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Common Channel Interoffice Signaling:

4A Toll Crossbar Application

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The No. 4 toll crossbar switching system is presently the backbone of the Direct Distance Dialing (DDD) network. Conversion of No. 4 offices equipped with the Electronic Translator System (ETS) is vital to the rapid introduction of CCIS to the DDD network. CCIS capability represents a major increase in the role of the ETS software in the call switching process. Significant changes and additions to the switching equipment are required to support this expanded software control.

I. INTRODUCTION

1.1 General

The No. 4 toll switching system comprises a family of common control crossbar switchers which presently form the backbone of the Direct Distance Dialing (DDD) network.[1] As of year end 1976, there were 183 Bell System No. 4 crossbar offices serving this network in the class 1 though class 4 categories, including all ten regional centers and virtually all sectional centers. All but 19 were of the 4A/ETS type which utilizes the Electronic Translator System (ETS) to perform the route translation and network management functions. Although existing No. 4 crossbar offices will be gradually replaced by No. 4 ESS, it is planned to retrofit CCIS into about half of the 4A/ETS offices to expedite the conversion of the DDD network from SF/MF signaling and, therefore, take maximum system advantage of the reduced signaling costs, faster call setup, and new services available with CCIS.

The introduction of ETS in 1969 greatly reduced the equipment investment and administrative costs associated with the route translation and network management functions.[2] This stored program control adjunct was intentionally designed to effect minimum change to the basic call processing structure of the No. 4 crossbar system in order to reduce the application expense to in-service offices.

1.2 Impact of CCIS

Introduction of CCIS capability into a 4A/ETS office represents a significant increase in the role of the stored program software in the processing of calls being switched through the system. With ETS the software is used primarily to translate incoming call information, to select the appropriate outgoing route and to provide a number of plant and traffic administration and control features. The control of sequencing the call switching process in 4A/ETS is contained within the wired logic of the common control switching circuits. The software system is only used to obtain a call translation or to report completion of a call switching attempt for traffic administration purposes.

Whereas with conventional signaling all address and supervisory information is received directly by the per-trunk hardware and then transferred to the common control circuitry, for calls using CCIS this information will be received by the processor from the signaling link and must then be acted upon appropriately. Therefore, when calls using common channel signaling are being switched, the software must interact very closely with the sequencing of the electromechanical switching equipment in order to successfully complete a call through the office. To further complicate the control structure, some calls being switched will require only conventional signaling, so that the system must perform similarly to 4A/ETS. Alternatively, the call may use common channel signaling for both the incoming and outgoing trunk circuits, putting the software heavily in control of the sequencing. Finally, the call may use conventional signaling on one side and common channel signaling on the other, making the connection a hybrid sequence. One could quite reasonably visualize the total switching system as a multiprocessor environment, with each of the common control units and senders (perhaps over five hundred in a large office) representing a special purpose, wired logic "processor" working with, and sharing access to, a central stored-program switching processor.

1.3 4A/ETS organization

A brief review of the 4A/ETS will be presented to familiarize the reader with conventional call switching concepts before proceeding with the description of the CCIS application. Figure 1 illustrates the major switching circuits and their interconnection.

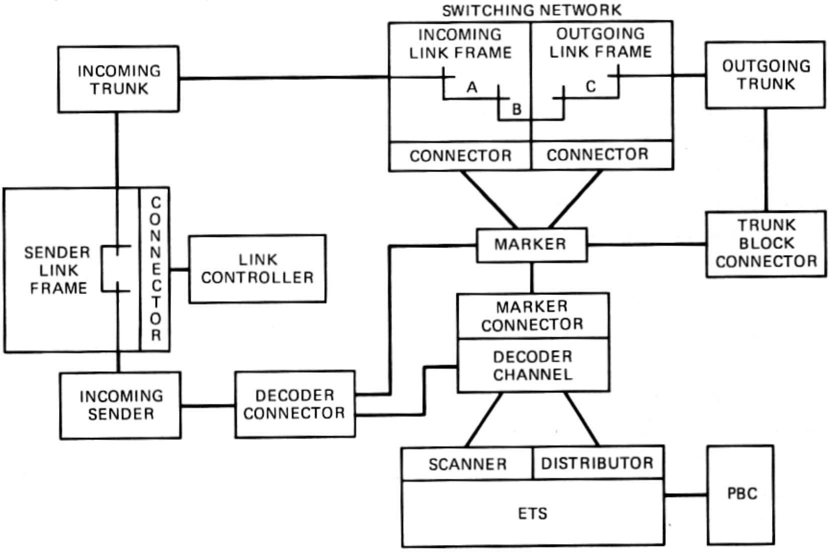

Fig. 1—Block diagram of 4A/ETS.

1.3.1 Network, senders, and trunks

4A/ETS uses a four-stage crossbar switch matrix as the trunk switching network. The switches are mounted on individual incoming and outgoing link frames which are interconnected by junctors (B links) and contain links (A, C) to provide access between the trunk and junctor switches. Since the network design is unidirectional, two-way trunks require an appearance on both an incoming and an outgoing link frame. Furthermore, two parallel networks are necessary to accommodate the engineered traffic load of 240,000 CCS; consequently, incoming trunks are terminated on both networks to allow access to all outgoing trunks.

Incoming trunks also require connection to an incoming sender for registration of the called number address digits used to route the call. Senders are dedicated to an incoming pulsing type [Multifrequency (MF) or Dial Pulse (DP)] or special function [Centralized Automatic Message Accounting (CAMA)]. All incoming senders are capable of outpulsing MF or DP over the cross-office connection to the next office. Trunks are connected to senders by means of a simple two-stage auxiliary crossbar network called a sender link frame. Sender link frames are furnished in groups dedicated to a specific type of sender.

Supervisory signals during the conversation stage of the call, such as answer and ring forward, are transferred directly between the interconnected trunk circuits by means of dc signals simplexed over the transmission pairs of the switched connection.

1.3.2 Common control circuits and connectors

Call switching is controlled by autonomous wired logic electromechanical common control circuits known as link controllers and markers. The link controller connects trunks to senders through the sender link frames while the marker establishes cross-office connections between trunks. A separate marker group is provided for each of the two trunk switching networks; similarly link controllers are dedicated to a sender group. Execution of these switching connections requires the common control circuits to identify the trunk bidding for service and search for an idle server (sender or outgoing trunk). The marker's search is limited to a maximum of 40 trunks in a subgroup as specified by ETS route translation of the called number. Another type of common control circuit is the decoder channel which serves as an interface between the electromechanical switching equipment and ETS. The decoder channel provides ETS with access to the first six digits of the called number for route translation purposes, controls selection of an idle marker in the indicated trunk switching network, and establishes a temporary connection between the ETS and the marker for distribution of call routing data.

During the processing of a call, large amounts of data must be exchanged between the common control and other switching circuits. Temporary communication channels are established through connectors which are arranged in two basic configurations. The first type permits a multiplicity of bidding circuits to access a specific serving circuit. The second type accepts requests to search for an idle serving circuit and connect it to a specific bidding circuit. The connectors also contain logic to queue multiple bids for service. With reference to Fig. 1, the incoming and outgoing link frame connectors and the trunk block connectors are representative of the first type while the sender link frame and marker connectors constitute the second type. The decoder connector combines both connector functions, since several senders share a single connector. Thus, a sender must first gain exclusive use of the decoder connector before the connector will select and connect an idle decoder channel.

1.3.3 Electronic Translator System (ETS)

ETS consists of a common systems Stored Program Control (SPC No. 1A) duplicated processing system and peripheral units dedicated to the 4A application, principally distributors and scanners to interface with the electromechanical switching equipment.[3] Sender requests for route translation of the called number are placed through the decoder channels via the decoder connector. The ETS processor reads the sender input through a block of scanner terminals associated with the decoder channel, determines the appropriate routing and then returns routing instructions by operating the appropriate output relays in the distributor register circuit associated with the decoder channel. Since the incoming trunk group characteristics may influence routing of the call, ETS must also identify the incoming trunk group associated with each call in order to read the appropriate trunk group data from memory during the route translation. Therefore, the link controller informs ETS, through the scanner, of both the incoming trunk and sender identities being switched through the sender link frame. Later, the decoder channel will identify the sender serving the call to permit ETS to link back to the trunk group data associated with the incoming trunk. The markers are also scanned by ETS to determine call disposition following route translation since unsuccessful attempts may be retried or routed to announcement by the marker depending on the routing instructions. These marker disposition reports are sent by ETS to the Peripheral Bus Computer (PBC) which uses them to administer trunk group measurement data.[4]

II. CCIS DESIGN STRATEGY

2.1 General

Among the major considerations influencing design of a new feature addition to an in-service switching system is the relative impact of retrofit application. If a significant number of existing switching entities are involved, the design approach will often strive to minimize the replacement and modification of present equipment to reduce retrofit costs, and may result in a less than optimum package for a new office application. CCIS constitutes an extreme example of this situation since it will be applied almost exclusively to existing 4A switchers. In fact, there was only a single new office application, the Madison 2, Wisconsin installation placed in service in May 1976. Madison is unique as it is not only the first 4A CCIS installation but, with the introduction of No. 4 ESS, it is also the last new 4A.

2.2 Conversion of MF trunk circuits to CCIS

The rapid implementation of CCIS in the toll network over the next few years will make surplus substantial numbers of MF trunk circuits and senders in converted 4A CCIS switching offices. Replacement of these MF trunk circuits by new CCIS trunk circuits would be economically unjustified since in addition to the trunk circuit itself, there is also the cost of outpulsing equipment required for incoming CCIS calls which switch to an outgoing conventional trunk, plus the rearrangement costs of substituting new CCIS trunk circuits for MF trunk circuits as trunk groups convert to CCIS operation. Therefore it was decided to add CCIS capability to in-service MF trunk circuits. Operation in either the MF or

CCIS mode is selected by a switch on hard-wired trunk units or option straps on plug-in trunk units.

The provision of new CCIS trunk and outpulsing equipment will generally be limited to offices with an inadequate quantity of MF trunk circuits eligible for CCIS modification, or in offices where the combined demands of CCIS conversion and growth exceed the supply of surplus MF trunk circuits.

2.3 Reuse of MF senders

The attractiveness of the MF to CCIS trunk circuit modification is enhanced by the ability to use existing senders for outpulsing on incoming CCIS calls which complete to outgoing conventional signaling trunks, since the modified trunk circuits retain access to senders through the sender link frame. Furthermore, extensive changes to 4A call processing sequences are avoided by also connecting a sender on CCIS to CCIS calls, even though the sender usage in this case is apparently superfluous.

This design decision was based on two major considerations. First, incoming trunk circuits are arranged to autonomously request sender attachment from the link controller upon seizure; to negate this function only on CCIS outgoing calls would require an added per trunk instruction from the processor. Secondly, the absence of a sender on this one class of call would require processor capability to seize a decoder channel to switch the call; also the marker would need direct access to the incoming trunk termination on the switching network which is currently furnished by the sender to trunk connection.

2.4 Basic CCIS call switching concepts

The resultant CCIS design approach, adopted for both modified and new CCIS trunk circuits, thus allows the 4A common control equipment to process an incoming CCIS call in basically the same manner as a conventional call. All senders in groups containing modified CCIS trunk circuits are arranged to function as either an MF sender or CCIS outpulser, depending on the incoming call type as will be described in Section 4.1.5. New CCIS trunk circuits are served by one or more dedicated CCIS outpulser groups. An office may contain a mix of MF sender groups serving only MF trunks, combined sender-outpulser groups serving both MF and CCIS trunks, and outpulser groups serving only CCIS trunks.

2.5 CCIS trunk circuit

A CCIS trunk circuit may be viewed conceptually as a conventional MF trunk circuit whose E&M leads are made available to the processor through a distribute and scan point instead of being connected to an SF signaling unit. The scan-distribute interface provides the processor with the ability to control CCIS trunk circuit seizure and release, and to convert supervisory signals for connections to conventional signaling trunks. Supervisory signaling between conventional and CCIS trunk circuits is accomplished by means of dc signals applied on a simplex basis to the transmission pairs of the cross-office connection. However, for CCIS to CCIS calls, the processor transfers signaling messages directly between the signaling links serving the trunks.

Separate functions are assigned to the distribute and scan point depending on whether the trunk circuit is operating in the incoming or outgoing mode.

2.5.1 Incoming call

Operation of the distribute point for an idle trunk circuit seizes it in the incoming mode to start a cross-office connection. If a connection to an outgoing conventional signaling trunk circuit is established, the scan point follows answer and hang-up supervision from the outgoing trunk circuit causing the processor to send corresponding CCIS messages over the signaling link for the incoming trunk. Receipt of a forward transfer message for the incoming CCIS trunk causes the processor to momentarily release the distribute point for approximately 100 ms, causing the trunk circuit to send a ring forward signal to the outgoing trunk circuit. The incoming trunk circuit disconnect timer will not expire on this short pulse and the trunk remains off-normal. On a true disconnect, the trunk circuit releases itself and the outgoing trunk after the timer expires. The scan point is activated during disconnect timing and then deactivated after the trunk circuit has returned to idle to inform the processor that trunk release has been completed.

2.5.2 Outgoing call

The trunk is seized by the marker as directed by the processor, thus conditioning the trunk circuit for outgoing operation. Activation of the scan point signifies completion of this event. If a conventional signaling incoming trunk is connected, the processor converts answer and hang-up CCIS signaling messages from the distant office by using the distribute point of the CCIS outgoing trunk circuit to send cross-office signals to the conventional incoming trunk circuit. A ring forward signal from the conventional incoming trunk circuit results in a momentary release of the outgoing CCIS trunk scan point, causing the processor to send the forward transfer message over the signaling link when the scan point is reactivated. The processor times the release of the scan point to distinguish between a ring forward and disconnect signal. If the timer expires without reactivation of the scan point, the processor considers the cross-office connection to the outgoing CCIS trunk to have been disconnected and sends a clear forward signal over the signaling link.

Success in minimizing the field modification cost for the MF to CCIS trunk circuit conversion is directly attributable to maximum retention of conventional trunk logic. This approach also reduces the processor interface to a single scan and distribute point. Incoming and two-way CCIS trunk circuits require additional circuitry to assist in the performance of the voice path continuity test to be described in Section 3.3.

III. NEW DESIGN

Several new circuit designs were developed for CCIS. The signaling terminal and Distributor and Scanner (DAS) are electronic adjuncts to the SPC processing system and communicate with the processor via the peripheral unit bus system.[5] The other circuits are additions to the 4A switching equipment.

3.1 Signaling terminal

The administration of data flow over the signaling link involves a number of highly repetitive tasks which are executed on an exacting schedule.[6] The entire administration of the signaling link is delegated to the signaling terminal which is primarily a small special purpose stored program processor. The terminal sorts incoming signaling data into the respective priority classes, assembles multiunit messages, and stores the data until the switching processor is ready to retrieve it. Outgoing signaling data is accepted without delay from the switching processor and queued as necessary for transmission.

3.2 Distributor and Scanner (DAS)

The DAS provides the processor with an economical scan and distribute point interface necessary to control the operation of CCIS trunks and common control equipment. Upwards of 1000 scan points and 2000 distribute points are required for the senders and common control equipment. Additionally, a single set of DAS points is required for each CCIS trunk.

DAS executes single point distribute orders primarily used to control trunks and multipoint orders for common control equipment. The DAS also scans the 4A switching circuits and reports only transitions to the processor. Scanning is performed at approximately a 5 ms rate but, to avoid false reports due to relay contact bounce, a transition must persist for two consecutive cycles before it is reported to the processor. This rapid scanning rate aids in achieving the fast call switching objectives established for CCIS. Scan points may be converted to the nonreporting mode which inhibits transition reports but still allows the processor to

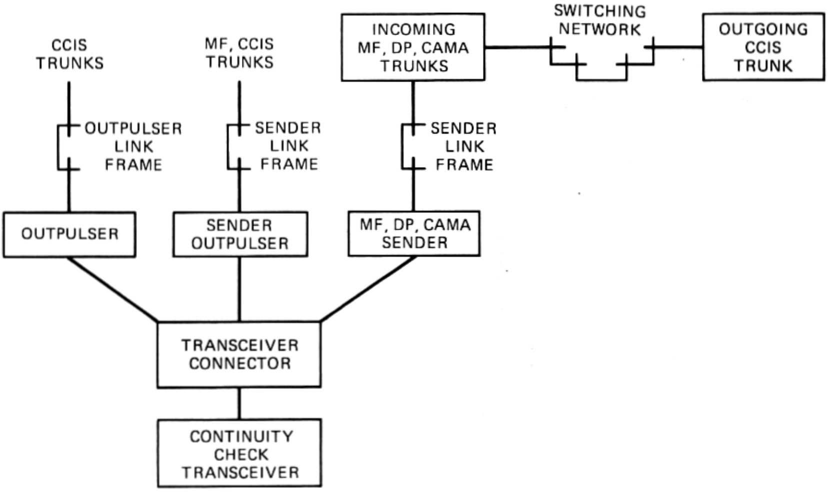

Fig. 2—Connecting continuity check transceiver.

read the scan point state. This feature is used to read blocks of data from common control equipment following detection of a bid for service.

3.3 Voice path continuity check

A continuity check of the interoffice path is conducted whenever a CCIS trunk is selected to switch a call forward. This check not only insures a satisfactory transmission path for the customer, but more importantly precludes billing for an otherwise undetectable faulty connection since CCIS signaling is performed independent of the speech connection. Conventional in-band signaling systems do not require this check since transmission integrity is indirectly verified by the receipt of the called number at the far end via MF pulsing, and at the near end by the wink or delay dial signaling sequence which precedes outpulsing.

The continuity check is performed on a loop basis between 4-wire switching offices, whereas each transmission direction is checked independently when one or both offices involved are 2-wire switchers. For the 4-wire test, a single frequency transceiver is connected at the outgoing office and the transmission pairs are looped by the incoming office. For the 2-wire test, both offices connect transceivers and different frequencies are employed in each direction.

The 4A system connects the continuity check transceiver to the incoming sender or outpulser serving the call, rather than directly to the CCIS trunk, as shown in Fig. 2. When an outgoing CCIS trunk is selected, the continuity check is deferred until completion of the switched connection between the incoming and outgoing trunks. Transceiver access to the outgoing trunk transmission pairs is achieved through the trans-

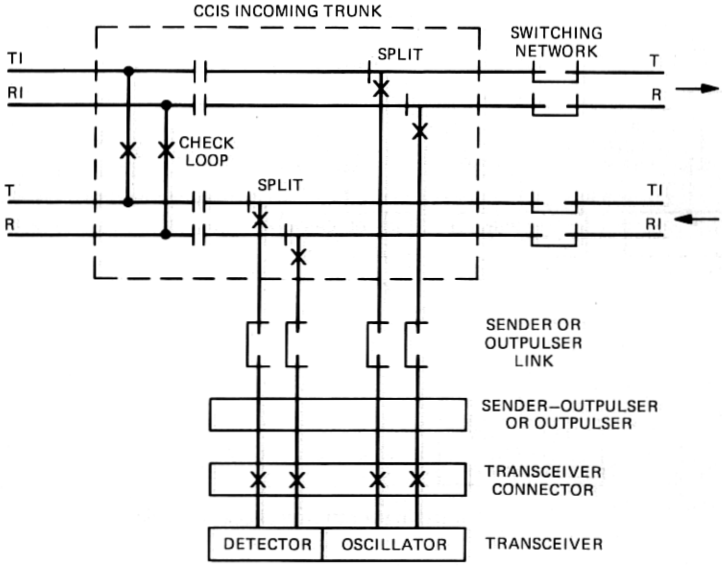

Fig. 3—Continuity check.

ceiver connector, the sender or outpulser link connection to the incoming trunk, and the cross-office connection. Incidentally, the sender or outpulser uses the latter two stages of this same connection to outpulse over a conventional signaling outgoing trunk.

When a call arrives from a 2-wire CCIS office, the transceiver is connected before starting the cross-office connection and the incoming trunk circuit temporarily switches the transmission path from the transceiver back towards the preceding office. After completion of the check, the transceiver is disconnected and the trunk circuit transfers the transmission path from the sender or outpulser link forward in preparation for starting the switched connection to the outgoing trunk. A transceiver is not connected for calls arriving from a 4-wire office, instead the incoming CCIS trunk circuit temporarily loops the transmit and receive pairs when seized by the processor. Figure 3 depicts both the incoming and outgoing continuity check between 4-wire switching offices. The incoming trunk circuit has looped the transmit and receive pairs for the preceding office, while the SPLIT relay provides the continuity check transceiver with access to the outgoing trunk.

Transceiver selection is performed by the processor. The connection to the incoming sender or outpulser is executed by the link controller for incoming trunks from 2-wire offices, and the marker for outgoing trunks. The transceiver connector is a single relay switch to one of the four transceivers dedicated to serve a subset of the senders and outpulsers. This group size represents a balance between efficient transceiver utilization and the size of the connector plus control access from the controllers and markers. Traffic utilization is maximized by allowing transceiver requests to queue for a short interval (1.0 to 1.5 seconds), while a balanced offered load is achieved by distributing the members of each sender or outpulser group evenly among all transceiver groups. Connectorized cables allow for load balancing when transceiver groups are added.

On an outgoing CCIS call, the processor searches for an idle transceiver when the decoder channel reports the marker identity just prior to releasing from the call. If a transceiver is available, the processor operates DAS distribute points associated with the marker to indicate which one of four transceivers has been selected. The transceiver group identity is not required since the marker is connected to the transceiver connector relays of the sender or outpulser through the decoder connector. The marker operates the indicated connector relay which seizes the transceiver and alerts the processor via a scan point. The processor conditions the transceiver by distributing instructions for 2-wire or 4-wire operation, incoming or outgoing test, and transmission level. The transceiver then applies locking ground to hold the connection which the marker senses as a connection complete signal. Upon receipt of a marker report indicating completion of the transceiver and cross-office connections, the processor starts the transceiver timer. The transceiver reports results of the continuity check by tone recognition and timing expired scan points. A successful test is indicated by activation and deactivation of only the tone recognition point. The processor then resets all distribute points to release the transceiver.

If a transceiver is unavailable, the processor so informs the marker. The marker will establish the cross-office connection, report completion to the processor, and wait. If a transceiver does not become available before a software timer expires, the processor distributes a release signal to the marker. The call is terminated by sending an ineffective attempt message to a preceding CCIS office, or distributing a reattempt instruction to the sender to cause a conventional incoming call to be routed to reorder tone or announcement.

Transceiver connection on an incoming call from a 2-wire office is executed by the link controller in a similar manner, except the controllers have direct access to the transceiver connector relays. Continuity check timing is performed by the 2-wire office and may be recycled by a signaling message from the 4A office whenever the accumulation of queuing delays for a link controller, outpulser, and transceiver approaches the timing limit.

3.4 New trunk circuit and outpulser

A new CCIS trunk circuit, outpulser link, link controller, and outpulser have been designed for offices which are unable to satisfy their CCIS trunk demand by conversion of surplus MF trunk circuits. From a system viewpoint, these new electromechanical units are functionally identical to corresponding MF equipment converted to CCIS use. However, they offer lower cost, faster call setup, reduced floor space, and superior maintenance. Trunk circuits are available as either a combined incoming and two-way plug-in unit or outgoing only plug-in unit, and are interchangeable with converted MF plug-in units. New trunk circuits may also be added for CCIS growth to MF sender groups converted to serve incoming CCIS traffic.

IV. MODIFICATIONS

Changes are necessary in all senders, common control equipment, and outgoing link frames to support the previously described CCIS call switching procedures.

4.1 Senders

Sender modifications are divided into two categories. All sender types (MF, DP, CAMA) require the first four modifications described below for CCIS compatibility. Only those MF senders serving incoming CCIS trunks need be arranged for the outpulser function.

4.1.1 Processor access to called number

Prior to CCIS, the senders presented only the first six called number digits to the decoder channel since ETS route translation capability was limited to that number of digits. When an outgoing CCIS trunk is selected, the processor must read the entire called number from the sender in order to formulate the Initial Address Message (IAM) to the next office. Therefore, five additional digits are made available through an expanded decoder connector and presented to the processor by a block of DAS nonreporting scan points associated with each decoder channel. DP senders and older vintage MF senders were arranged to request route translation before called number registration was completed thus allowing overlap outpulsing to speed call completion. This feature is eliminated from the MF sender since selection of a CCIS outgoing trunk requires the availability of all called number digits. Retention of overlap outpulsing in the DP sender was deemed advisable for calls selecting slower signaling conventional outgoing trunks to avoid an increase in call setup time. Therefore, the DP sender is arranged for pretranslation. If the first available outgoing route is CCIS, the processor signals the DP sender to release from the decoder channel and to rebid after all called number digits are available.

4.1.2 Operation with CCIS outgoing trunk

Another sender change is the ability to accept a new outgoing trunk class (CCIS) from the marker. This class conditions the sender to extend the transmission path to the continuity check transceiver, to cancel its retrial timing after completion of the usual checks with the outgoing trunk circuit, and to remain linked to the call until signaled to release by the processor via a distribute point. The sender is held while the outgoing voice path continuity check is performed and until receipt of an Address Complete (ADC) message from the last CCIS office signifying successful call progress to that point. A scan point confirms sender release to the processor.

4.1.3 Reattempt order from processor

When a CCIS call cannot be completed by a succeeding switching office, an ineffective attempt message is returned to the first CCIS office requesting that the call be routed to the appropriate tone or announcement. Unlike CCIS trunks, the processor is not linked to conventional trunks by a distribute point for starting or releasing cross-office connections. Consequently, the sender has been held on the call expressly to aid in establishing another cross-office connection. The sender is signaled by another distribute point to release the previous connection to the outgoing CCIS trunk and rebid for a decoder channel to start the connections to the tone or announcement trunk. The reattempt procedure is also used to retry the call upon failure of the initial CCIS outgoing attempt, e.g., because of a continuity check failure.

4.1.4 CAMA overlap operation

Route translation for a CAMA call is started after the first digit of the calling number is identified following reception of the called number. Thus, the completion of calling number identification and the subsequent initial billing entry overlap the switching process. A delay in the billing entry, particularly on calls requiring operator identification of the calling number, could result in completion of the connection to the called customer before release of the CAMA sender. To avoid this possibility, the Continuity (COT) message is withheld by the 4A CAMA office until the CAMA sender signals completion of the billing entry to the processor via a dedicated scan point. Completion of outpulsing to a conventional trunk or cut thru to the called customer is delayed at the last CCIS office in the connection until receipt of the COT message.

4.1.5 Outpulser function

MF senders in groups serving incoming or two-way CCIS trunks are further modified to function as either an MF sender or CCIS outpulser

Table I — Conditioning Sender or Outpulser

Function	Distribution	
	P2	P1
Incoming:		
MF sender	—	—
Outpulser: 4-wire, seize decoder channel	—	×
Outpulser: 2-wire, start continuity test	×	—
Outpulser: 2-wire, seize decoder channel	×	×
Outgoing:		
Reattempt	—	×
Release	×	—

and are termed sender-outpulsers. The following description also applies to outpulsers serving only CCIS trunks.*

Upon seizure by the link controller, the processor conditions the outpulser for incoming MF or CCIS service, per Table I, using the same two ditribute points furnished for outgoing operation. In the outpulser mode, MF digit reception is bypassed and a decoder channel is seized either immediately, or upon completion of the incoming 2-wire continuity check. Control is assumed of the incoming trunk relay which applies the 4-wire check loop or switches the transmission pairs to the transceiver for the 2-wire check. The incoming trunk circuit continuity check relay is released upon completion of the 2-wire continuity check, or when the outpulser is signaled to release for the 4-wire check.

When the call completes to an outgoing conventional trunk, the called number digits to be outpulsed are loaded through the decoder connector from a group of DAS distribute points associated with the decoder channel. To reduce modification costs, a maximum of eight digits are loaded in this manner while the existing code conversion instructions through the marker are used for up to three additional digits. Outpulsing of the last digit is deferred until the processor receives the COT message indicating all preceding CCIS switching offices have successfully switched the call. The processor then distributes the release instruction to allow outpulsing to be completed. The 4-wire continuity check loop in the incoming trunk is also released and an address complete message returned to the first CCIS office. Any irregularities encountered during outpulsing will cause the outpulser to reattempt the call in the normal manner.

Outpulser operation following selection of an outgoing CCIS trunk is identical to the previously described sender operation. However, the outpulser is dismissed following the outgoing continuity check and receipt of the continuity message from the preceding office, thus reducing holding time. If a reattempt is necessary following outpulser release, the

* During the remainder of this article, the term "outpulser" will be used to include both outpulser and sender-outpulser operation.

previous connection is released by resetting the incoming CCIS trunk circuit's distribute point and a new cross-office connection is then started.

4.2 Markers and outgoing link frames

Processor selection of CCIS outgoing trunks requires a change in the current marker method of establishing connections through the switching network. For conventional outgoing trunks, the processor preselects a subgroup of trunks and presents the marker with the trunk block connector location of a pair of control leads per trunk. The marker hunts and seizes an idle trunk by means of the sleeve lead, and then identifies the trunk's outgoing link frame appearance by a coded three frequency ac signal on the select magnet lead. After connecting to the link frame, the marker operates the select magnet preparatory to closing the crosspoint and then verifies this segment of the connection via the sleeve lead.

When a CCIS outgoing trunk is selected, the processor presents the marker with the identity of the trunk's outgoing link frame termination during the decoder channel stage, using the same distributor register output field assigned to trunk block connector identity. Two new bits in the distributor register indicate whether an outgoing conventional or CCIS trunk is involved to permit the marker to properly interpret the distributor register output. The marker then connects to the indicated outgoing link frame to gain access to the CCIS trunk preparatory to establishing the cross-office connection. In addition to the marker modification, all outgoing link frames require a complementary modification to make the two trunk control leads available for all or part of the trunk terminations.

Elimination of trunk block connector usage on CCIS outgoing calls removes the administrative overhead of the control lead cross-connections between the trunk and trunk block connector. Furthermore, marker holding time is reduced by approximately 17 percent on outgoing CCIS attempts.

The other significant marker modification is the capability to connect a continuity check transceiver to the incoming sender or outpulser for the voice path continuity check of the outgoing trunk. This operation has been previously described in Section 3.3.

V. SOFTWARE STRUCTURE

5.1 General

The software control structure used in both the 4A/ETS and 4A/CCIS systems is that of the Stored Program Control No. 1A (SPC/1A),[7] which was originally developed for use in the Traffic Service Position System

No. 1 (TSPS No. 1) and 4A/ETS. This structure has been described extensively in previous BSTJ articles.[8] The primary feature of this structure is a hierarchy of hardware and software driven priority levels of program execution. The lowest three levels, known as base (or main), J-level, and H-level, are used for call processing, administrative, input-output, and routine maintenance functions. Levels G thru A, in ascending priority, are used for various types of higher priority maintenance functions, and are entered by hardware stimuli. Level J is entered every 5 ms by a simulus from the hardware clock, and level H is driven by the 5 ms clock as an overflow to ensure attention to high priority timed tasks. Base level is divided into six classes of work by a software algorithm. Five of these classes, named A thru E, are entered in a rotational scheme that causes class A to be entered twice as frequently as class B, class B twice as frequently as class C, C twice as frequently as D, and D twice as frequently as E. The sixth class, known as interject, is used as a very short delay class, and entry into interject is effectively interspersed among the various tasks executed in all of the other classes. This base level control structure, which is actually just a task sequencing algorithm, permits control of intertask entry delays by judicious class assignment. It is a structure that is fairly well behaved with load variations, and overload situations can be controlled by task cancellation within classes or by dynamically shifting tasks between classes to adjust delays.

5.2 CCIS approach

The most significant deviation from the operational software structure of both No. 1 ESS and No. 1 TSPS is the use in 4A/CCIS of an external-stimulus driven approach rather than the periodic entry of internal processing routines that are interconnected by work hoppers. A set of external "call-advancement" stimuli have been defined that are used to drive an individual call from state to state. When a simulus is recognized for a call in a particular state, that call is advanced in the switching process as far as possible and is left in a new state in which it is awaiting another external stimulus to drive it on. These external stimuli are items such as a trunk supervisory scan point changing state because it has become hardware busy, the scan point indication that a common control unit has become associated with this call, or receipt of a message from the CCIS signaling link. Another very commonly used stimulus that is not truly "external" is the expiration of one of several software interval timers that are used for activities such as protection while awaiting an external action, e.g., the response to a message sent over the CCIS signaling link, or for properly timing the interval between a pair of software activities, such as two sequential distributions to trunk hardware to form a ring forward pulse.

The external stimuli are presented to the call processing software by a set of monitor programs that are scheduled in various base level classes according to the delays which may be tolerated in recognizing and acting upon the stimuli. Some of these programs are carried over from the 4A/ETS system. These include routines for recognizing bids for service from sender link controllers, decoder channels, and markers. While these programs are conceptually the same as those provided in 4A/ETS, they have been modified to accommodate new hardware units, e.g., outpulsers and outpulser link controllers, and new processing requirements introduced by the CCIS design. Scheduling of these tasks within base level generally uses the same technique as in 4A/ETS, whereby each of these tasks is permanently assigned to a particular base level class, but entry during the execution of an individual class is contingent upon the expiration of a software timer used to guarantee a minimum time between entries to the task.

New monitor programs have been provided to gather stimuli from the new Distributor and Scanner (DAS) and signaling terminal circuits. The DAS monitor program is scheduled for execution in every class A base level entry, and gathers autonomous scan reports that have accumulated in the DAS since the last entry. Each report is received from the DAS change report buffer, and the change address is examined to determine the hardware unit associated with that point. Based upon the type of hardware reporting and the direction of change, the monitor program will enter a processing program to take the appropriate actions. Upon completion of the processing of this point change of state, the processing program will reenter the DAS monitor. The monitor will then pick up the next entry in the DAS change report buffer, and the process will be repeated until it is determined that no more change reports are available. At this time the DAS monitor will return control to the next class A task.

The monitor for the signaling terminal is very similar to that for the DAS, except that is broken into two separate portions. One of these is executed as a base level class A task, and is used to receive CCIS messages from the signaling terminal's nonpriority receive buffer. Each nonpriority message received, which includes all of the normal telephone signals except Answer, is removed from the buffer by the monitor, and is decoded by a series of table look-ups. Upon determination of the message type, the monitor enters the appropriate processing program for determination and execution of the proper action. Upon completion of this action, the processing program returns control to the terminal monitor, and the next message is removed from the terminal's receive buffer. This procedure is then repeated until it is determined that no more messages have been received by the signaling terminal, and control is passed to the next class A task.

Certain CCIS messages, of which the most significant is the Answer signal, require priority attention due to more stringent limitations on permissible cross-office delays. Upon reception from the signaling link, the terminal sorts the messages from the rest received and places them in a separate, priority buffer for special handling. This buffer is serviced by a portion of the terminal monitor program that is entered as a J-level task at a 10 msec inter-entry rate. This program processes each CCIS message found in the priority buffer in a fashion directly analogous to its base level counterpart, except that all of the message processing is conducted on J-level so as to control the service time. It is interesting to note that simulations have demonstrated that at low traffic levels, the class A reentry time is low enough that nonpriority messages actually encounter less handling delay than priority messages due to the fixed priority monitor reentry rate. At moderate-to-high traffic levels, however, the mean and variance of the class A reentry time become too high to allow servicing priority messages on base level and still meet the cross-office delay requirements.

5.4 Software structures

The software package required to support the CCIS capability is divided into two distinct parts: the generic program and the office data. The generic program is identical for all 4A/CCIS offices which support CCIS trunks while the office data tailors the operation to the characteristics of the individual installation. The office data is compiled by the Western Electric Co. based on information supplied by the telephone company in questionnaires which uniquely define a particular office. The office data is composed of approximately 230 different data table types. This data is required for three primary purposes. First, the generic program must be provided with sufficient information to maintain the office during trouble conditions. Secondly, data is required to describe how equipment is assigned in the office. For instance, the selection of outgoing CCIS trunks is completely processor controlled. Therefore the outgoing link frame appearance of every equipped CCIS trunk must be described in data tables. The third class of office data which is required describes the routing strategy for the office. Nearly all of this data is subject to modification from time to time due to equipment additions to the host office, the addition of offices to the DDD network, changes to routing strategies, etc.

Data which varies on a per call basis is stored in, basically, one of two storage areas; the trunk register or the call register. Each CCIS trunk has three 20-bit words of temporary memory devoted to storage of transitory information. Contained in this area are such items as the trunk's state during call setup and whether this trunk is being used as an incoming or outgoing trunk. The other major storage area for per call information is the call register. Stored here are such items as the digits which were received from the previous office, any special instructions which were received, and the status of the call at all times during the processing. Unlike trunk registers, the call register is not associated with any piece of hardware. Instead, 127 call registers are provided in each 4A/CCIS office. Each call register is 14 20-bit words long. Any call register may be used to process any CCIS call. Because of its very central nature, the call register is the subject of very close scrutiny at all times. Many call failures are noted first by inconsistencies in the state or contents of the call register. Due to the limited number of call registers available for system use, every reasonable precaution is taken to limit the time during which a single call register is associated with a given call.

The storage of the generic program, the office data, and provision of all temporary memory requires nearly 400,000 20-bit memory locations. In addition to a complement of conventional trunks, this memory space will accommodate the data and associated routing translations for between 4,000 and 7,000 CCIS trunks. Additional trunks each require approximately eight to thirteen 20-bit words of memory depending on trunking patterns and exclusive of any route translation changes which might be implied by any such addition. If additional storage is required, a duplicated module of memory (65,536 20-bit words) is added to the system. This should be sufficient to support the maximum expected number of trunks.

VI. CALL PROCESSING

6.1 Call types

A given office will have a combination of CCIS and conventional signaling trunks. This creates four basic call types for the call processing programs to deal with: conventional incoming and outgoing, CCIS incoming and outgoing, CCIS incoming and conventional outgoing, and conventional incoming and CCIS outgoing. These basic call types are further modified by whether the connection is to or from a 2-wire or 4-wire switching office. The call processing programs are arranged to accommodate any of these combinations of call types. By far the greatest software involvement is for a CCIS incoming call which is switched to a CCIS outgoing trunk. The conventional incoming to conventional outgoing call has been previously described.[3]

The processing of a CCIS call is separated into a number of real-time segments. These real-time segments are largely created by the interaction of the software with the hardware at various stages of the call. Because of these many interactions, the call register is used to store the details of the call as it progresses.

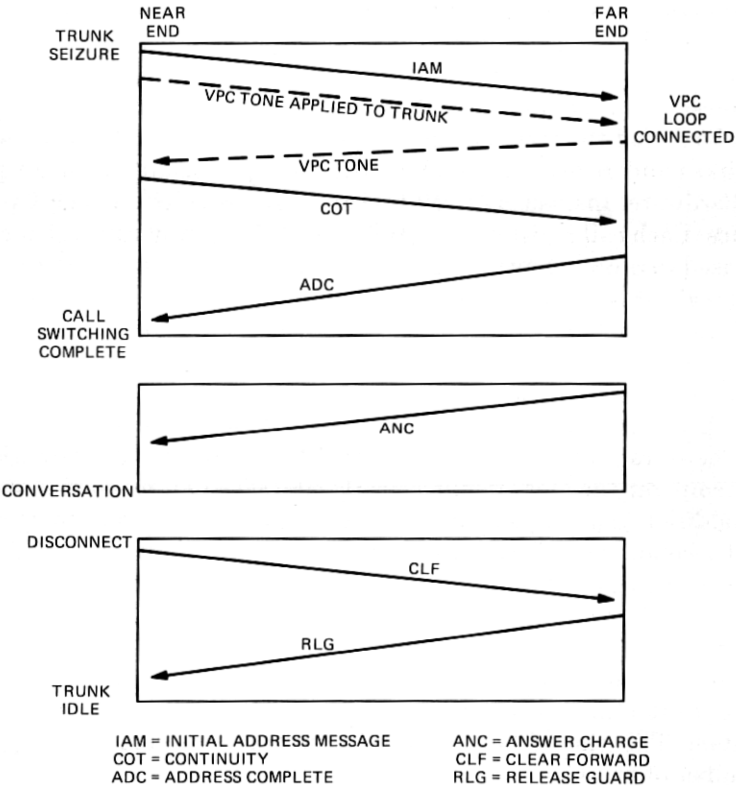

Fig. 4—Typical signal unit exchange.

6.2 CCIS incoming call

6.2.1 Incoming trunk seizure

A simplified sequence of CCIS signals exchanged on a CCIS to CCIS call is shown in Fig. 4. The first stimulus is the reception of an Initial Address Message (IAM). This multiunit message contains the identity of an incoming trunk which has been selected by the preceding office and the called number which will be used for the purpose of route translation. Upon receipt and decoding of the IAM, the status of the identified incoming trunk is changed to indicate it has been selected. A call register is selected and the associated temporary part of the trunk register and call register are linked together. The called number digits, which were received in the IAM, are deposited in the call register. At this point a route translation is made to select an outgoing trunk. If a CCIS outgoing trunk is selected its trunk register is linked to the incoming trunk register and to the call register, the trunk is marked busy to prohibit its selection by another call, and the IAM to be sent to the succeeding office is formed and transmitted via a CCIS signaling link. The selected trunk's identity is stored in the associated call register. Next, the distribute point assigned to the incoming trunk is operated under program control to connect a transmission loop in the incoming trunk circuit so that the preceding office may complete its Voice Path Continuity (VPC) check of the trunk, and to start the selection of an idle outpulser.

If the first available outgoing trunk group selected contains conventional signaling trunks, route translation is deferred since the marker will select the outgoing trunk.

6.2.2 Link controller stage

The next software action for this call occurs when a link controller notifies the processor that it is attempting to establish a connection between an incoming trunk and an outpulser. The validity of the request is checked and if a legitimate incoming CCIS trunk is identified the link controller is notified, via program controlled distribute points, to complete the connection between the incoming trunk and the outpulser. The identity of the outpulser is recorded in the call register and the identity of the incoming trunk is stored in the temporary memory associated with the outpulser (referred to as the STORE table). The outpulser is also conditioned for incoming CCIS operation and performance of a 2-wire or 4-wire continuity check with the preceding office by means of program controlled distribute points. The call register state is advanced, ending this real-time segment. When the outpulser has been attached, a scan point will report that the outpulser is busy. The call register will then be updated to indicate that an outpulser is attached and no additional program interaction will be required at this stage.

6.2.3 Completion of incoming VPC check[5]

During all these operations other activities which occur but require no immediate action will be recorded in the call register. It is possible, for instance, that the preceding office could have successfully completed the VPC check of the trunk. In this case a COT message would be transmitted by the preceding office. When received, the event is recorded in the call register but if this office is not ready to transmit COT to the succeeding office, no further action is taken.

6.2.4 Decoder channel stage

The next hardware stimulus that should occur is the decoder channel request for service. This request will occur immediately following seizure of the outpulser if the preceding CCIS office is a 4-wire switching office. However, for calls from 2-wire offices, the outpulser will have been instructed to delay decoder channel seizure until the preceding office has completed the continuity check of the interconnecting transmission path. When the COT message is received from the 2-wire office, the outpulser is directed by the processor to proceed with decoder channel selection.

As part of its input, the decoder channel will identify, via scan points, the outpulser with which it is currently associated. Based on the identity of the outpulser the incoming trunk's identity will be retrieved from the STORE table. Since the incoming trunk is CCIS, the STORE table will contain the index of the incoming trunk unprotected trunk register. This will be used to retrieve the identity of the associated call register which had previously been stored in the trunk register. The call register is updated to indicate which decoder channel is being used on the call. The results of the route translation, which was performed when the IAM was received, are distributed to the decoder channel via distribute points. However, the first available outgoing route may have contained conventional trunks, therefore, outgoing trunk selection was deferred. Route translation is then repeated at the decoder channel stage and either a CCIS or conventional route may be selected, depending on the characteristics of the first available outgoing route. Selection of a CCIS trunk results in sending an IAM to the next office and the distribution of the outgoing trunk identity to the decoder channel. An incoming conventional call is also connected to a CCIS outgoing trunk in this manner. If a conventional outgoing route is chosen, the processor distributes the trunk block connector location of an idle trunk subgroup to the decoder channel's distributor register and the marker selects an idle outgoing trunk to complete the connection in the normal manner. The called number digits to be outpulsed to the next office are also distributed to the decoder channel and passed to the outpulser through the decoder connector.

6.2.5 Marker stage

When the decoder channel requests release, it is the signal that the marker has been selected. This information is received via scan points associated with the decoder channel. At this time an idle transceiver is selected to perform the VPC check on the outgoing CCIS trunk and its identity is passed to the marker via distribute points. The decoder channel distribute points are reset so that it may release.

When the marker connects the selected transceiver, the transceiver activates a scan point. Recognition of this stimulus causes the program to distribute to the transceiver the information necessary to set the proper tone levels for the VPC check. Once again the state of the call register is updated and another real-time segment ends.

During this time the marker is also attempting to make a connection between the incoming and outgoing trunks. If it is successful it will report success to the processor via scan points associated with each marker. The success of the cross-office connection is noted in the call register. The program now waits to be notified that the VPC check has been completed. If the COT message has been received from the preceding office and there is indication of a successful cross-office connection, the COT message will be sent to the succeeding office and the transceiver will be reset. When the transceiver reports that it is idle, the outpulser will be released. The program waits for the indication that the outpulser has been released and updates the call register.

6.2.6 Call completion

Two stimuli remain before the call reaches the talking state. The first of these is the Address Complete (ADC) message which indicates no reattempt of this call will occur and that all address information may be erased. At this time the call register is released and the ADC message is relayed to the preceding office. The final signal to be received is the Answer Charge (ANC) message. When this message is received the unprotected trunk registers are updated to the answered state and the ANC message is sent to the preceding CCIS office. The call is now in a stable talking state.

If the incoming trunk is a conventional trunk, the answer signal is passed backward by program operation of the distribute point associated with the outgoing CCIS trunk.

6.2.7 Call termination

When the call terminates, several additional CCIS signals will be exchanged. Suppose the calling party disconnects first. A Clear Forward (CLF) message will be received from the preceding CCIS office. The incoming trunk's distribute point is reset to start release of the incoming trunk and the cross-office connection. When the incoming trunk reports release via its scan point, a Release Guard (RLG) message is returned to the preceding CCIS office. The incoming trunk status is then changed to idle. Release of the outgoing CCIS trunk from the cross-office connection is indicated via its associated scan point. After a short interval, to assure complete release of the outgoing trunk, the CLF message is sent to the succeeding CCIS office. Upon receipt of RLG for the outgoing trunk, its software state will be changed to idle thus permitting selection for another call.

6.2.8 Ineffective attempts and reattempts

If, during the translation or processing of a call, it is determined that the call should not be permitted to complete, the preceding office can be so notified via CCIS signals. This condition may arise for any number of reasons. A good example of this capability occurs when a customer dials a nonexistent or unassigned number. In this case a Vacant National Number (VNN) message is sent to the preceding office. It is the responsibility of the preceding office to repeat the VNN message to its preceding office if that incoming trunk is CCIS, or if the incoming trunk is a conventional signaling trunk then a reattempt of this call must be made to route the call to the appropriate announcement. By using these failure messages, it is possible to eliminate some unproductive use of trunk facilities. A failure indication may be received at any time during the processing of the call until the ADC message is received. If the incoming trunk uses conventional signaling, a reattempt signal is sent to the sender to initiate the release of the initial connection. Another decoder channel seizure is required to obtain an announcement routing.

This same mechanism may be used to reattempt a call following detection of simultaneous two-way trunk seizure. When the reattempt occurs, it is necessary to release all common control equipment which may still be processing the initial attempt. The marker will accept a trouble release distribution from the processor to expedite release of the CCIS trunk. Link controllers and decoder channels are similarly arranged to accept the trouble release signal during their normal operation.

VII. NETWORK MANAGEMENT

7.1 General

Network management, the capability of modifying routing patterns and controlling the flow of certain types of traffic in a real-time response to congestion in the switched network, has always been provided in the 4A/ETS system. Due to the limited role of the ETS switching processor in call handling and the inability to carry call history information between offices with conventional signaling, it was not possible to provide many useful network management features.

Modification of 4A/ETS for CCIS operation has eliminated many of the constraints on network management capabilities, and the 4A/CCIS system offers several new and expanded features. Two of the new features take direct advantage of the interoffice communication capability afforded by CCIS.

7.2 CCIS dynamic overload control

The first of these new features, CCIS Dynamic Overload Control (DOC), permits an office that encounters an overload to automatically communicate a distress signal to all connecting offices by the broadcast of a series of DOC signals over the CCIS signaling links to those offices that normally originate telephone traffic to the office. Upon receipt of a DOC signal, the connecting offices will cancel or alternate route portions of its outbound traffic for that office for a brief timed interval or until another message is received canceling the DOC condition. The amount of traffic being alternate routed or canceled is determined by parameters previously set and the level of congestion defined by the received message. Three levels of machine congestion are defined ranging from a relatively mild overload to a complete loss of switching capability. One determination of machine congestion state is made by monitoring the average time between reentries to class E base level work. When this average time is noted to exceed certain threshold values, the proper DOC message is broadcast repeatedly until the condition subsides, at which time messages will be broadcast indicating that the situation has returned to normal.

7.3 Out-of-chain routing

Another new feature makes use of the CCIS capability of sending call history information along with the call address information as a traveling classmark. Without CCIS, it is necessary to be very careful about the routing treatment given calls which overflow from first choice or direct routes. Normally such overflow traffic is offered to a fixed series of alternate routes intended to route the traffic upward in the switched network hierarchy. Rules for specifying these alternate routes are carefully defined to prevent a "ring-around-the-rosy" condition from occurring, and calls thus routed are said to be routed "in-chain." Certain abnormal events, such as peak busy days or machine failures, however, occasionally make it desirable to temporarily establish an "out-of-chain" routing pattern. Without CCIS, such out-of-chain routing must be carefully set up to prevent the "ring-around-the-rosy" condition. To avoid this condition with CCIS, a traveling classmark has been established to describe when a call has been routed out-of-chain. Such a call can then be prevented from being rerouted at subsequent switching points.

7.4 Code blocks

With CCIS the switching processor has access to all of the address digits of a call making it possible to expand code blocking capability to include seven or ten incoming digits rather than the three or six digit capability of 4A/ETS. Certain abnormal network events, such as mass calling to a particular number due to a telethon program or natural disaster, make it desirable to regulate as close to the sources as possible the number of attempts being offered to the network destined for that station without disturbing traffic that may be destined for that same local area but not related to that particular event. With seven or ten digit code blocking capability this can be done, and the control can be specified for application to one of several different percentages of traffic bearing those address digits. Choice of the individual calls to the specified destination to which the control is actually applied at a given percentage level is determined by a random number technique.

7.5 Selective trunk reservation

Another new feature with 4A/CCIS is that of trunk reservation. This feature takes advantage of the fact that selection of the trunk to be used from an outgoing group which uses CCIS is done by the switching processor. With this feature active on a trunk group, when the number of idle trunks in that group falls below prespecified thresholds, controls are applied to the outgoing traffic being offered to that group so as to favor incoming and direct routed outgoing rather than alternate routed traffic accessing the remaining trunks.

7.6 Expanded capabilities

In addition to the implementation of the new features described above, the numbers of controls that can be simultaneously active in the office has been considerably expanded, as has the selectivity of the portions of the traffic load affected by each control. New teletypewriter input messages have been designed to provide for manual activation of the new and enhanced control capability, and new status messages have been provided for display of controls in effect in the system and to describe which trunk groups have controls applied.

VIII. SYSTEM REAL-TIME CAPACITY

There are many different ways in which to describe the real-time capacity of a switching system. One of the most easily understood is to define an upper limit for processor occupancy, make some reasonable assumptions about the characteristics of the incoming traffic, and then describe the number of incoming trunk terminations that can be supported under those conditions. One must also, however, keep in mind any other system characteristics that may also limit system capacity. In the case of 4A/CCIS, the limit of 135,000 marker attempts per hour must be considered as such a limit.

For the 4A/CCIS system, usable processor occupancy of 80 percent can be assumed as a reasonable upper limit. Also, one can assume that each equivalent one-way incoming trunk offers an input of ten calls per hour, that the incoming calls will be divided between conventional and common channel signaling in the same ratio as their respective numbers of trunks, and that these incoming calls will be switched to trunks having conventional versus common channel signaling again by the ratio of the number of trunks of each type. These latter two assumptions are necessary because of the wide variation in the amount of processor time required to switch the different call types.

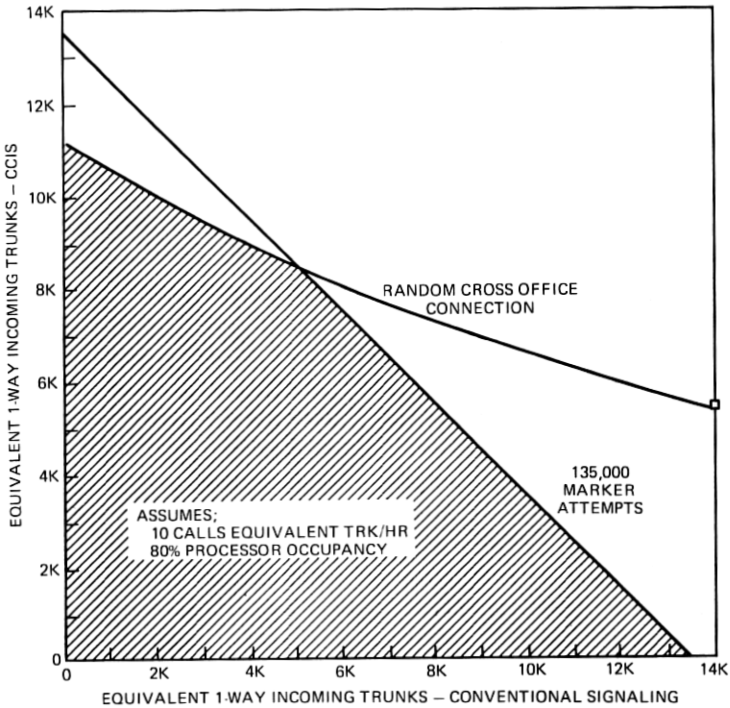

Fig. 5—4A/CCIS switching office equivalent one-way incoming trunk capacity. Cross-hatch indicates operating region.

Within the above assumptions, studies indicate that for numbers of CCIS equivalent one-way incoming trunks exceeding approximately 8000, the switching processor is the limiting element in the system; the maximum number of equivalent incoming CCIS trunks that can be handled is about 11,000 (15,400 actual incoming terminations on the average), if no trunks are provided with conventional signaling. For numbers of conventional equivalent one-way incoming trunks exceeding 8000, the total number of marker attempts becomes the limiting factor; in this range the processor real time will not impact the system's switching capacity.

Sensitivity analysis of the effects of variations in the distribution of the types of cross-office connections has been made. The position of a particular switching office within the toll network hierarchy and variations in the types of traffic which it switches, whether predominantly intertoll or toll connecting, may skew this distribution one way or the other. This analysis has shown that the crossover point between a processor real-time constraint and a marker attempt constraint is shifted very little by these variations. Further, these variations were shown to have a nearly negligible impact on the number of trunks that can be handled in the region in which processor real time is the dominant factor. A summary of these conditions is shown in Fig. 5.

IX. MAINTENANCE

9.1 General

A major factor in the success of a telephone switching system is the ability to provide continuous service regardless of component failures. The component failure rate is minimized by the use of highly reliable components in conjunction with adequate circuit margins. The effect of failures on the system, and hence the required maintenance strategy, depends on the degree of concentration of system control. In the CCIS addition to the 4A/ETS, concentration of control varies widely, from the Distributor and Scanner (DAS) which controls a large portion of the system operation, to the individual trunks which provide one message circuit capability. In addition, the 4A/ETS, as well as the CCIS addition, contains a mixture of electronic and electromechanical technologies. The CCIS maintenance features which provide fault recovery and repair, as discussed below, take into account the number of units, system function and hardware technology of each unit to produce a maintenance plan which is compatible with the existing 4A/ETS operation.

9.2 Electronic frames

The implementation of CCIS in 4A/ETS requires the addition of two electronic frames, namely the Distributor and Scanner (DAS) and the Terminal Group (TG).[5] Since these units contain a high concentration of system control, the maintenance requirements are strict, and are summarized below:

(*i*) Immediate detection of all service affecting faults.
(*ii*) Detection of nonservice affecting faults at a rate which is significantly greater than the occurrence rate.
(*iii*) Proper system operation in the presence of any single fault.
(*iv*) Moderate repair time by office craft.

The general fault reaction sequence for the DAS and TG, as well as existing 4A electronic units, is shown in Fig. 6. The primary fault detection ability resides within the individual units, in the form of additional circuitry or software which verify circuit operation, and in the central processor to individual unit communication checks. When a fault is detected, normal processing is interrupted and a special program sequence is executed. This program localizes the fault to an individual unit and reconfigures the system to avoid the suspected circuit. At this point normal processing is resumed with an interleaved diagnostic scheduled. The craftsperson upon examining the diagnostic results effects repair,

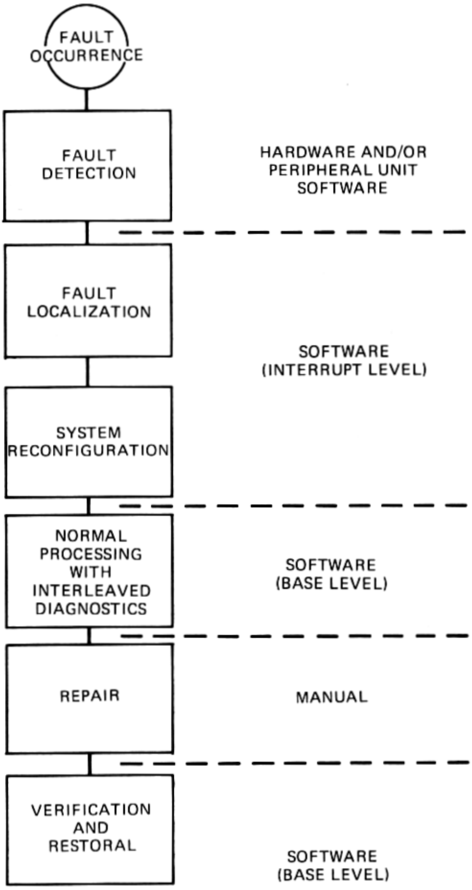

Fig. 6—Fault reaction sequence.

verifies correct operation using the diagnostic program, and returns the unit to service. Both the DAS and the TG follow this sequence; however, there are some differences in the implementation which are discussed below.

9.2.1 Distributor and Scanner

The DAS unit consists of duplicated controllers which access a non-duplicated matrix of scan and distribute points. In the normal mode, the two controllers are running in synchronism and comparing results at critical points in the operation. This matching operation is the major detection mechanism for controller faults. If a mismatch occurs, both controllers immediately stop and signal the central processor. When the processor begins to service the DAS, an immediate interrupt sequence is initiated.

The nonduplicated matrix is designed such that matrix faults affect only a small number of scan and distribute points. The majority of these faults are detected by normal operational checks of the circuits which utilize the points. The maintenance plans for connecting circuits provide for resolution and repair of this class of matrix failures. The remaining matrix faults are detected by the controllers when the point is accessed. Controller detected matrix faults result in the same sequence of actions as controller faults.

When the processor is interrupted, as a result of communicating with the DAS, a fault recognition program is entered. The major object of this program is to distinguish controller faults from matrix faults and take the appropriate action. In the case of controller faults, the failing controller is identified, the system is reconfigured to operate with the remaining controller, and a diagnostic of the faulty controller is scheduled. In the case of matrix faults, the affected scan and distribute points are located and further interrupts on these points are inhibited by setting hardware controls within the DAS. On a deferred basis, the circuits which connect to these points are identified and either automatically removed from service or reported for manual attention, depending on the connecting circuit type.

The diagnostic output identifies the suspected circuit pack or packs to the craftsperson who implements repair. After the repair has been completed the diagnostic is manually requested in order to verify proper operation as well as to restore the system to the normal configuration.

9.2.2 Terminal group frame

The terminal group frame consists of two duplicated Terminal Access Circuits (TAC) and up to sixteen terminal units. The TACs are self-checking and each circuit has full access to all sixteen terminals. Each terminal is a self-checking stored program unit capable of controlling one signaling link. For reliability each signaling link, including the terminal unit, is duplicated.

Faults detected by either a terminal unit or one of the TACs results in a processor interrupt on the next processor access, causing the terminal fault recognition software to be entered. The major function of the fault recognition routine is to distinguish between TAC and terminal faults and to perform the appropriate system reconfiguration. In the case of TAC faults, the failing TAC is identified, scheduled for diagnosis, and the system is reconfigured to use the remaining unit. In the case of terminal faults, the faulty terminal is removed from service and scheduled for diagnosis. Whenever a terminal is removed from service, the signaling network must be reconfigured to use the mate signaling link as described in the next section. The repair, verification and restoration to service procedure for the TAC and a terminal are similar to that of the DAS controller.

9.3 Signaling links

The CCIS signaling link consists of a terminal unit, including modem, at each end of a Voice Frequency Link (VFL).[6,9] CCIS switching offices exchange information over these signaling links in the form of messages consisting of one or more signal units. Because of signaling delay limitations, the occupancy of each signaling link, at the present 2400 bps transmission rate, is approximately 0.6 erlang (six-tenths of the available signal unit slots carrying messages). Assuming each trunk produces an average of ten call attempts per hour, approximately 3000 trunks may be assigned to a signaling link. If only one signaling link were carrying the signaling traffic for these trunks, a signaling link failure would result in a total loss of signaling for all trunks assigned to that link. Therefore, all switching office links are equipped in load sharing pairs, called signaling link complements. Normally, each signaling link carries traffic for up to 1500 trunks, but in the event of failure of one link, the mate link can carry the traffic for all 3000 trunks without excessive signaling delays. Because of the large number of trunks that may be served by a link complement the availability requirements are strict and the reliability of two links is, in some cases, insufficient. Thus a signaling link can be equipped with two voice frequency links, one normally in service while the remaining VFL provides a switched backup. After a failure of the in service VFL, signaling capability can be recovered after a short time by using the standby VFL. During this recovery time the mate link, if available, carries the entire load.

Signaling links directly interconnecting two CCIS switching offices are called fully associated links, or F-links. Normally, trunk groups are not large enough to economically justify F-links. Instead, each switching office connects to each of the Signal Transfer Points (STPs) in the same signaling region over what are referred to as A-links. The A-links are always provided in pairs (complements) and are not associated with a particular trunk group. Each message, consisting of one or more signal units, has a 13-bit label field in the first signal unit. Each trunk is uniquely identified with this label in conjunction with an associated signaling link; thus each duplicated pair of signaling links can support the signaling traffic for up to 8192 trunks. However, as noted earlier, queuing delays limit this to about 3000 trunks. The STP, using routing data, transfers CCIS messages to the distant switching office over the signaling network. Routing at the STP is based on the incoming signaling link number and the incoming label. Note that, in addition to routing messages between links, a portion of the incoming label is translated at the STP. Thus switching offices at each end of the trunk can uniquely identify the trunk by a label which is independent from the label in the other switching office. An administrative process has been established to coordinate labels with trunks at both switching offices and with the STP translation data.

9.3.1 Signaling link fault detection

Terminal faults have already been discussed in Section 9.2. Many other faults, primarily due to transmission impairment in the voice frequency facility, do not cause maintenance interrupt level activity, yet must be recognized since the link becomes useless for signaling. To accomplish this, the terminal checks each signal unit to ensure that it has been received error-free and detects unacceptably high error rates. If the acceptable error rate is exceeded, the terminal notifies the processor that this link is currently not suitable for carrying traffic. The signaling link failure initiates the fault reaction known as changeover, discussed below.

Many facility failures are only in one direction of transmission; however, the CCIS system requires signaling capability in both directions. Hence, when the processor is notified of an excessive error rate, it places the terminal in a mode which continuously sends a specially coded signal unit, changeover, to the far end. On receiving changeover signals, the processor at the far end is aware of the signaling link failure and also initiates the changeover sequence.

9.3.2 Signaling link fault reaction

When the processor receives notification of a signaling link failure a changeover sequence begins. The processor first places the terminal in a mode which retains all unacknowledged and untransmitted messages. Additional messages are diverted immediately to the mate signaling link, while the processor retrieves all untransmitted and unacknowledged messages stored in the terminal of the failed signaling link and retransmits them on the mate link. Some messages encounter a slight signaling delay, but none are lost.

Both ends switch immediately to the standby VFL if it is available and the processors attempt synchronization on the failed signaling link. Until synchronization is achieved, both ends continue to switch voice frequency links, the switching office at a five-second rate and the STP at a ten-second rate to assure overlap half the time. Because of facility diversity, synchronization is usually achieved on the initial attempt on the voice frequency link which was standby at the time of the failure.

When the signaling link is synchronized, each processor measures the error rate to determine the suitability for CCIS service. After a sufficient interval of acceptable performance, the processors at each end of the

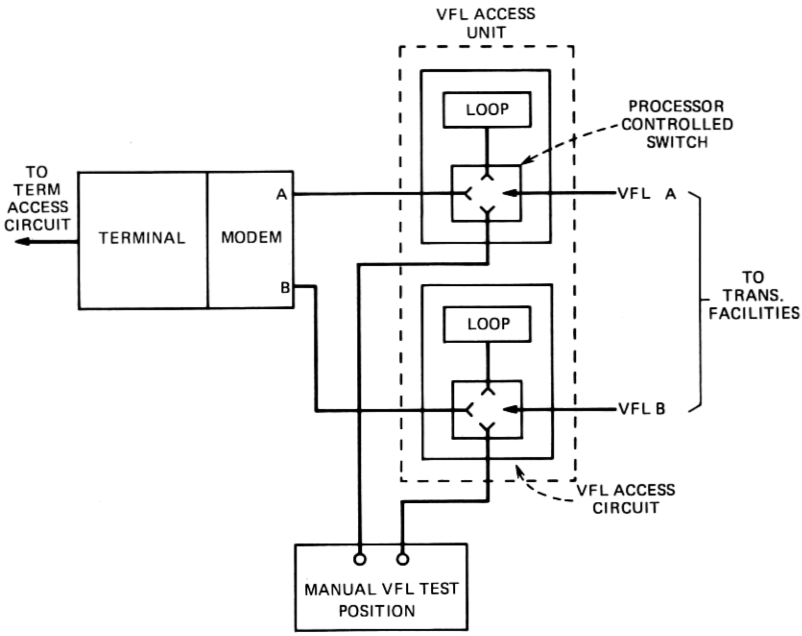

Fig. 7—Switching office VFL test arrangements.

signaling link exchange specially coded signals, load transfer, and load transfer acknowledgment. In addition, information concerning the condition of the signaling network which may affect routing, is received from the STP. Traffic can then be returned to the signaling link which equalizes the load between the restored link and its mate.

9.3.3 Voice frequency link testing capability

The error performance of signaling links equipped with single VFLs is continuously measured by the terminals at each end concurrent with normal service. A special testing capability is provided for A-links, since they may have a standby voice frequency link. Each STP has a maintenance terminal, used exclusively for VFL testing, and each switching office can loop back the standby VFL. The loop back ability, as well as manual test access, is provided by the VFL access circuit as shown in Fig. 7. When the signaling link is active, the two ends can exchange signals to schedule a standby VFL test. The STP maintenance terminal measures the error rate on this looped back facility and can signal the switching office of the pass/fail results. This test may be requested manually from either end, and is scheduled automatically by the STP several minutes after a signaling link failure to determine if the VFL should be reported to maintenance personnel.

Any VFL not actively carrying telephone traffic, including all standby VFLs on A-links, may be connected to the testboard for maintenance. The connection is made by manual request only at each end and is not preempted by any signaling link failures. The VFL must be manually removed from the testboard, at both ends, at which time the system VFL test mentioned above may be scheduled and the VFL returned to service. All VFL connections are controlled by the processor.

9.3.4 Automatic routines and measurements

Every 24 hours, just after midnight, each STP schedules an automatic voice frequency link transfer on half of its A-links. This ensures that all standby VFLs are tested and used by the system and exercises the transfer capability. This exercise is scheduled in such a manner that both members of a link complement are not transferred during the same 24-hour period.

A signaling link status report is printed hourly or on demand to inform maintenance personnel of all abnormal states. These states agree with those previously reported and with office visual status displays.

Every five minutes, the PBC[4] triggers the processor to read all of the plant and traffic counters stored in the terminal. These counts are immediately sent to the PBC for accumulation. In addition, the processor notifies the PBC on each signaling link failure, restoral, or other event needed for PBC exception reports and daily measurements.

9.4 Common control

9.4.1 General

Fault detection for the 4A electromechanical switching equipment resides in the individual common control circuits (link controllers, decoder channels, markers) which employ function timers and critical control lead monitors to sense equipment malfunction. Once a problem is encountered, a punched card record identifying call progress and all switching equipment engaged on the attempt is made available to the maintenance force for analysis. Typically a blocked attempt involves several switching elements, therefore, fault resolution requires analysis of a number of related trouble records to locate the faulty unit. After recording the fault, the common control circuit releases from the call and a reattempt is initiated, either by the sender or outpulser link connector for failures encountered by the link controller, or the decoder connector following decoder channel or marker failures. A different common control circuit is preferred on the reattempt to improve the probability of successful call completion.

The division of the 4A call switching process into distinctive stages, each executed by a dedicated set of common control circuits, coupled with the inherent redundancy resulting from multiple control units, provides an extremely high degree of tolerance to multiple faults. Furthermore, most faults have minor impact on system operation since they occur outside the common control circuits in the trunks and switching networks which comprise the bulk of the 4A electromechanical equipment. Once a faulty equipment unit has been identified by trouble card analysis, the offending trunk, sender, or common control circuit may be tested by office test frames to aid in trouble clearance.

9.4.2 Sender, outpulser, transceiver tests

Prior to CCIS, the Incoming Sender and Register Test circuit (ISRT) functioned as a semiautomatic test frame to perform a series of inpulsing, outpulsing and ineffective attempt tests on the incoming senders and DP registers. Once primed by the maintenance force for a particular test condition by means of keys and switches, the ISRT tests all applicable circuits in sequence. ISRT access to senders is achieved by a test relay which simulates a sender link connection. During the progress of the test, the sender is connected by its decoder connector to both a decoder channel and marker as for a service attempt, but no connection is established to an outgoing trunk.

Continuation of a manually assisted mode of operation was judged impractical in view of the direct processor control of sender functions on CCIS related attempts, as well as the increased testing load generated by the dual usage of senders as CCIS outpulsers and the introduction of continuity check transceivers. ISRT automation involves the substitution of memory relays for the keys and switches previously used to specify test parameters and for the wired sequencer which controlled selection of the circuit to be tested. The processor operates the memory relays at the outset of a test through a dedicated distributor register to specify both the test configuration and the circuit under test. Only the circuit identity distribution is changed as the test cycle advances through the circuits to be tested. Data for each test is stored in processor memory in a group of tables constituting a test catalog. Sender and outpulser requests for routing instructions during the decoder channel stage of the call are no longer dependent on service route translation. Instead the outpulsing instructions (class and either the called number to be loaded into an outpulser or the called number conversion instructions for a sender) are included in the test catalog for distribution to the decoder channel, thus permitting all possible test conditions to be applied regardless of office routing constraints. Continuity check transceivers are tested by a single test segmented into seven phases. Additional tests are performed to check that a sender or outpulser can successfully connect to each of its four assigned transceivers through the transceiver connectors.

The testing schedule is divided into high priority, time filler and low priority segments and a maximum of two ISRT frames may be controlled. High priority tests consist of about a dozen comprehensive tests and are run daily starting at 6:00 a.m. Time filler tests include all other normal service features while the low priority class primarily checks ineffective attempt treatment. The time filler tests are scheduled to follow the high priority tests and continue until 12:15 a.m. when the low priority tests start. Tests are executed continuously unless maintenance personnel interrupt with a demand request via a system teletypewriter to use an ISRT for trouble clearing purposes.

9.4.3 Decoder-marker test and trouble recorder

The trouble recorder is updated to add pertinent CCIS call progress and equipment identification items to the trouble record card. The processor distributes supplementary data to the trouble record, such as transceiver identity and the status of information scanned from common control units.

The Decoder-Marker Test circuit (DMT) is a manually operated test frame which serves to apply various operational conditions to decoder channels and markers. During a test, the DMT simulates a sender and uses the trouble recorder connecting relays of the decoder channel and marker as a substitute for the decoder connector to communicate with these units. The verification of CCIS functions in these common control circuits requires the processor to apply appropriate distribution patterns and/or check for particular scan reports to assist the DMT in the conduct of tests. Coded test instructions to the processor are entered through DMT switches which are connected during the test to the decoder channel scan field normally used to identify the sender attached to a service attempt. Each coded sender identity input instructs the processor to apply a specific test condition. Certain inputs also request the processor to read other decoder channel fields for additional test instructions. For example, to test the marker's ability to connect CCIS outgoing trunks, the outgoing link frame address of a CCIS trunk is entered on the DMT switches which correspond to the called number digit field. During the decoder channel stage of the test call, the processor distributes this address to the marker and then intercepts the CCIS trunk scan report following marker seizure to verify the test connection. The processor distributes test results to the DMT to light test progress lamps and provides additional detail concerning test failures via a system teletypewriter.

The DMT can also provide a rapid check of routing data. Any of the direct and alternate routes corresponding to a specific set of called number digits can be selected for verification and the associated route translation data displayed in a teletypewriter output message.

9.4.4 Outpulser link controller test

This processor controlled test frame tests the link controllers serving CCIS outpulser groups. All service and fault detection functions of the controllers are exercised daily. Processor communication with the test frame is accomplished by means of DAS distribute and scan points. Test results are outputted on a system teletypewriter and a test frame lamp display. Demand tests may be requested through a system teletypewriter.

9.5 Trunk maintenance

The task of the detection of faults within CCIS trunks has been delegated to a group of specialized test frames. These test frames can access any CCIS trunk as directed by manual request or by the trunk maintenance software during routine tests. Access to the trunk unit to be tested is normally through the 4A common control equipment which provide the requested cross-office connection. Using this maintenance approach reduces the amount of logic circuitry required within the trunk unit which would be dedicated to fault detection.

The three basic strategies used for trouble detection on CCIS trunks, along with examples of each, are the following:

(*i*) Per-Call Testing—Voice path continuity check test and retest procedure.
(*ii*) Routine Testing—Routine CCIS intraoffice test circuit testing, routine voice path continuity check retest, and routine transmission testing;
(*iii*) Manual Testing—Integrated manual trunk test frame testing.

The remainder of this section will discuss these strategies.

9.5.1 The voice path continuity check retest

Because on CCIS trunks the voice and signaling are routed separately, it is necessary, in order to prevent poor service and false billing, to verify that there is continuity over each CCIS voice trunk in turn before it is switched in a connection. To accomplish this a per-call voice path continuity check (VPC) is made on each trunk before the call is set up over the trunk, as discussed previously. If the VPC test fails, the call is reattempted on another trunk and the following maintenance actions are performed: (*i*) the failed trunk is temporarily taken out-of-service, (*ii*) a blocking message is sent to the far-end office over the signaling link, and (*iii*) the trunk is scheduled for a voice path continuity check retest.

The VPC retest is performed in the following manner (see Fig. 8). One of four continuity check retest access circuits are seized to initiate the

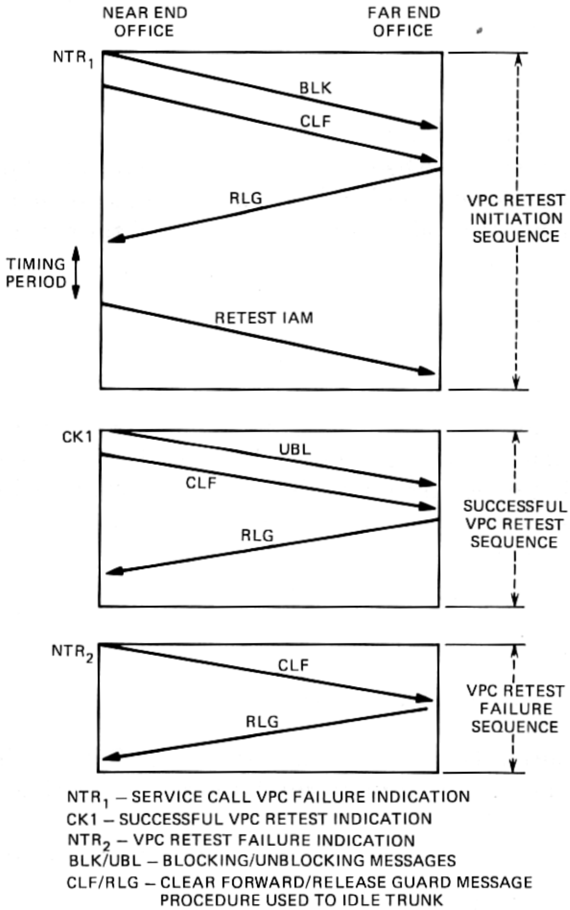

Fig. 8—VPC retest signaling sequence.

retest concurrent with the sending of retest Initial Address Message (IAM) over the signaling link. The access circuits are utilized to gain access to the continuity check transceivers and the failing trunk through the 4A common control equipment. If the terminating office is a four-wire machine, the transceiver will apply a 2010 Hz tone. The distant office in response to the retest IAM will connect the receive side of the trunk to the transmit side through a zero-loss loop. If the terminating office is a two-wire office, the transceiver transmits 1780 Hz. The terminating office, upon receipt of the retest IAM attaches a transponder to the incoming trunk and returns 2010 Hz upon recognition of the 1780 Hz tone. In either case the transceiver checks the level of the returning tone to verify that transmission loss is within acceptable limits.

If the trunk passes the voice path continuity check retest, the trunk is returned to service and an unblocking message is sent over the signaling link so that the trunk is available for service at both end offices. However, if the trunk fails the VPC retest, the failing trunk remains in an out-of-service state and the blocking message remains in effect at the far-end office. In this way a failed trunk is unavailable for normal call processing selection at both offices. In addition, maintenance personnel at the office which originated the VPC retest failure are notified of the VPC failure and the maintenance personnel at the far-end office are notified of a trouble at the connecting end of their trunk.

9.5.2 Routine trunk testing

Routine automatic operational testing of the 4A CCIS trunk relay circuit and cross-office transmission and signaling path is performed by the CCIS Intraoffice Trunk Test circuit (CIOT) frame. This processor controlled frame consists of four access circuits each of which is capable of performing a complete set of tests on any CCIS trunk. Each night at 11:15 p.m., the CIOT begins its testing routine. The routine begins with a series of tests termed self-tests which cause each CIOT access circuit to be tested against every other access circuit. The results of these tests are analyzed to detect a faulty CIOT access circuit and, if one is detected, the faulty unit is automatically prevented from being utilized in the routine trunk test sequence. In addition, the resulting diagnostic messages are provided for the maintenance personnel. Following the self-tests, the routine trunk test procedure will utilize all remaining CIOT access circuits to establish cross-office connections under processor control for testing the incoming and outgoing features of all CCIS trunks which are in service. If a trunk fails a routine CIOT test, it is immediately subjected to another test. If the second test is also a failure, the trunk is removed from service and the blocking message previously sent to the far-end prior to starting the CIOT testing sequence is allowed to remain in effect causing the trunk to be unavailable for call processing in both offices. If the second test passes, no maintenance action is taken. In either a single or double failure situation, the appropriate diagnostic messages are presented to the maintenance personnel.

Each morning at 6:15 a.m., the processor initiates the routine voice path continuity check retest sequence. The sequence is intended to provide detection of circuit failures before traffic is offered to trunks. Prior to the commencement of trunk test activity, a special test is run between the VPC retest access circuits and the CIOT access circuits to detect faulty VPC retest access circuits. As with the CIOT access circuits which fail self-test, VPC retest access circuits which fail this test do not participate in the routine trunk test sequence. The remaining VPC retest access circuits are used to perform tests of all the CCIS trunks in service.

If a trunk fails the routine VPC retest, the trunk is treated as if it had failed a per-call voice path continuity check. The procedures described in Section 9.5.1 then apply.

Routine automatic transmission trunk testing for CCIS trunks is available through the Automatically Directed Outgoing Intertoll Trunk Test frame (ADOIT) or the Outgoing Trunk Testing System (OTTS). In both systems, the test frame requests that a test call be established between it and a specific trunk. At the conclusion of the transmission test, the test frame may request that the trunk be removed from service due to a failure.

It should be noted that for all routine test procedures, limitations are placed on the number of trunks a single access circuit or test frame can automatically remove from service. These limitations were set to prevent a faulty testing unit from turning down excessive numbers of trunks.

9.5.3 Manual trunk test capabilities

While emphasis has been placed on the ability of the trunk maintenance software to provide routine and automatic trunk test capabilities, each trunk test mentioned in the previous sections can be requested on a manual single trunk basis for trouble clearance, circuit order work, or installation testing. Of particular interest is the CIOT which allows three of its access circuits to be used for manual testing. The CIOT has a detailed set of tests which, when coupled with the ability to continually repeat a test and test failure-oriented diagnostic message, allow improved trouble sectionalization.

The major portion of manual CCIS trunk testing is provided by the modified Intertoll (or Integrated) Manual Test Frame (IMTF). The IMTF may gain access to a CCIS trunk via a cross-office connection, a belt line connection at the trunk equipment frame, or the Switched Maintenance Access System (SMAS) if the office and trunks are equipped with this option. Manual transmission tests are performed to distant office 10× test lines for loss, noise, gain slope, return loss, and echo suppressor measurements. In addition to transmission tests the IMTF is equipped to perform operational tests such as DC continuity and cross-checks of transmission leads, answer supervision and ring forward operation, pad checks, and echo suppressor control. The IMTF is equipped with a *DATASPEED* ® Model 40 (DS-40) unit for communication with SPC processor. The DS-40 is utilized to initiate testing, to receive test results, to obtain both near-end and far-end software status of a CCIS trunk, and to change the software state of a CCIS trunk.

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