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Design of an Automatic Telephone Intercept Switch*

Abstract: A system has been designed to automatically perform the functions of intercepting misdirected telephone calls and providing correct dialing information. This paper concentrates on the design of the switching unit of the system. The switch is a space-division, wired-logic controlled device using dry-reed relays as crosspoints. It is organized so that separate networks perform the functions of concentrating incoming lines and selecting operator positions for identification of the number the customer thinks he called. While the presently installed system is not completely automatic, provision is made for incorporation of automatic identification of the "called number" when the necessary telephone central office features become available. Although the system was built for a particular telephone installation, modular construction makes it readily adaptable to installations with a variety of requirements. The switching networks can handle a maximum of 200 incoming intercept trunks, 64 automatic audio response trunks, 22 called-number identifying operators, and 14 special intercept operators.

Introduction

When a telephone customer dials a number that has been removed from service, he must be advised that the number is no longer working and be given the new number. Calls to such numbers are said to be intercepted. In conventional telephone plants, they are directed to intercept operators who consult directories to provide the customer with the information he needs. In addition to disconnected and changed numbers, calls to unassigned or vacant numbers must be intercepted. In some of these cases, the call is directed to an announcement machine which plays a message to the customer such as, "The number you have reached is not a working number. Please consult your directory and dial again. Thank you."

The purpose of this article is to present the results of an effort by the Southwestern Bell Telephone Company and IBM to develop a system for automatically handling the intercept service. The immediate goal of the effort was to provide, for the St. Louis, Missouri metropolitan area, an intercept system utilizing automatic switching with operator identification of called numbers. The system was put into operation in St. Louis in February, 1965; when fully loaded it will serve about 600,000 telephones. A broader goal, however, was to design a system that could be installed in plants serving other numbers of telephones and be capable of fully automatic operation (i.e., automatic identification of called numbers). The design of a switching unit to achieve this flexibility will be described. Conventional technologies have been used to implement the switch. It is the special system considerations leading to the chosen network organization that will be of primary interest. As a background to the discussion of the switch, a brief resume of the components and operation of the entire automatic intercept system is provided.

System components and operation

The system consists of the following major components (Fig. 1): An IBM 2910 Automatic Intercept Switch concentrates the traffic from a maximum of 200 incoming intercept trunks to a maximum of 64 audio response trunks. It also provides access to the IBM 2925 Mod II Intercept Operator Positions which accommodate the called number identifying (CNI) operator and to the special intercept (SI) operator who handles the unusual situations described later. A maximum of 22 CNI and 14 SI operators may be accommodated. Two SI positions are arranged as hybrid positions to accommodate both CNI and SI traffic during light traffic hours.

The IBM 7770 Audio Response Units (ARU) assemble and emit an audio message under computer control. The message words, syllables, and phrases are recorded on a

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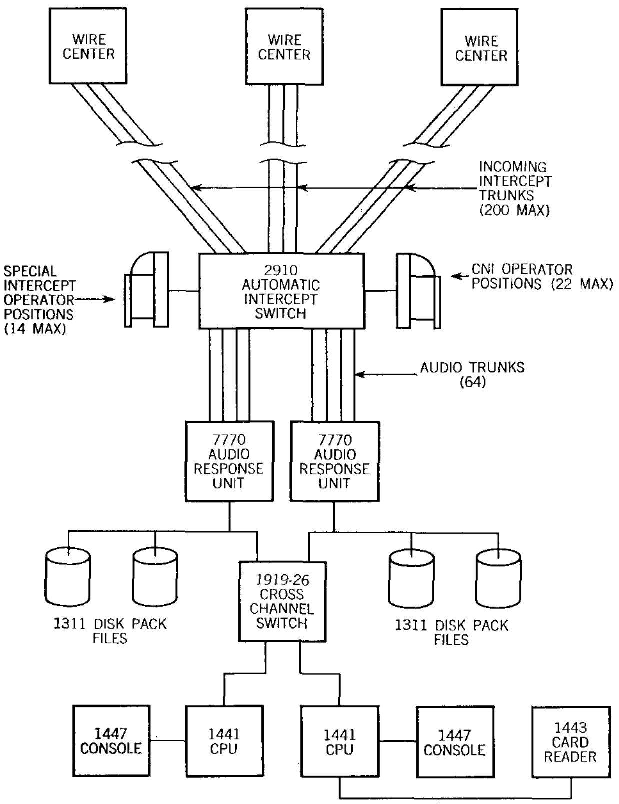


Figure 1 Components of intercept system.

magnetized drum. Up to 48 audio trunks may be provided in each ARU, and all trunks may be used simultaneously, each with a different message. The vocabulary of this particular audio machine is limited to a total of 128 words, syllables, and phrases. The maximum message length is 60 words.

The control computer is an IBM 1440 Data Processing System consisting of two 1441 central processing units (each with 8K core memories), two 1447 consoles, a 1443 card reader, and one 1919-26 channel switch which permits placing either 1441 on line with both 7770's.

Two types of calls are routed from the telephone network to the automatic intercept system: calls which cannot be handled by the 6A Announcement System (the standard telephone company recorded announcement system), and calls which the caller has continued to hold after receiving a recorded announcement from the 6A system. The first type of call is referred to as a "regular intercept call" and consists of such traffic as number changes, temporary disconnects, and temporary transfers. The second type is referred to as a "6A time-out call." It occurs when the caller dials an unassigned or vacant number.

Regular intercept calls require connections between the incoming trunk and a called number identification (CNI) position to permit the operator to obtain the number which the customer dialed or thinks he dialed, i.e., the "called number"; between the CNI position and an Audio Response Unit trunk to permit the operator to key in the called number; and between the ARU trunk and an incoming trunk to permit the customer to hear the response. A regular intercept call may also require a connection to a special intercept operator in cases where the nature of the called number is such that it cannot be served by the processor. Such cases occur when a number has multiple listings, when the customer, after hearing the audio response, requires further assistance, or when the CNI operator has made a keying error and no response can be generated. Timeout calls from the 6A Announcement System require connections to special intercept operators only.

A fundamental problem in planning any automatic intercept system is the fact that, in all current versions of dial central offices, the identity of the called number is lost when connection is made to an intercepting trunk. It is possible to modify the central office equipment to identify this number and pass it forward over the intercept trunk by means of multi-frequency pulsing. The modification would involve changes in the equipment presently used to identify automatically the number from which the call is placed (ANI equipment). Since automatic "called number" identification is unavailable, the intercept system installed in St. Louis uses an operator to identify the called number; however, provision has been made for incorporating automatic identification in the future.

Figure 2 illustrates the operation of the IBM 2910 Automatic Intercept Switch (AIS) in the system. A call is routed to intercept at a particular terminating central office, and the intercept trunk appears at the AIS input. The AIS recognizes a request for service, selects an idle audio trunk, and associates that trunk with an idle called number identification operator position. Supervision is returned to the terminating central office, causing ringing to be tripped without returning supervision to the office of the customer, and causing the trunk circuit to go into talking condition. Then a tone is sent to the selected CNI operator. She asks the customer what number he called, and keys this number on a 10-button keyset. This number is transmitted to the 7770, and the operator is disconnected and made available for another call. The number which the operator keyed into the 7770 is transmitted to the 1441 central processing unit. The number is then translated to a 1311 file address, and any relevant information retrieved, e.g., the new number, if the intercepted number has been changed. The 1441 sends control information to the 7770 to cause an appropriate message to be transmitted to the customer. Should the customer not hang up at the end of the audio message, the connection to the audio trunk will be broken after a time-out interval varying from 8 to

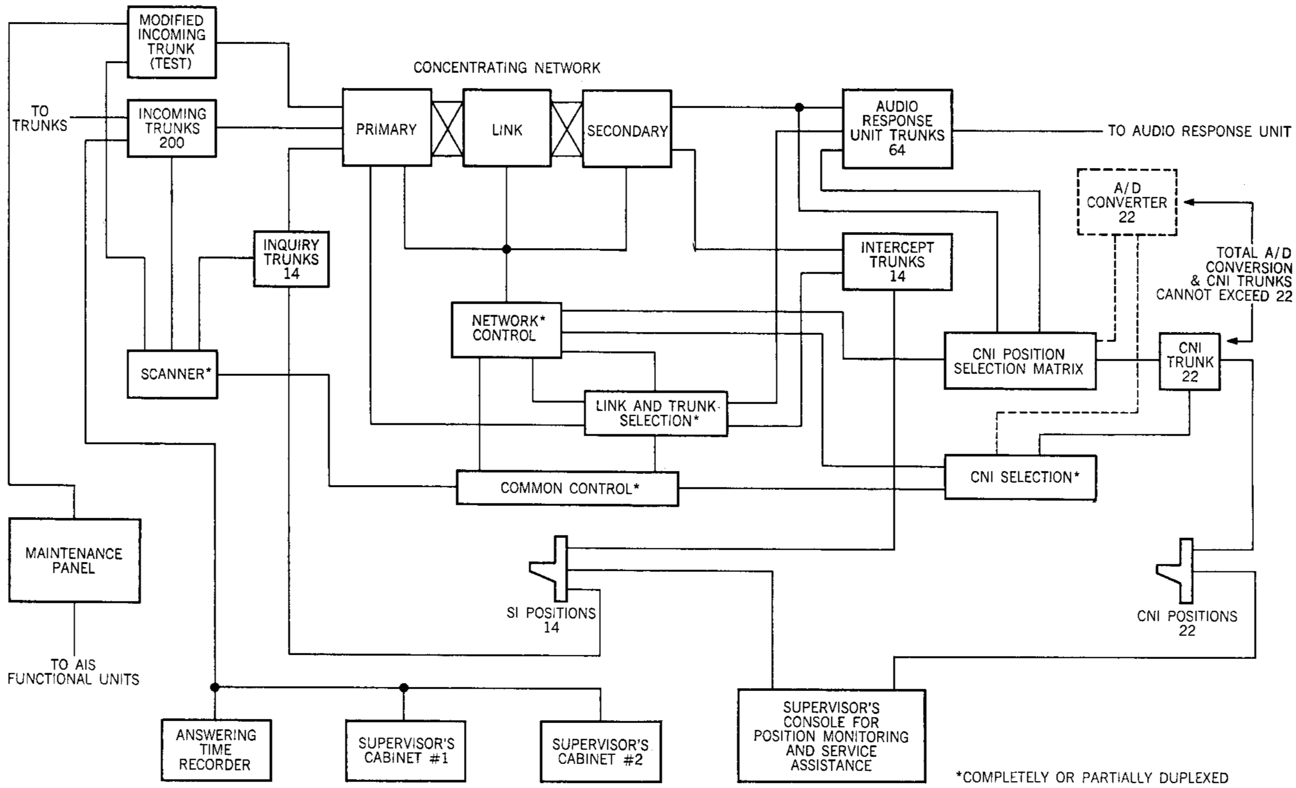


Figure 2 System block diagram. Numbers in boxes are maximum quantities. Dashed lines indicate modifications required for automatic called number identification.

16 seconds, and a new connection established to an SI position.

In addition to time-outs from audio messages, there are two other types of calls which are directed to the SI positions. Calls to vacant codes or numbers, which are handled by the 6A Announcement System and then timed out, will be routed to the mechanized intercept system, which will recognize a special indication at the incoming intercept trunk and connect directly to an SI position. Calls to numbers which have multiple listings will also be directed from the CNI operator to the SI position rather than sent a recorded message since the operator must ask the name of the party desired. In this type of call, the computer determines that the number cannot be handled by an automatic audio response and signals the 2910 to transfer the call immediately to SI.

When the SI operator receives a call, she takes the number given by the customer and keys it into the system via an inquiry trunk. The 7770 returns either an audio message giving the new number, or a code phrase, such as, "ML" (for multiple listing), or "TT" (for temporary transfer) describing the status. When the status message is ML, the operator obtains the necessary information from a directory of multiple listings.

When central offices become equipped to identify the called number and pulse it to the intercept system, the operation will differ from that described above. Upon the recognition of a service request and the selection of an audio trunk, a multi-frequency receiver rather than a CNI position will be connected. Plans for incorporating automatic called number identification are described later.

Design of the 2910 Automatic Intercept Switch

The previous section of this paper has described in general terms the entire complex that constitutes a mechanized intercept system. Attention is now directed to a specific component of the system, viz., the 2910 Automatic Intercept Switch. The major considerations and subsequent decisions which influenced its design are discussed.

A basic consideration was whether to use space-division or time-division switching techniques. Both methods have merits and either could have performed equally well as a vehicle for implementing the switching functions of the 2910. However, the existing telephone plant used the space-division technique. Since the 2910 was to become an integral part of the existing facilities and since there was a possibility that the telephone company would eventually assume maintenance of the system, space-division switching was judged to have the greatest merit for this particular project.

Similar practical considerations were paramount in deciding whether to build the switch as a self-contained unit with its own wired-logic control circuits or to derive control from the computer. Either approach could have provided a satisfactory technical solution to the problem. But once again the desire to make the control technique of the switching system as compatible as possible with that of existing plant equipment led to the decision in favor of designing a wired-logic common-control device.

After the selection of space-division switching and wired-logic control, it was decided that dry-reed relays would be a suitable means of implementing the switching network. Besides their ability to meet all requirements of the application with respect to speed of operation, reliability, transmission characteristics, etc., these relays were readily available for use. Thus, it would not be necessary to design and manufacture special solid-state crosspoint devices.

The switching networks themselves had to be capable of meeting the following requirements:

1. A call originating at any incoming trunk (200 incoming trunks, maximum) must have access, via the switching network, to any ARU trunk (64, maximum) and, as part of the same connection, to any CNI operator's position. In addition, any incoming trunk must have access to any SI position.

2. A call originating at any SI position must have access to any ARU trunk circuit.

3. The probability of delay of a call due to internal congestion of the switching network (i.e., the possibility that the call cannot be completed because a path is not available between end points of the connection) must not be greater than 0.01.

The engineering objectives involved in designing the switching network topography were primarily to minimize the number of crosspoints required and still provide a configuration which was manageable from a control standpoint. Another consideration was that although the AIS was designed primarily to accommodate the maximum size system, its network configuration should be compatible with smaller systems. That is, the same basic configuration with fewer crosspoints would be used for smaller systems.

A preliminary examination of the system requirements indicated that it would be feasible to divide the switching networks into two separate entities: (1) a large multi-stage network (concentrating network) for connecting incoming trunks with ARU and intercept trunks, and for connecting inquiry trunks with ARU trunks; and (2) a smaller single-stage matrix (CNI matrix) which would provide access between ARU trunks and CNI trunks. The reason for designing two independent switching networks was as follows.

The connection between an ARU trunk and a CNI trunk exists only during the time that an operator is challenging the customer and keying the called number. During this period the operator must have access to both the customer and the channel to the Audio Response Unit. It is also necessary to establish a connection between the ARU trunk circuit and the customer so that the customer may hear the audio response. Since an ARU trunk circuit is permanently associated with an ARU channel, it became apparent the desired communication could be established by connecting the CNI trunk circuit to the ARU trunk circuit during the time the services of the CNI operator were required. The decision was made, therefore, to build a separate network whose sole function would be to associate the CNI trunk with the ARU trunk (and, hence, the incoming trunk) during that portion of the call which required the services of a CNI operator. This network was designated as the CNI matrix and was designed as a single-stage matrix with full access between all ARU trunks and all CNI trunks. This two-network approach eliminated the possibility that network blocking would cause a switching delay during an attempt to make connection with an idle CNI trunk. It also provided an additional degree of design latitude in determining the optimum configuration of the larger and much more complex concentrating network.

With the basic switching arrangement determined, the next step was to specify the exact network configuration and the optimum number of SI and CNI operators that would be required to provide an acceptable grade of service. Results of traffic studies of the Southwestern Bell Telephone Company area to be served (St. Louis) were obtained and a simulation model of the system was devised. The traffic information, simulation results, and a description of the final configuration of the switching networks are contained in the following paragraphs.

• *Traffic considerations*

In St. Louis there are about 600,000 telephone terminals of which approximately 480,000 are working main telephones. Experience with the manual intercept system has led to the following estimates of use for the mechanized system:

Telephones requiring intercept service:	120,000 (1965),	160,000 (1972)
Intercepted calls per busy-hour (avg.):	3,900 (1965),	4,700 (1972).

Table 1 shows the distribution of intercepted calls by type. It also gives estimates of the average holding times for each type. These figures lead to a calculation of average

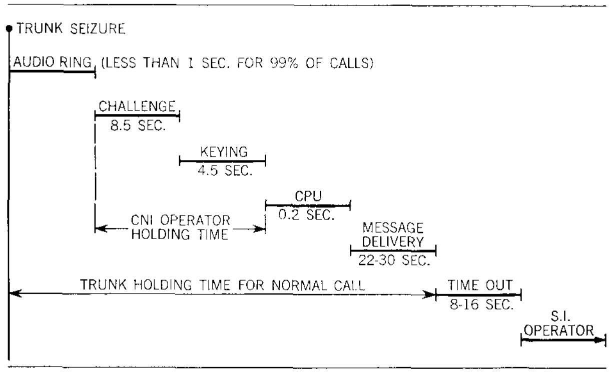


Figure 3 Typical call sequence showing holding time at each step.

Table 1 Distribution of intercepted calls by type and estimated holding times for each type.

Type of call	Percent of total	Holding time in seconds: Operator	Audio message	Incoming trunk
Special Intercept (including overflow from audio)	13.5	26.5	8.8	26.5
Changed number	60.2	13	30	43
Disconnected number	15.2	13	22	35
Special Intercept operator inquiry	10.1		16	16

holding times for over-all system use: average incoming trunk holding time, 36.3 sec., and average audio trunk holding time, 34.1 sec. Figure 3 illustrates the sequence of operations for a typical intercepted call and shows the expected holding times at each stage of the sequence. Projected loads on the system are given in Table 2.

With these traffic estimates, the quantities of audio response trunks and operators' positions were determined by conventional traffic analysis techniques. The number of incoming trunks is fixed by the existing telephone plant configuration rather than by traffic requirements. It was determined that a minimum of 100 and a maximum of 200 incoming trunks, with provisions for modular growth from 100 to 200, would adequately cover the market.

The 1972 CNI operators' busy-hour load of 13.3 erlangs can be handled by 22 positions with the following grade of service:

Probability of any delay	0.025
Probability of delay ≥ 1.3 sec	0.01
Probability of delay ≥ 13 sec	0.0001.

The 1972 SI operators' busy-hour load of 4.7 erlangs can be handled by 10 positions with the following grade of service:

Probability of any delay	0.03
Probability of delay ≥ 1.6 sec	0.02
Probability of delay ≥ 16 sec	0.00035.

The 1972 Audio Response Unit load of 49.5 erlangs can be handled by 64 trunks with the following grade of service:

Probability of any delay	0.2
Probability of delay ≥ 3.6 sec	0.07
Probability of delay ≥ 36 sec	0.0001.

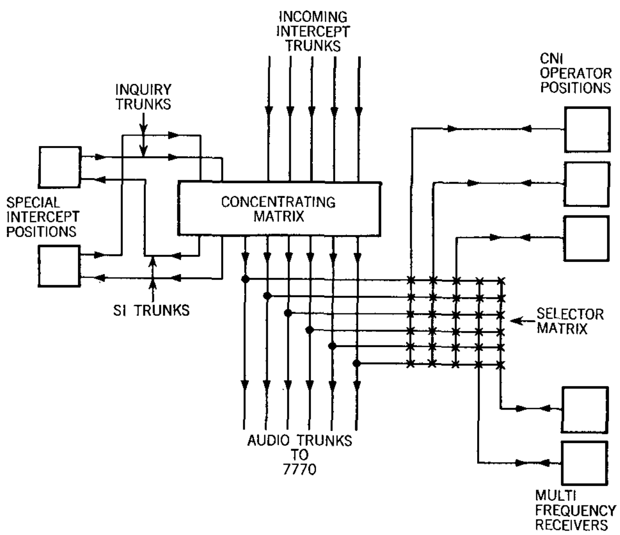
Since the assumption of CNI holding time is based upon similar functions in current telephone practice, it was felt that the figure of 22 positions could be taken as a maximum with a high degree of confidence. The SI function, however, has no direct analogy in manual intercept systems; thus, to be conservative, it was decided to provide for a maximum of 14 SI positions.

Table 2 Estimated system loads.

Type of load	Load in erlangs*: 1965	1972
CNI Operator	11	13.3
Audio Response Unit	41	49.5
SI Operator	3.9	4.7

* One erlang equals 3,600 call-seconds per hour.

Figure 4 Connection of switching networks to trunk lines.



With the preceding traffic quantities, a simulation model of the system was prepared to determine the proper switching network configuration, and to compose random and sequential trunk and link selection methods. The simulation showed that a 3-stage switching matrix would perform within the limit of one delayed call in 100, if its input and output switches each had 12 links, serving 15 and 9 trunks, respectively. In the simulation, a marked system improvement was gained by using a random selection of trunks and links.

Switching networks

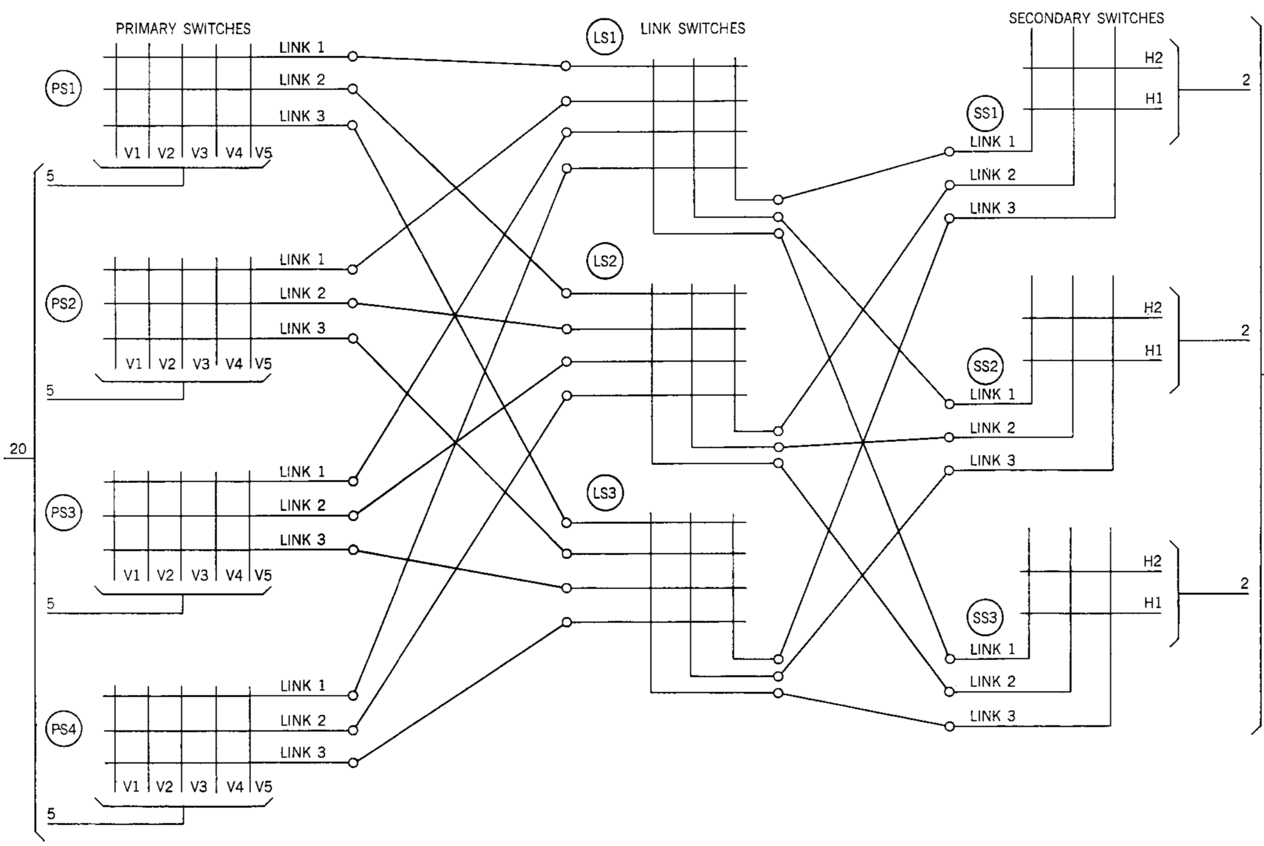
As mentioned earlier, two separate switching configurations are employed to perform the required switching operations: the concentrating network and the CNI position selection matrix. The relationship between these switching configurations and the various trunk circuits is illustrated in Fig. 4.

- *Concentrating network*

The concentrating network is a 3-stage, blocking network designed to provide service where the probability of delay is one call in 100. The network consists of three sets of rectangular switches designated as primary, link, and secondary. Each connection through the concentrating network involves a crosspoint closure in a primary switch, a link switch, and a secondary switch. The connection through the concentrating matrix consists of three wires identified as tip, ring, and control. The tip and ring leads constitute the transmission path and the control lead is used exclusively for internal automatic intercept system signaling. A fully equipped concentrating network consists of 5,292 crosspoints where each crosspoint is a four-position dry reed relay. Three of the contacts are assigned to tip, ring, and control leads, and the fourth serves as a holding contact.

Primary switches. Primary switch verticals are assigned to the incoming trunks from telephone company wire centers, to the inquiry trunks from the special intercept and hybrid operator positions, and to the test trunk which originates at the AIS maintenance panel. Each primary switch consists of 15 verticals and 12 horizontals. There are 15 primary switches, which provide a total input capacity of 225 terminals. Of the maximum 225

Figure 5 Method of switch connection in three-stage concentrating network.



primary-switch verticals available, a total of 215 are used in the AIS. Assignments to the primary-switch verticals are distributed as follows: 200 for incoming trunks, 14 for inquiry trunks, and 1 for a test trunk. The test trunk is assigned to primary switch 1, one inquiry trunk is assigned to each of the first 14 primary switches and the incoming trunks are evenly distributed over all primary switches.

Link Switches. Link switches provide facilities for establishing connections between primary and secondary switches. The method of connecting link switches in the concentrating network is illustrated in Fig. 5. Essentially, each link switch contains one crosspoint for each of 135 possible primary/secondary combinations. Since 12 link switches are provided, there are then 12 possible paths between any primary switch and any secondary switch.

Secondary switches. Each secondary switch is a 12×9 rectangular array. The outputs of the link switches enter the secondary switches on the switch verticals (Fig. 5). Secondary-switch horizontals are assigned to ARU trunk circuits and intercept trunk circuits. Each of nine secondary switches has nine horizontals giving a total of 81 secondary-switch horizontals. A fully equipped AIS can accommodate a maximum of 64 ARU trunks (one per 7770 channel) and 14 intercept trunks (one per special intercept and hybrid position). Thus, 78 of the 81 secondary-switch horizontals are used in the fully equipped system.

- *CNI position selector matrix*

The CNI matrix is a rectangular array which provides nonblocking access between ARU trunks and CNI operator positions (via CNI trunk circuits). A crosspoint in the CNI matrix switches five wires. Of these five wires, two are used for the audio path between incoming trunk and the CNI position, and the remaining three are used for internal AIS signaling. ARU trunks (a maximum of 64) appear on the verticals of the CNI matrix, and CNI position trunk circuits appear on the horizontals of the CNI matrix. A fully equipped CNI matrix contains 1,408 crosspoints.

Maintenance

An important consideration in the design of the 2910 Automatic Intercept Switch was the fact that it is intended to function as an integral part of the telephone plant and therefore, must be on-line 24 hours a day, 7 days a week. Maintenance and testing facilities incorporated into the 2910 were designed with the requirement that trouble diagnosis and repair as well as routine testing be done while the machine is on-line. In order to implement this maintenance philosophy the 2910 is designed so that most failures in logic or power distribution are contained within a small area of the switch and do not cause a system interruption. In addition, the common-control wired-logic is duplexed internally with provision for automatic switchover to the standby unit if a failure is detected.

Some of the maintenance features are:

1. Test calls using any preselected combination of operator position and ARU channels can be initiated from the 2910 maintenance panel.

2. Any operator position or ARU channel can be made to test "busy" to normal paths. The significance of this feature is that a unit such as an ARU channel can be made to function in such a way that it will not be involved in normal traffic but is still accessible for test calls.

3. On a test call a preselected path through the switching network can be defined at the maintenance panel and the test call will be automatically directed to that path.

4. When a trouble is encountered during the processing of a call, the status of all control circuits is recorded on a lamp-display panel. Although the switch continues processing calls, this status information is retained until it is manually released by maintenance personnel.

5. The 2910 is connected to the telephone plant alarm system so that a major alarm in the 2910 will alert maintenance personnel at the telephone company maintenance center.

6. Each operator position is equipped with a trace key. If an operator who is handling a call depresses her trace key, a lamp will light at the 2910 maintenance panel to identify the incoming trunk and ARU trunk (if any) to which the position is connected. The ability to trace is valuable from the maintenance standpoint because it permits rapid identification of trunk circuits which may be in trouble. In addition it is a necessary operational feature for the telephone company since it provides the first information that is required for tracing a call to its source.

7. By utilizing a special code, it is possible to verify from the maintenance panel the accuracy of operator keying as well as the ability of the 2910 detecting circuits to transmit the proper characters to the 7770.

Perhaps the most significant characteristic about all the maintenance features described is that all maintenance operations can be performed while the 2910 is engaged in serving live traffic.

Modularity

Although the automatic intercept system is intended to serve, initially, a particular community, the 2910 switch configuration is adaptable to the needs of a variety of telephone installations. Factors such as traffic on incoming trunks, operator holding time, length of message, and grade of service required all influence the system configuration chosen for a particular installation. It is also possible that once a system is installed, changing traffic patterns may require changes in system configuration. To provide an operating company with the greatest latitude in planning the arrangement of a mechanized intercept system that will be adequate for present requirements and capable of being modified to meet future requirements without service interruption, the entire switching network, as well as all trunk circuits, has been designed on a modular basis. With the exception of incoming trunk circuits, which must be added in increments of three, all other trunk circuits are equipped as single units. The concentrating network is constructed entirely with standard printed-circuit cards, each containing nine dry reed relays arranged in a 3×3 matrix. The CNI matrix uses as its sole building block a printed-circuit card containing four dry reed relays arranged in a 2×2 matrix configuration. Different modules are used for the concentrating network and the CNI matrix since the concentrating network switches three wires and the CNI matrix switches five wires, thus requiring different relays. With this modular design, changing the configuration of a 2910 involves only adding or removing cards—no changes need to be made to the control circuits, or to the maintenance facilities.

Automatic called number identification

The IBM 2910 Automatic Intercept Switch is currently intended to function with operator identification of the called number. As mentioned earlier, it is expected that telephone company wire centers will eventually be equipped to provide automatic identification of the called number, probably by multi-frequency pulsing techniques. Automatic called number identification (ACNI) has been anticipated in the systems design of the 2910 as far as practicable. With some modifications, the 2910 will be able to provide intercept service for the operating company both during the transition period when there will be some automatic, as well as operator called number identification, and ultimately when there will be a completely automatic called number identification.

Basically, the approach to be taken for the incorporation of ACNI into the 2910 consists of replacing each CNI position with an analog-to-digital converter unit. The unit would receive the multi-frequency pulses from the incoming trunk, simultaneously translate to the dc signaling currently used in the CNI positions, and outpulse the called number to the ARU trunk circuit. The converters will appear on the CNI matrix in lieu of CNI trunk circuits and their associated operator positions. On calls from dedicated ACNI trunks, a connection will be set up via the concentrating network and CNI matrix to converter unit in exactly the same manner as a connection is presently made to a CNI position. When the connection is made, the converter will receive, translate and transmit the called number. When identification has been made, a start signal will be sent to the ARU trunk circuit, the CNI matrix connection will be automatically released, and the converter unit will be available for another call.

Modifications to the system's present control circuits for operation with ACNI will consist of minor additions of wiring and circuit cards. Changes will also be required in the test trunk and maintenance panel to accommodate equipment for testing the multi-frequency signaling through the system.

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