, Schematic Diagram

console actuate the transfer-switching function which can route inputs 1 and 2 either directly to the A and B outputs respectively, or to the B and A outputs respectively.

CONCLUSIONS

The teletype-transfer system has been installed and operating for nearly 2 years with a total down time of 8 hours; however, the flow of traffic through the computer switching systems was interrupted for only about 5 minutes. The lone trouble was identified as a broken wire in the control system which caused loss of control of three multiplexer systems. This has been the only major failure of the system to date, but several minor failures have affected individual circuits without much effect on NASCOM as a whole. The high-speed data-transfer switch now being installed is expected to have the same reliability as the teletype system on a per-circuit basis. The control system for the data and teletype transfer will, of course, have the same reliability because a common control system is used.

In all cases of failure experienced on the transfer system, operators at the technical control facility have been able to restore the system to operation within 5 minutes of the discovery of the failure. The make-good time is considerably shorter in single-circuit failures; recovery is usually accomplished by use of bypass patching, because the trouble is most frequently the failure of a single circuit to transfer. Any failure resulting from a master control failure may be corrected by switch overriding of the master transfer control circuit, although this failure has not been experienced as yet.

The teletype-transfer system has met all mission requirements placed on it to date, and has been able to meet the requirements of all required test configurations. The data-transfer system is expected to be equally reliable. Use of the transfer system has usually required the operation of only one switch; when more than one switch has been used, it has been because of an unusual operational configuration of the computer complexes where a failure has occurred in one of the multiplexer cabinets.