Common Control Telephone Switching Systems

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In the development of dial telephone switching systems two fundamentally different arrangements have been devised for controlling the operations of the switches. In one arrangement the switch at each successive stage is directly responsive to the digit that is being dialed. Systems using this method of operation are called direct dial control systems, an example being the step-by-step system as commonly used in the Bell System. In the other arrangement the dialed information is stored for a short time by centralized control equipment before being used in controlling the switching operations. Systems using the second arrangement are known as common control systems, examples of which are rotary, panel and crossbar. These two arrangements have different economic fields of use, the direct dial control being better suited for the smaller telephone exchanges and the common controls for the larger exchanges, especially those in metropolitan areas. A history of the evolution of these types of switching systems is presented, followed by a discussion of their comparative merits for various fields of use.

HISTORY

Invention of machines for switching telephone connections started shortly after the invention of the telephone. A forerunner of the step-by-step system, the Connolly and McTighe "girlless" telephone system,* was patented in 1879 and the first patent on the Strowger step-by-step system† was issued in 1891. The first commercial installation of automatic switching equipment was made at La Porte, Indiana, in 1892. This installation used step-by-step mechanisms.

In the early 1900's many telephone engineers regarded full automatic switching as uneconomical but technically feasible if restricted to single office exchanges with individual flat rate lines. They were, however, un-

* U. S. Patent 222,458—1879—Connolly and McTighe.
† U. S. Patent 447,918—1891—Almon B. Strowger.

certain about the future of this method of operation. It appeared to them that the greatest promise in the use of automatic apparatus was in distributing calls to manual "A" operators and in the elimination of the "B" operators. Consideration was being given to systems capable of operating on either a semi-mechanical or a full mechanical basis depending on whether the dial was located at the "A" board or at the subscriber's station. Development was also under way to provide arrangements for trunking calls between dial offices and to overcome the numerous weaknesses and deficiencies of existing dial systems.

The Strowger Company, the Bell System, and several other companies were planning or developing automatic and semiautomatic systems at that time. These included the full automatic, the network automatic, the automatic operator, and the semiautomatic. Short descriptions of some of them follow.

EARLY FULL AUTOMATIC SYSTEMS

The full automatic systems were mostly direct dial control. They included the Strowger, the Western Electric 100-line and 20-line, the Clark, the Faller* and the Lorimer systems.

The Strowger system of the middle 1890's provided 100-point two-digit selectors, one for each line. For each group of 100 lines the 100 outlets of each selector were multipled to the corresponding outlets of the other selectors serving the group. Each outlet of the group ran to a two-digit connector, each connector having access to 100 lines. Thus every group of 100 lines had 100 selectors and a maximum of 100 connectors and could reach 10,000 lines in a full office. Each group of connectors, up to the maximum of 100 connectors per group, had a multiple of 100 terminating lines. This was therefore a 4-digit single-office system theoretically of 10,000 lines capacity, requiring 1 selector and 1 connector per line. Subscribers in a given originating group of 100 lines had only one path to a particular terminating group of 100 lines. Since a selector was provided for each line, no dial tone was necessary. The switches used the familiar up and around motion. The exchanges of this type that were installed were small, the largest being in the order of 1000-line capacity. This type was followed by a new arrangement when automatic trunk selection was introduced. This provided multiple paths to each terminating group of 100 lines; the selector at this stage became a single-digit switch.

The Western Electric 100-line system could actually serve only 99

* U. S. Patent 686,892—Ernest A. Faller—Nov. 19, 1901.

lines. (The record does not disclose why one of the terminals of the system could not be assigned.) It used a rotary selector per line directly driven by a single train of pulses generated by a lever operated dial at the station. The selector had 100 points and the number of pulses sent corresponded to the number of the called line. The 20-line system was similar to the 100-line system.

The Clark system was a single motion rotary step-by-step system using 75-point switches which accommodated a maximum of 74 lines. (Here again there is no record as to why one terminal was not used for a line.) It did not provide a busy test. There were no relays in this system.

"AUTOMATIC OPERATOR" SYSTEMS

The Faller and the Lorimer systems were called "automatic operator" systems but they were actually versions of direct dial. The Faller system was apparently never used commercially, but the Lorimer system was.

The inventors of the Lorimer system had several objectives. One was to produce a system which could be installed in 100-line building blocks, called sections. As little as one section could be installed and operated alone. Additional sections in increments of 100-line capacity could be added as required up to the limit ot 10,000 lines. Another object was to get good contacts and they therefore employed switches with heavy contacts like those used in power switches. The power needed to drive switches with such contacts led to the adoption of a common power drive for a number of switches instead of electromagnets individual to the switches. Still another aim was to provide a minimum of equipment on a per line basis and to provide equipment only to the extent required by traffic. Line relays were therefore omitted in early offices and the 100-line sections were divided into divisions, maximum 10 divisions per section, with arrangements for omitting divisions if not required by traffic.

The Lorimer system was a direct dial system operated from a pre-set calling device. It had a line finder stage, a selector stage and a connector stage. The calling device, wound up by a crank, had four settable levers, one for each digit, each of which grounded one terminal in its own set of ten terminals corresponding to the digit set up. The levers also operated a visual indicator. In the calling device there was also a switch driven over its terminals by a magnet-controlled escapement. Pulses were sent from the central office to control the escapement and the central office equipment was driven in synchronism with the station switch until a grounded station terminal was found. The central office equipment was then stopped but the station switch continued stepping until the starting point for the next digit was reached. When the central office equipment was ready for the next digit the process was repeated until the called line was reached.

The Lorimer system has now disappeared from the scene in spite of a number of attractive features. The reasons for this disappearance are not clear from available records, but some reasonable conjectures can be made. For one thing, the pre-set calling device must have been expensive both in first cost and to maintain; it was also designed for a maximum of four digits and a re-design for more than four digits would have entailed substantial effort for developing both the calling device and the central office equipment. There is also some evidence to indicate that the system cost more than either step-by-step or panel.

THE NETWORK AUTOMATIC SYSTEM

The network automatic was a proposed form of semiautomatic in which the subscribers retained their manual instruments and were served by small unattended branch offices, each of which had a single group of trunks to a central operator office. On originating calls the branch offices acted as concentrators, automatically connecting calling lines to trunks to the central office where the operators were located and who asked for the called number as in straight manual practice. Called lines were reached through the branch offices by the operators at the central office who were provided with keysets to control the branch office equipment.

SEMI-AUTOMATIC SYSTEMS

There were several plans for other types of semi-automatic systems. Most of them contemplated replacing the "B" operator by a machine under control of the "A" operator. The plan of using machines under control of the "A" operators to replace the "B" operators was operated successfully in Saginaw, Mich. with Strowger apparatus. A similar plan was in operation in Los Angeles, and several groups of engineers studied improvements and variations.

STATUS IN 1905

The status of automatic switching by 1905 was this: there were several single office cities which had commercial installations of Strowger step-by-step equipment with severe limitations even for this field of use; a number of Western Electric Companv 100-line and 20-line automatics were in commercial service; a small amount of semi-automatic equipment was also in operation with the equipment under direct control of the "A" operator's dial; and planning and development work were under way to remove some of the limitations and extend the field of use of the automatic and semi-automatic systems.

The rotary dial was developed in 1896. However, many of the early systems did not use this type of dial. Various calling devices were used for a number of years. Among these were lever operated pre-set devices, keysets of several types, and dials with holes (in one case as many as 100) in which a peg could be inserted to act as a stop for an arm which was pulled around and allowed to restore. In all the early systems, regardless of the device used, the signals generated at the calling station directly controlled the selections.

RECOGNITION OF NEED FOR ACCESS TO LARGER TRUNK GROUPS

While mechanisms and circuits were being developed for direct dial control switching, work of a theoretical nature was going on which was to have an important effect on future designs. This work consisted of traffic probability studies and observations the outcome of which was the development of formulae and curves on the efficiency of trunk groups which influenced strongly the views of engineers as to the economical sizes of switches. G. T. Blood of the American Telephone and Telegraph Company in 1898 found that the binomial distribution closely fitted the observed data on the distribution of calls. The first comprehensive paper on the matter was one by M. C. Rorty in 1903, *Application of the Theory of Probability to Traffic Problems*. Curves accompanying his paper indicated that trunking efficiency improved with group size. Subsequent work by E. C. Molina in postulating that the grade of service experienced by a particular call applied to every call in the office and in developing the Poisson approximation to the binomial expansion formed the basis for trunking theory as used in the Bell System. Fig. 1 is a reproduction of three curves produced by Molina on July 6, 1908, showing the average load carried by various numbers of trunks for three probability conditions namely P.01, P.001 and P.0001 corresponding to an all trunks busy condition encountered by calls once in a hundred, once in a thousand, and one in ten thousand times respectively. From these curves it can be seen, for example, that ten trunks can carry a load averaging slightly over four calls with a probability of loss of P.01. Twenty trunks can carry an average of over eleven simultaneous calls with the same P.01 loss but with an increase of efficiency of 15 per cent. The efficiency rises from 41 to 56 per cent.

EVOLUTION OF PRINCIPLE OF TRANSLATION

These studies had considerable effect on the trend of system design. For example, it appeared that grouping subscriber lines on the connectors in groups of more than 100 might result in some economy and that other economies were possible if the limitations imposed by decimal selections were avoided.

However, a new invention, namely translation, was required before systems could operate with large access switches and non-decimal selections. Translation is a mechanical rearrangement which permits conversion of the decimal information received from the dial to non-decimal forms for switch control and other purposes. When translation is made changeable by some means such as cross-connections, it is the basis of much of the flexibility of common-control systems. Translation was first proposed by E. C. Molina late in 1905. A patent application* for a *Translating and Selecting System* was filed on April 20, 1906.

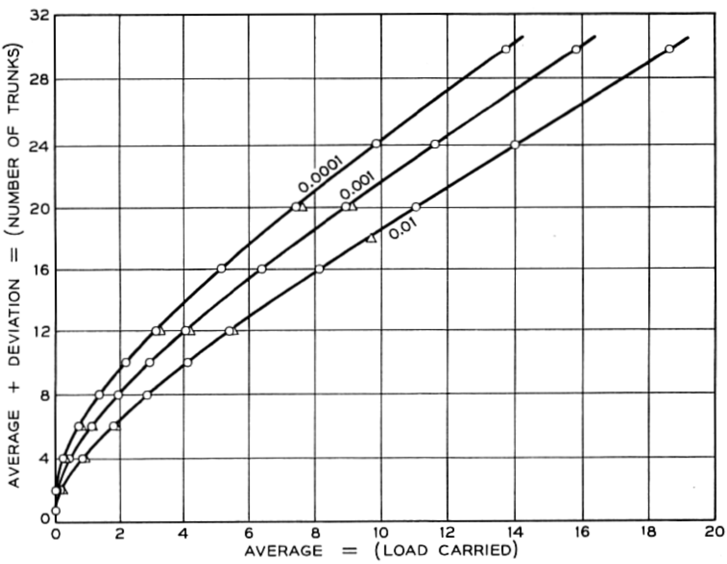

Fig. 2—Bypath system.

* Patent No. 1,083,456 issued to E. C. Molina, Jan. 6, 1916.

A necessary feature of systems employing translation of a series of digits such as an office code is digit storage. It was only a small step from the concepts of translation and digit storage to arrangements which provided these features in common circuits. Common controls with translation were first employed in the rotary system.

THE ROTARY AND PANEL SYSTEM DEVELOPMENTS

The rotary system was a full-fledged common-control system using register-senders to store the dialed information, to translate it to control the two-hundred point ten-level power-driven switches in selecting outgoing trunks from the originating office and in making line selections in the terminating office. The translation of the digits used for selecting trunks was changeable, but the translation of the numerical digits was fixed in permanent wiring of the register-senders.

In a search for less expensive cabling arrangements than those required by the rotary system, the panel bank employing punched metallic strips was developed. Each bank in the selectors of this system can accommodate 100 outlets with three wires per outlet, and five banks are stacked into a frame over which 60 power-driven selectors can hunt. For several years, starting in 1907, parallel development of the rotary and panel systems was carried on and desirable features of one were incorporated in the other. The panel system also has register-senders with changeable translation for selecting trunks and fixed translation for controlling selections in the terminating equipment. The major differences in the early designs of rotary and panel were due to the different access of the two systems and to differences in the methods of controlling the selectors. Both panel and rotary use revertive pulsing to control the selections. With revertive pulsing as the selectors progress they send back pulses which the sender counts. When a selector reaches the desired position, the sender stops it by opening the pulsing circuit. Both panel and rotary, like the Lorimer system, use a continuously operated power drive common to a number of switches because the increased size of switch which the greater access of these systems required, made a separate power drive economical.

The panel and rotary systems were originally designed for semi-mechanical operation with automatic distribution of calls to operators as a possible adjunct and with provision for full automatic operation if it proved desirable, by locating the dial or some other calling device at the subscriber's station rather than at the operator's position. This was a reasonable plan when development of these systems was started. Studies indicated that semi-mechanical systems could reduce the number of operators required by an amount ranging from 30 to 50 per cent by eliminating the "B" operators and increasing the efficiency of the "A" operators. At that time, full automatic systems were subject to a number of shortcomings such as the complications and unreliability of the pulsing device at the subscriber's station, the need for a local battery at the station, and the lack of arrangements for party line and message rate service. Furthermore, there was considerable doubt as to the ability of the subscriber to dial with acceptable accuracy the six or seven numerical digits required in some of the multi-office exchanges.

There was an acute need for relief from the difficulties of manual operation after the start of World War I. Telephone growth was so rapid that it appeared for a time that the demand for new operators, particularly in the large cities, might outstrip the available supply. Competition from other industry for female help was also increasing. As more offices were added, the situation was further aggravated by the increasing complexity of operation. On account of the increasing number of trunked calls, the growing number of central offices, and the increasing amount of manual tandem operation, the quality of service was being degraded.

DEVELOPMENT OF A LARGE CITY NUMBERING PLAN

By 1916, the full automatic system (Strowger) had established a competitive position with manual for single-office cities, and both manual and full automatic offices were considered to be more economical than semi-mechanical for such cities. Because the number of dial pulls for a single office was four or less, little concern was felt about dialing accuracy.

For the multi-office cities it appeared that full mechanical operation would improve service and be more economical than either the semi-mechanical system or manual and would reduce the pressing need for operators. However, in spite of these factors urging the adoption of a dial system and even though automatic equipment was actually used in Los Angeles and Chicago in the first decade of the century, there was a reluctance to adopt full automatic operation in the very large multi-office cities because of the lack of a suitable numbering plan. A cumbersome plan was under consideration for handling dial traffic in these cities. This required the use of seven-digit numbers with the dial customers being called on to use arbitrary three-digit numerical codes for the office names. At the same time, the existing office names would be retained for use by the manual customers. Adoption of this dual arrangement would have required the provision of a cumbersome directory, but worse than that, it was felt that dialing seven numerical digits would be too confusing to customers and that consequently there would be an excessive number of dialing errors. It was therefore planned to use semi-mechanical operation for cities like New York, retaining an operator between the customer and the machine. While this scheme did not save as many operators as the full mechanical method, it was believed necessary to have trained operators so that the customers would not be subjected to the complications of dialing. Under the proposed arrangement, the customer would pass the office name and number orally, and the operator would substitute the dial code for the office name and key or dial the code and number into the machine. Trial installations of the semi-mechanical panel system placed in service in the Waverly and Mulberry offices, Newark, N. J., in 1915 demonstrated that this method could provide reliable and improved telephone service under severe conditions.

However, in 1917 W. G. Blauvelt of the American Telephone and Telegraph Company proposed a numbering plan which would permit the customer to dial up to seven digits with acceptable accuracy and which would also be satisfactory for manual operation. This arrangement consisted of the use of one to three letters and four numbers. The first one, two or three letters of the office name were printed in bold type in the directory as an indication to dial customers that these were to be dialed ahead of the four numbers. Manual customers used the office name as before. Letters as well as numbers were placed on the dial plate in line with the finger holes of the dial. This proposal was immediately adopted and further Bell System development proceeded along the lines of full automatic operation. The Bell System planned to use the panel system in large cities not only because of the trunk efficiency which was possible with the use of the large panel switch, but also because trunking, being no longer under direct control of the dial in this system, was divorced from numbering. The panel system was also attractive because it had flexibility for growth and for contingencies such as the introduction of new types of service. These advantages would be provided by the common senders and translators of that system.

EARLY INSTALLATIONS OF COMMON CONTROL SYSTEMS

Early in 1918 tentative schedules were set up for 6-digit panel offices for Kansas City and Omaha and late that year a 7-digit office was recommended for the Pennsylvania office in New York City. When the Atlantic office in Omaha was placed in service on Dec. 10, 1921, it became the first commercial installation of a full automatic panel system.

Commercial installations of rotary equipment preceded the first commercial panel offices. A semi-mechanical rotary system was installed in Landskrona, Sweden, in 1915 but remained in service for only a short time. A similar system was installed later in 1915 in Angiers, France. The first full mechanical rotary installation was at Darlington, England, in 1914. This system is still in service.

A common control system using Strowger switches, the director system, was developed in 1922. This development was prompted by the desire to provide automatic equipment in the London, England, multi-office exchange where the layout of the outside plant required considerable tandem trunking if a reasonably economical trunk network was to be achieved. All of the outside plant in London for the manual system was underground and it was required that this arrangement be retained when dial equipment was installed. This tended to fix the routes of telephone cables and to make it expensive to open new direct routes as new offices were opened. The trunking economies of tandems were extremely desirable under this condition and common controls with translation were necessary for a practical scheme capable of operating with the tandems. The director scheme, which in principle parallels the sender-translator scheme of the panel system, was designed to meet this situation. The director system was first placed in operation in Havana, Cuba, in 1924 and later in London in 1927.

EVOLUTION OF THE MARKER PRINCIPLE

In retrospect, it is obvious that the development thinking up to the early 1920's was limited by the belief that it was necessary to have the selectors do the testing for idle trunks even with common controls. This arrangement had been successfully used in the step-by-step system and it was natural to follow the same plan in the panel, rotary and director systems. Subsequent development of the common-control idea, starting with an experimental "coordinate" system in 1924, has resulted in marker systems in which the trunk testing is done by the markers.

The coordinate system derived its name from the method of operation of its switch, the process resembling the method of marking a point by the use of coordinates. The switch was essentially a large version of the crossbar switch and selected and held a set of crosspoints by the operation of horizontal and vertical members. Translation of the called office code, selection of a trunk, and operation of the switches to connect a transmission circuit to the trunk were functions of a new circuit, the marker, which the sender called into use for a fraction of a second after it had received the office code digits.

When the marker does the testing for idle trunks the trunk access from a particular switch is no longer a limiting factor in the size of the trunk group. Once markers were invented it became possible to design systems using markers to do the trunk testing and any type of switch to do the connecting. When a trunk has been selected by the marker, the appropriate switches can be operated to connect to the marked terminal. The maximum size of trunk group need not be limited by the number of terminals on one switch. With a primary-secondary switch array groups much larger than those accessible on a single switch can be handled.

The coordinate system was not developed for commercial use. The first commercial marker system was PResident 2, a No. 1 crossbar office cut into service in Brooklyn, New York, in February, 1938. Improved crossbar systems have been developed since then including No. 5 crossbar and several types of toll crossbar systems

There is an interesting sidelight on the development of crossbar systems. The crossbar switch was invented by J. N. Reynolds of the Western Electric Company in 1913.* At that time proposed plans for using this switch assumed that it would be used as a line switch. The arrangements did not appear attractive and no serious attempt was made to develop a commercial system using the switch either as a line switch or as a selector. A number of years later an improved version of the crossbar switch was developed by the Swedish telephone administration. Their plans contemplated the use of the switch as a selector in a direct dial control system. In 1930 W. H. Matthies of Bell Telephone Laboratories visited Sweden and, impressed with the possibilities of the switch, ordered samples from Sweden after his return to the United States. Work was started to improve the switch and to develop a modern system around it. The crossbar switch, as previously mentioned, was a small version of the coordinate switch and the development of No. 1 crossbar was therefore started on a plan which was based on principles used in the coordinate system some of which had been successfully applied to the panel system with the adoption of the decoder in 1927.

TYPES OF COMMON CONTROL SYSTEMS

Four basic variations have been used in systems with common controls. These are (1) digit storage in common circuits on a decimal basis and control of switches by the stored digits without translation; (2) digit storage in the common circuits on a decimal basis, fixed translation and control of switches in a fixed pattern by the translated information; (3) a modification of the preceding plan in which the translation can readily

* U. S. Patent No. 1,131,734—J. N. Reynolds—issued March 16, 1915 and reissued December 26, 1916.

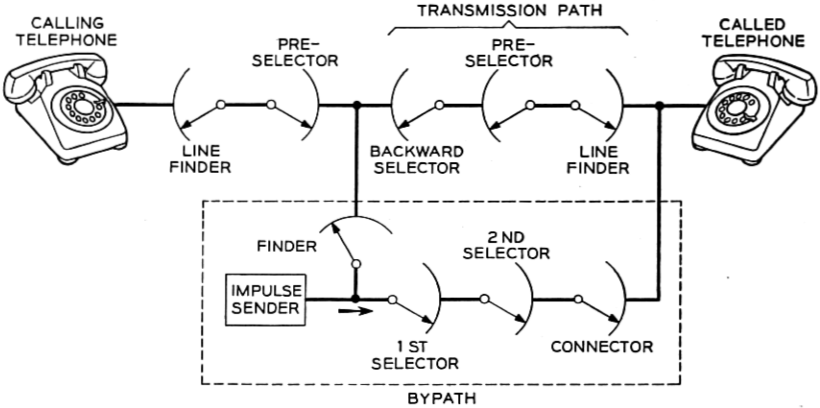

Fig. 1—Curves developed by E. C. Molina for trunk engineering.

be changed for any item of traffic; and (4) a still further variation where the function of hunting for an idle path is removed from the selectors and placed in new circuits called markers. Each variation resulted in improvements over preceding methods of operation.

The first plan is the simplest but also the least flexible. An advantage of this arrangement as well as of the other plans which also store the digits over step-by-step is that the interdigital time does not control the group size. By-path systems are examples of this method of operation. A system of this type is shown in Fig. 2. By-path systems use an auxiliary switch train that is under direct control of the dialed pulses to set up a connection. The talking circuit is then established over a parallel system of switches. The auxiliary train releases after the talking connection is set up and is available for use in setting up other connections. The Lorimer system avoided the penalties resulting from hunting during the interdigital interval by storing the digits at the station.

A further step in the direction of flexibility, but with added complication, can be taken by a *fixed* translation from a decimal to a non-decimal basis, i.e., a form of translation wherein a given decimal digit or a set of decimal digits is always changed into the same predetermined non-decimal equivalent. This permits the use of switches with less than ten groups of outlets thereby providing economies by permitting larger groups of outlets with a given size of switch.

A third variation with still greater flexibility than the first two, but also with greater complication, is a system with *changeable* translation. Changeable translation is achieved by providing some means such as cross-connections for readily changing the output pattern of the translators generally for sets of digits as, for example, for the called office

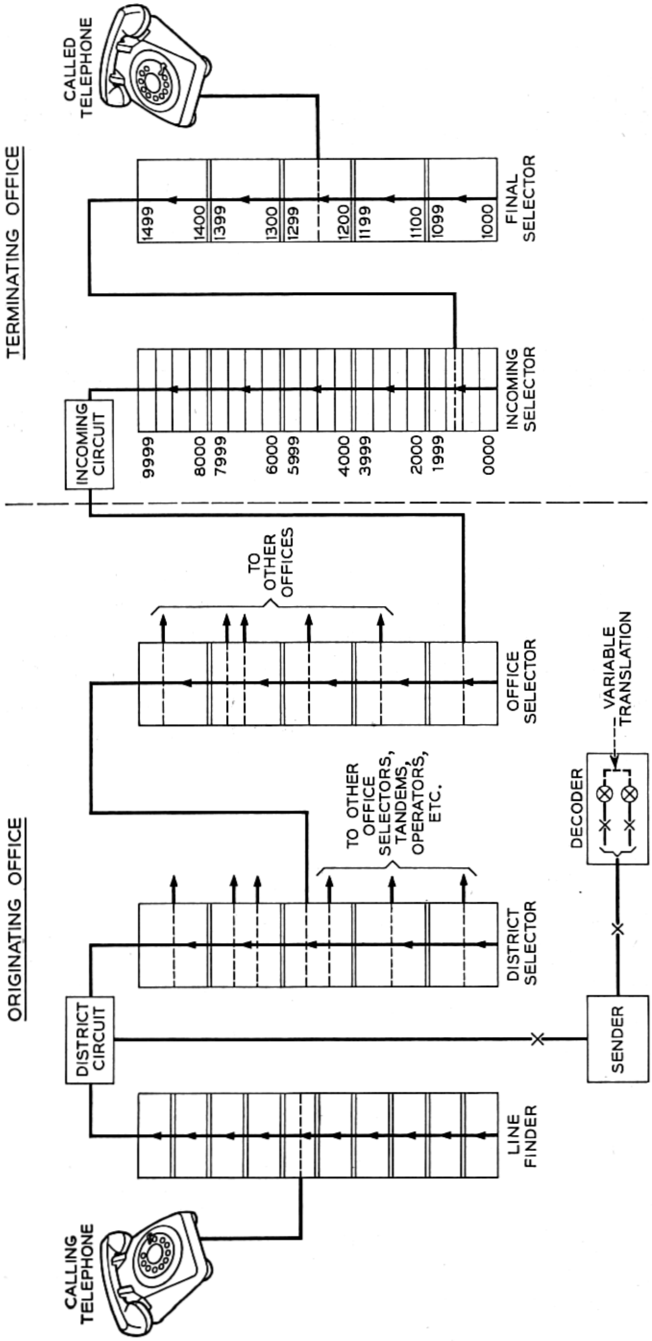

Fig. 3—The panel system.

codes. Changeable translation of office codes removes the limitation that the trunks for a given office designation must be located in a definite position on the switches which is the necessary result of fixed translation. Increased flexibility of numbering is now possible because office designation changes no longer require rearrangements of switch multiple. More economical arrays of switches are also possible because the switching plan can conform to traffic requirements without regard to numbering. Other advantages of translation—and as a practical matter, flexible translation—include the ability to operate with tandems, to operate with more than one type of outpulsing, and to operate with varying numbers of digits. The originating equipment of the panel system is an example of a system using changeable translation. This type of translation is also used for called line numbers as well as office codes in No. 1 and No. 5 crossbar thereby permitting these systems to shift lines for load balancing purposes without requiring numbering changes.

Finally, there is the most flexible but also the most complicated plan of all in which the selection of paths and trunks or lines is divorced from the selectors and placed in markers. In this plan the size of group is not limited by the number of terminals that a switch can hunt over in one sweep. No. 1 crossbar is an example of a system using the marker method of operation. In this system a switch generally has access to only ten trunks but on any one call a marker can test 160 trunks distributed over a number of switches.

Typical common control arrangements for systems using translation are shown in Fig. 3 for the panel system and in Fig. 4 for No. 1 crossbar.

The advantages noted are, in each case, the fundamental ones. Many others are inherent in common control and some will be brought out in further discussion.

A number of common control systems embodying the principles discussed have been designed. Rotary, panel and coordinate have been previously mentioned. Although the coordinate system never reached the commercial stage as a complete system, some of its features were adopted in the panel system starting in 1927 with the introduction of the decoder to replace the original three digit panel translator which used special panel selectors and pulse generating drums to do the translating job. This translator was limited in the digit combinations and number of three digit codes it could handle and also demanded a great deal of attention by the maintenance force. In place of the panel translators a small group of all-relay decoders, ranging from three to six, depending on traffic, was provided for each office. Senders were connected to decoders for about one-third of a second per call to obtain the information derived from translation of the three office code digits. The connector for making the momentary connection of the large number of leads required between the senders and decoders presented new problems which were solved by the development of new relay preference and lockout circuits to permit as many simultaneous connections between senders and decoders as there were decoders and to permit an even distribution of calls to decoders. Decoder circuits were completely self-checking for trouble, provided for second trial in another decoder when trouble was discovered, and recorded troubles on a lamp bank trouble indicator.

In the early 1930's, encouraged by the success of decoders, the Bell System started development of the No. 1 crossbar system with markers in both originating and terminating equipments and with improved features over the coordinate system which it resembled in many respects. Self-checking circuits, second trials and trouble indicators which had proven highly successful in the decoder type panel system were important features of No. 1 crossbar. Automatic alternate routing and the ability to operate with non-consecutive PBX assignments were major new features introduced in this system for the first time.

The subsequently developed No. 5 crossbar system included a number of improvements, the chief of which from a common-control standpoint was the use of common markers for originating and terminating business and the use of the call back feature in setting up the connection. In this system the common equipment records the calling line identification as well as the called number, and after setting up to the called line or outgoing trunk, breaks down the connection to the common equipment

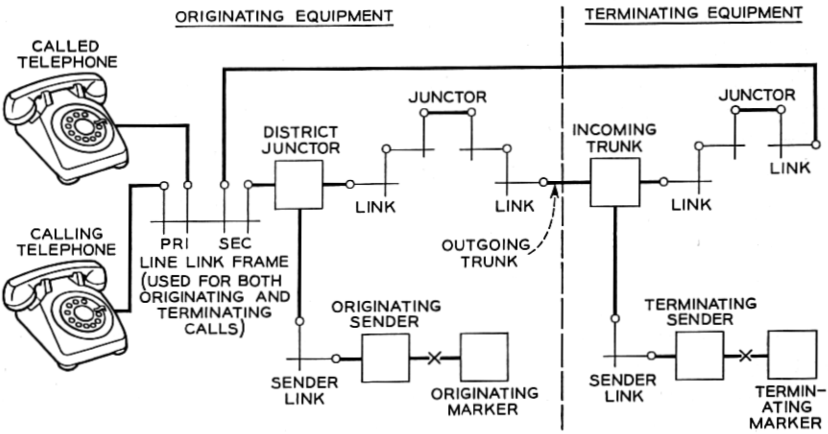

Fig. 4—No. 1 crossbar.

from the calling line and then re-establishes a connection back to the calling line.

Common controls have been employed by the Bell System in a number of systems in addition to those already mentioned. These include panel sender tandem, crossbar tandem, and No. 4, A4A and 4A toll crossbar.

COMPARISON OF COMMON CONTROL SYSTEMS AND DIRECT DIAL CONTROL SYSTEMS

Both direct dial control and common control systems have been developed to meet a wide range of situations for both large and small exchanges but, as previously noted, direct dial control systems have found their greatest field of use in the smaller exchanges and common control systems in the larger ones. The reasons for this can be brought out by a discussion of some of the features which have an important bearing on costs. These include the features affecting numbering plans, trunking arrangements, flexibility, quality of service, maintenance and engineering. A discussion of all the factors affecting costs will not be attempted. However, some of the more important ones will be covered.

RELATION BETWEEN TYPE OF SYSTEM AND NUMBERING PLANS

The requirements of a good numbering plan are well known. A good plan must be universal, i.e., must use the same number for reaching a called line regardless of the point of origin of the call in the area covered by the numbering plan, must permit dialing with acceptable accuracy, must permit directory listings that are readily understood by both dial and manual customers, and should use a minimum number of digits to reduce the labor of dialing. In small networks a satisfactory plan can be set up with almost any kind of system. However, especially in large networks, modern common control systems have outstanding advantages with respect to numbering.

These advantages of common controls are derived from the more flexible method of operation. Direct dial control systems use up the digits in the various stages of the switching operations whereas common control systems momentarily store them and can retransmit them. The result is that where direct dial control systems are used the numbering plan and the switching and trunking plans must conform whereas with common controls numbering, switching and trunking are not directly dependent on each other because the digits can be stored and translated. The effects of these differences on permissible latitude in numbering arrangements can be brought out by some examples.

Direct dial control systems cannot operate economically with a universal numbering plan in a network requiring any given call to have the possibility of completion over a variable number of links. The need for operating in this fashion arises when calls may be completed directly to the called office or via one or more tandem or toll systems. Numbering difficulties of a plan which attempts to use tandems with direct dial control systems can be illustrated by reference to Fig. 5. Assume that A, B, C represent three direct dial control type offices in a 6-digit numbering plan area and that these are connected by direct trunks between offices. Office B is designated ACademy (22 on the dial) and office C is designated BLue Hills (25 on the dial). Analysis of the trunk layout in this network indicates, let us say, that trunking economies can be made by establishing a tandem and that the direct route from A to C is no longer economical as compared to the route via the proposed tandem. The digits 25 must now select a route via tandem. However, if we use both digits for selecting the route to tandem we have none left for selecting the route to office C at the tandem office. Since this plan will not work, let us see what results if we assume that the tandem trunks are selected by means of the first digit. Now all calls starting with the code digit 2 at office A must be routed via tandem and even though economies call for a direct route to the ACademy office from A we are forced to use the uneconomical route through tandem for this office. Actually we must consider the economy of routing the traffic for all offices whose codes begin with a given digit via tandem, or routing it over direct trunks, or we must change the designation of one of the offices. We could, of course, adopt the undesirable expedient of using non-universal numbering, i.e., numbering that varied by points of origin, as, for example, by introducing extra digits on calls through tandem from A to C and omitting them on calls from B to C.

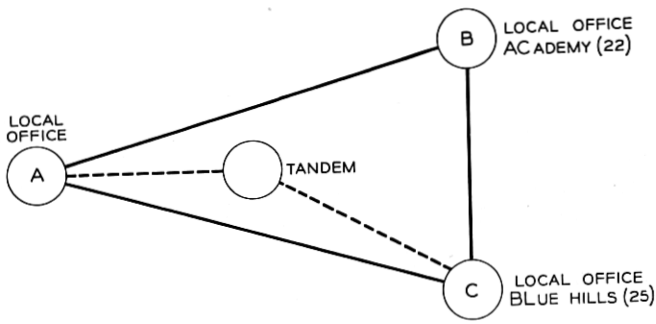

Fig. 5—Trunking scheme with a tandem office.

It is a situation such as has been described which has led to the practice, in some cases, of putting offices whose designations begin with the same first digit in the same building in step-by-step areas. This, of course, leads to restrictions.

Another alternative is to use selector repeaters. With these devices a "mitlaufer" action takes place in the local and tandem office selectors, i.e., both the local office selectors and the tandem office selectors follow the dial pulses until sufficient information is received to determine the route, whereupon the unneeded equipment is released. This equipment makes possible both the direct route to office B and the route via tandem to office C without an office designation change. However, selector repeaters are expensive and the cost of introducing them may be considerable. They also waste some trunk and equipment capacity because selector repeaters operate by seizing both local selectors and tandem trunks on every call. More often than not, perhaps, it would be cheaper to forego the trunk economy than to introduce the selector repeaters.

Now take the same network and assume common control equipment at all points. Prior to the introduction of the tandem the local offices translate the first two digits into information for selecting an outgoing trunk and then outpulse only the last four numerical digits directly to the called office. When the tandem is introduced, the translation at office A is changed to select a trunk to tandem on calls to BLue Hills and to tell the sender at A to spill ahead the code digits or equivalent information as well as the line number for these calls. For calls to ACademy the existing arrangement is retained. There is no special problem at tandem since the code for the called office, BLue Hills, is made available there. The translator at the tandem office tells the tandem sender to omit the office code digits in outpulsing to BLue Hills.

There is an essential difference in the coding between direct dial control and common control which is obscured by the use of the same codes in the examples. In the direct dial control case the codes are route codes (sometimes called group codes); that is, the digits directly correspond to the route through the switches and are expended in the switching operations. In the common control case they are destination codes and it is not necessary to have them conform to the route nor are they used up in the switching process. Only common control systems can operate with destination codes. Therefore common control systems are required where it is necessary to route calls to some offices by direct trunks and calls to other offices via tandems without numbering restrictions.

Another example of a numbering difficulty with direct dial control systems tracing back to the use of route codes, is illustrated by an extreme example in Fig. 6. This figure shows a multi-switch route through four automatic intertoll switching systems, A, B, C, D, to a customer whose listed number is 2345 in the central office, MAin 2. MAin 2 is in numbering plan area 217, a different area from that of the calling office. Typical digit combinations are shown at each place for reaching the next place with direct dial control systems. On a call from the A toll center area to the number MA 2-2345, the originating toll operator must dial 16 digits, such as 059 076 097 157 2345. Calls starting at intermediate points or in other networks use different numbers depending on the route. (Note that the route codes start with 0 or 1 to distinguish them from local codes.) It is rather obvious that dialing such combinations is cumbersome and requires elaborate routing information at each toll center. Intertoll calls through direct dial control systems are therefore generally limited to being switched at one place along the route, with infrequent use of two switching points.

However, with common control systems the situation is quite different. The originating point need dial only the ten digits of the destination 217 MA 2-2345. At each point except the one preceding the called area the full complement of digits is sent ahead. At that point the area code is dropped. At the last point, D, which is assumed to have direct circuits to the called office, MA 2 is skipped and 2345 is sent ahead. If calling and called points had been in the same numbering plan area, only seven digits would have been required. Note that since destination codes are used all points outside the numbering plan area dial the same 10 digits to reach a given line and all points within dial the same seven digits.

While only a small proportion of toll calls require multi-switch connections of the type just described, connections such as these are nevertheless required for an economically feasible nationwide network in which all calls are dialed to completion, and this objective cannot be attained practically without systems operating with destination codes.

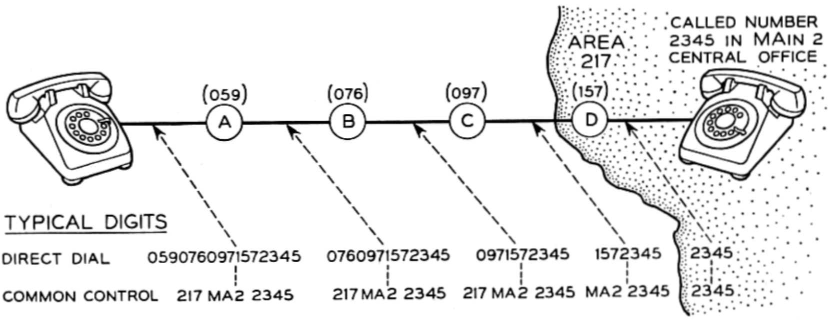

Fig. 6—Numbering with direct dial control and common control systems.

Also, as brought out later, destination codes are required in order to realize the important trunking economies of automatic alternate routing.

CODE CONVERSION

In passing, another feature of some common control systems, namely code conversion, can be brought out here because the illustration, Fig. 6, fits. Calls originating in a common control system can use office name codes (such as MA 2 for calls to the MAin 2 office) to reach destinations via step-by-step switching equipment where route codes (such as 157) are widely used. The translating equipment at the common control office can be arranged to substitute arbitrary digits for the office name code digits or in some cases to prefix arbitrary digits ahead of the called number. The arbitrary digits substituted or prefixed conform to the requirements of the office using route codes. In Fig. 6, office C when equipped with common controls could be arranged to convert MA 2 to 157, and therefore codes conforming to the nationwide numbering plan could be used for area 217 even though the calls were routed through step-by-step equipment.

RELATION BETWEEN TYPE OF SYSTEM AND TRUNKING ECONOMIES

The provision of a system which makes the most economical use of the trunk plant is important in any network but it is not as important in a small network as in a large one. Small networks can derive only small economies from arrangements which permit saving trunks. For example, in a single office network the trunks consist of wires running from originating to terminating equipment in the same building plus relatively cheap associated relay circuits. However, in a large toll network the trunks may include expensive repeaters, signaling equipments, carrier equipment and perhaps echo suppressors, as well as transmission channels running up to hundreds of miles in length and expensive toll relay circuits. For the larger networks there is therefore considerable urge to save as many trunks as possible. It is important therefore to operate these networks with switching plant that makes the most efficient use of the trunk plant by providing full access to groups, and to use an arrangement that permits the trunking economies of routes via tandems and of automatic alternate routing. These are features provided by common control systems and help explain why these systems are more attractive in the larger networks, both toll and local.

The cost of rearrangements for growth, new routes, load balancing and for restoring service under emergency conditions vary with the type of system. Because of the flexibility of common controls such rearrangements are easier to make and usually cost less than in direct dial control systems. Also the frequency of rearrangements is greater in the larger places. Therefore this is another factor in favor of using common controls for those places.

SUPERIORITY OF COMMON CONTROL SYSTEMS WITH RESPECT TO SWITCH ACCESS

It has already been mentioned that the efficiency of trunks increases as the size of the group in which they are selected increases. Recognition of this fact early in the development of machine switching (about 1905) led to the invention of common controls. An ordinary step-by-step selector has access to only ten outlets on a level. Access to more than ten outlets can be obtained by providing graded multiple or by the use of rotary out-trunk switches,* or by combinations of these. Whenever it is necessary to employ graded multiple or rotary out-trunk switches, there is still some slight loss of efficiency as compared to full access.

In a system such as the panel system in which trunk hunting is a function of the selectors, the maximum number of trunks accessible to a call at any stage of selection is limited by the number of outlets accessible to the switch at that stage. A panel district or office selector, for example, can test a maximum of 90 trunks in a single group, 90 being the maximum number of terminals to which trunks can be assigned on a single panel bank, the remaining ten of the 100 terminals on a bank being reserved for overflow purposes. In the step-by-step system a corresponding limitation is avoided by a combination of graded multiple and rotary out-trunk switches with the penalty of a slight loss of efficiency. Marker systems avoid this limitation, also, by having the markers select trunks before they select the paths to the trunks. Crossbar systems with markers can readily test several hundred trunks for a given call. In some crossbar systems—No. 1, for example—trunks are tested in sub-groups of forty, therefore marker holding time is increased when there is more than one sub-group to be tested. This increase in marker holding time is largely avoided in systems like the toll crossbar systems by providing special testing arrangements in which a single indication per sub-group tells the marker which sub-group has one or more available trunks, whereupon the marker only tests the individual trunks of a sub-group in which it is assured that it can find an available trunk.

* A rotary out-trunk switch is arranged to hunt over a single group of outgoing trunks and to connect to an idle one. It is arranged for preselection and switches not in use will advance from busy trunks.

The maximum access of ten terminals on a level in ordinary step-by-step is not inherent in the system and might be overcome by a different switch design. A review of how a direct dial control system operates will help to clarify this point. At each switching stage, two actions take place. First, the switch follows the dial pulses until it reaches a group of outlets corresponding to the dialed digit. Then in the interval following this digit and before the pulses of the next digit arrive the switch hunts over the outlets for an idle path to reach the next stage. The number of paths from a switch level is therefore limited by the number of terminals the switch can hunt over in the interdigital interval. Assuming, for example, an interdigital interval of six-tenths of a second and a hunting speed of 100 terminals per second, 60 outlets could be provided. However, if such a high speed of hunting could be attained, and the 60 outlets were provided, 60 terminals would be required per group even for small ones which are in the majority. Hence such a switch would be wasteful of terminals. Direct dial control systems have generally employed switches with ten outlets per level although special arrangements such as twin levels have been employed to increase the number of outlets. A twin level switch provides terminals for two trunks at each rotary step and thus twenty trunks per level can be reached.

TRUNK ECONOMIES FROM TANDEM OPERATION WITH COMMON CONTROL SYSTEMS

An important factor in trunk economies is the ability to use tandems. The numbering difficulties that direct dial control systems have with tandems have already been discussed. Tandems permit major trunk economies on two scores. First, tandem routings take advantage of the efficiency which results from concentrating the smaller items of traffic and handling them over common trunk groups. Fig. 7 shows how this economy is attained. Ten offices completely interconnected by one-way trunks require 90 interoffice trunk groups. Ten offices interconnected only by way of tandem require only 20 groups. The groups by way of tandem are larger in size than the individual direct groups they replace and because of increased efficiency with group size fewer trunks are required.

There is a second possibility for an increase of efficiency, an example of which occurs when part of the offices are in business districts and part in residential districts. The peaks of trunked traffic from these different types of offices frequently occur at different hours, hence the trunks through tandem can be provided more economically for a given grade of service than by an arrangement which must care for the peaks of each office separately. The non-coincidence of peaks of traffic of different types of offices permits economies both on trunks to tandem and trunks from tandem. For example, assume that a given office completes calls via tandem to some offices which have a morning busy hour and to others which have an evening busy hour. Then the group to tandem must provide capacity to handle the traffic for the busier hour of the two, but this capacity need care only for the peak traffic to part of the destinations. If individual direct groups had been provided instead of a common group to tandem, each group would have required capacity for its own peak, regardless of when it occurred. The common group to tandem therefore benefits by the noncoincidence of the peaks. A corresponding situation also occurs on trunks from tandem. Each group completes calls to a given destination from a number of originating offices whose peak hours may not coincide, and hence groups from tandem derive economies similar to those of the incoming groups to tandem.

Tandems are also required for alternate routing. Alternate routing is an arrangement to provide trunking economies by using a limited number of direct trunks for the traffic between two offices, and permitting the calls which do not find an available direct trunk to overflow to one or more tandems in succession. Because of the ability to load the direct circuits very heavily and yet provide good service by taking the overflow from and to a number of offices through a common tandem point, substantial economies are possible. Automatic alternate routing is practical only with common control systems. Common controls are needed to

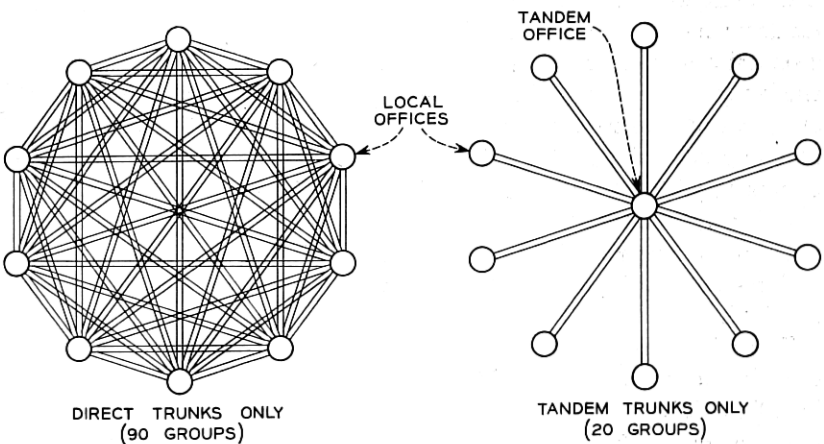

Fig. 7—Reduction of the number of trunk groups by the use of a tandem office.

provide the digit storage and digit spilling features in the office that does the alternate routing so that it can spill forward to the alternate route point the digits the latter requires.

Common controls have other advantages with respect to trunking which have already been covered in part. They also simplify the problems of assignment and load balancing as groups change in size or as new groups are added. An example of the difference in the methods of handling trunk growth in step-by step and crossbar is of interest. In step-by-step when groups grow beyond 10 trunks a grade must be introduced in the switch wiring, or trunks must be sub-grouped or rotary out trunk switches used. If further growth occurs, regrades must be made or rearrangements may be required in the sub-grouping or in the rotary out-trunk switches. In a crossbar system, however, in most cases added trunks are merely assigned to spare switch terminals which are left vacant for this purpose.

ROUTINGS FOR IRREGULAR CONDITIONS

Common controls are adapted to the efficient recognition and handling of irregular conditions such as permanent signals, vacant codes, and discontinued or temporarily intercepted lines.

Registers or senders detect line troubles which cause permanent signals or receivers off the hook by a timing circuit which waits for a short time for dialing to start. If the dialing does not start within the interval allowed the line is directed to a common group of permanent signal trunks which may appear before operators or at a test board. In No. 5 crossbar a trouble recorder card can be produced on which the location of the line in trouble is indicated. The step-by-step system indicates permanent signals by alarms to the maintenance force on a line group basis, and lines in trouble must be traced.

Vacant codes are detected by the translators, decoders and markers of common control systems and the calls are routed to a common trunk group which appears before operators or which returns "no such number tone." The corresponding arrangement in step-by-step requires connections from the switch multiple to operator or tone trunks.

In systems like No. 1 crossbar and No. 5 crossbar which have common controls in the terminating equipment, lines on which service has been discontinued or temporarily intercepted can be recognized by the markers and the calls rerouted to a common group of intercepting trunks. For example, temporary discontinuation of service is indicated by lifting a single cross-connection at the number group frame. In the step-by-step system, however, one intercept trunk is commonly provided per 100 numbers and lines whose service is to be intercepted must be cross-connected to these trunks.

FURTHER ADVANTAGES OF COMMON CONTROL SYSTEMS ACCRUING FROM THEIR ABILITY TO OPERATE WITH TANDEMS

Some of the economies permitted by common control systems operating with tandems have been previously mentioned. Tandems are also useful because they provide centralized points at which special features can be concentrated with considerable saving.

For example, tandems are used for pulse conversion and for concentration of message charging equipment. Pulse conversion is needed when it becomes necessary to change from one type of pulsing to another, as, for example, on calls from a panel office to a step-by-step office. Panel can send out only revertive and panel call indicator pulses and step-by-step can receive only dial pulses. The two systems are therefore incompatible without special arrangements. The following are some of the plans which might be used for handling calls to step-by-step. First, all the panel senders could be modified to send out dial pulses. Second, spill senders could be provided at the outgoing trunks in the panel office or at the incoming trunks in the step-by-step office to receive, say, revertive pulses and convert them to dial pulses. Finally, if there is a tandem in the area, the tandem senders could be arranged (as they actually are) to accept revertive or panel call indicator pulses and send out dial pulses. The first two arrangements are usually more expensive than the last. Therefore, when pulse conversion is required it is generally done by routing calls via tandem.

To complete calls in the reverse direction, that is from step-by-step to panel, there is a requirement that is due to the use of the step-by-step system, namely that in cases where second dial tone is not employed the equipment at the called office or at an intervening tandem must be ready to accept the step-by-step pulses which are being dialed by the customer within a short time after the incoming trunk is seized. To meet this requirement, special high speed and costly link mechanisms are required to attach senders to incoming trunks or the incoming trunks must be arranged to record and store one or two digits. When calls are made between two systems both using senders, however, cheaper and slower link mechanisms can be employed because the calling senders are arranged to wait for a sender attached signal from the called office.

ADVANTAGES OF COMMON CONTROLS FOR AUTOMATIC RECORDING OF INFORMATION FOR CHARGING

The crossbar tandem system offers an economical method for making a record for charging purposes on multi-unit bulk billed calls called remote control of zone registration. At present this is limited to use with originating panel offices. The tandem is arranged to send back signals to the originating office for operating the customer's message register up to six times for the initial period on one call and also to operate it on overtime. Thus the application of extended customer dialing can be economically increased by applying this arrangement in places which cannot justify the registration arrangements available in the panel system itself which are economical only for a relatively heavy volume of this business. Local crossbar systems provide these features economically enough to obviate the need for tandem control of message registers for calls originating in the crossbar offices.

When tandem offices are required to control the equipment which records customers' charging data, they must be equipped with common controls if the arrangement is to be economical. The data includes the origin of the call—the particular trunk group incoming to tandem over which the call arrives—and the destination—the called office code. These elements must be analyzed and combined to determine the basis for the amount charged. Since elaborate equipment is required for these functions, economy must be attained by providing a minimum amount of equipment to do the job. This objective is accomplished by providing the required features in the common controls. In tandems arranged for remote control of zone registration, for example, the number of times the customer's message register is operated is determined partly by the choice of trunk group at the originating office and partly by the tandem markers.

In addition to remote control of zone registration, there are several other methods of determining and recording charging data which also require the use of common control equipment. These are automatic ticketing, automatic message accounting and coin zone dialing.

In automatic ticketing, which is used with step-by-step systems, calls which are to be ticketed are directed to outgoing trunks which select senders and other common equipment which determine the calling line number, reconstruct the called office code and store and outpulse the digits required for selections beyond the local office. The calling line number and the called office code are transmitted by the common equipment to the outgoing trunk which is equipped with a ticket printing device which prints this information and other data required for charging. The tickets can be used for bulk bills as well as detail records since they can be summarized at the accounting center by manual methods for calls on which detail information is not required.

Automatic message accounting is used with crossbar systems both for bulk billing and detailed call records. With this system the data required for charging is perforated on paper tape by common central office equipment. The arrangement has been described in the technical literature* and will not be further described here.

Both the ticketing method and automatic message accounting require the collection of a large amount of data and the ability to do a complicated job in handling and recording this data. This demands elaborate and expensive equipment which is practical only when provided on a common basis so that it can be called into service for a short time and then restored to the common pool for other calls.

Direct dial control systems without common controls can only have message registers on the line and therefore can handle nothing but bulk billed calls. Furthermore because of the expense of arrangements for determining multiple unit charge data and for operating the message register more than once on a call, multiple operation of message registers on individual calls is not practical.

From coin stations in direct dial control systems the customer may dial calls only to offices within the local charge zone. However, in panel and crossbar areas the "coin zone dialing" arrangement is available to permit coin customers to dial beyond the local zone. With this plan calls are routed to a tandem office where completion is delayed until an operator can plug into the trunk to tandem and supervise the collection of the required coins. The amount to be collected is indicated by trunk lamps which appear in a switchboard multiple. Common controls enter into this scheme at the originating office to route the call to tandem and to determine the charge, and at the tandem office so that the digits can be stored while the call is held up prior to collection of the coins.

TYPES OF PULSING

Direct dial control systems are restricted to operation with dial pulses and are usually limited to pulsing speeds of about 10 pulses per second and about one digit per second. Dial pulsing has range limitations which can be overcome by the addition of pulse repeaters at appropriate points.

Common control systems store the digits in senders which can regen-

* *A.I.E.E. Transactions*, **69**, Part 1, pp. 255 to 268, 1950.

erate them in various types and combinations of types of pulsing. Types of outpulsing found today in various systems include revertive, panel call indicator, dial pulsing, dc key pulsing, and multi-frequency pulsing. Panel sender tandem and No. 4 toll can also send digital information ahead to operators by the call announcer method which uses voice announcements derived from recordings on film. Provision for receiving and sending several types of pulsing in one system makes it more flexible since it can then connect to a variety of equipments. Regenerating the pulses adds to the range without the need of adding pulse repeaters.

Some of the advantages which common control systems derive from the ability to operate with a modern type of pulsing can be brought out by a brief description of multi-frequency pulsing which is a relatively recent development. Digital information is transmitted over any facility capable of handling voice by sending spurts of alternating current which consist of pairs of frequencies in the voice range selected out of five frequencies. There are ten such pairs. At the receiving end a check is made to insure that exactly two frequencies are received for each digit. When only one or more than two frequencies per digit are detected the call is not set up but a reorder signal is returned to the originating end. In addition to the advantages of being capable of transmission over voice facilities, including repeaters and carrier systems, and of providing checks for accuracy, this type of pulsing can be transmitted at the rate of seven digits per second at present. Operators can be provided with keysets capable of sending MF pulses into either local or distant switching equipment with improved operating resulting from the higher speed and other advantages of MF pulsing.

It is quite feasible to add new types of pulsing to common control systems. Multi-frequency pulsing has only recently been added to crossbar tandem, for example, although it has been in use with other crossbar systems for some time. In this case it required the development of new senders capable of receiving and sending the MF pulses. The addition of these senders, even in existing offices, is not a difficult job.

IMPROVED STATION APPARATUS

The stations in most exchanges are provided with dials which operate at approximately 10 pulses per second. In step-by-step exchanges this pulsing speed is the maximum permitted by the capabilities of the switches. In panel and crossbar areas the common equipment is capable of operating with higher speed dial pulsing, and PBX and central office operators in these areas are usually given dials that operate at about 18 pulses per second.

Even fast dials are inefficient as compared to the push button keysets used by operators for key pulsing and it is obvious that subscriber sets with push buttons would be faster and more convenient than dials. Such sets were used at Media, Pa., on an experimental basis and have functioned in a highly satisfactory manner. Their introduction merely required the design and installation of registers to receive the pulses they generate. This was done with little difficulty or expense at the central office end. However, with ordinary step-by-step systems such devices are impractical because of the short interdigital interval they allow and because of the cost of adding the pulse receiving equipment in every selector and of providing translation to change the key pulses into a form to drive the switch.

CLASSES OF SERVICE

Differences in the handling of calls from non-coin, coin and PBX lines and differences in rate treatments require the recognition of classes of customers at the central office. In step-by-step separate groups of line finders are provided to permit segregation in classes and where routings for different classes vary, separate selector multiples are required for these routings. Class distinctions within a line finder group can be made by normal post springs and by marking a fourth conductor in the line circuit.

Common control systems permit the economical handling of many classes of service. The No. 5 crossbar, for example, is most flexible in this respect. As many as thirty classes of service can be handled in a single line link frame, including coin and non-coin. Special handling, reroutes and restrictions are mostly functions of the common controls and inefficiencies due to segregation of traffic in small groups of switching equipment are largely avoided.

DOUBLE CONNECTIONS

In systems such as panel and step-by-step in which selectors do the hunting, several selectors may be hunting over the same terminals simultaneously, and since there is an unguarded interval just after an idle terminal has been found before it is made busy by the release of the busy testing relay, double connections occur. Considerable effort and expense have been expended to reduce the probability of double connections in these systems. In systems which employ markers, on the other hand, the trunk testing schemes do not normally permit double connections to occur. In most marker systems a lockout arrangement permits only one marker at a time to test trunks in a given group. There are cases where trunks are common to two offices and two markers are allowed to test trunks simultaneously. In these cases special circuit arrangements are provided at nominal expense to avoid double connections. Modern common control systems with markers are, therefore, free of double connections resulting from weaknesses of the system and they can occur only as a consequence of defects in circuits or apparatus.

THEORETICAL OFFICES

It is sometimes desirable to assign more than one office designation to customers in a single central office unit. A new unit may be planned for sometime in the future and if growth on the existing unit can be taken with a new office designation, then when this new office is placed in service it can be done without directory changes by transferring a block of lines from the old unit. Another occasion for assigning more than one designation to a single unit arises when customers served by the unit are in two rate zones, and service to lines in one of the rate zones must be restricted or extra charges collected. The lines served by an additional designation are called a theoretical office. Common control systems handle theoretical offices with little difficulty. In the first case mentioned the translating equipment in the originating offices recognizes that the physical office and theoretical office designations require identical treatment until the new unit is cut into service at which time translator cross-connection changes take care of the new routings. Where different rate treatments are involved, records for billing purposes depending on both the origin and destination of the call can be made by methods previously mentioned. In some cases where the billing data is determined at a tandem office and different treatments for the same destinations must be given to customers calling from one office, split trunk groups must be provided to tandem, one for each treatment.

In the step-by-step system, theoretical offices can be opened up by multipling two selector levels together. For example, if the physical office is designated 25 and it is desired to open a theoretical office, say 26, the 5 and 6 levels on the proper second selectors in the network can be strapped until the 26 office is changed to a physical office. At that time the levels are split and trunks to the new office are connected to the 6 levels of the second selectors. Restrictions in reaching blocks of numbers can be applied by splitting selector multiples and intercepting calls to restricted blocks from one of the splits.

ADAPTABILITY TO NEW SERVICE FEATURES

One of the major advantages of common controls, which has been covered in part but which deserves further emphasis, is their adaptability to new service features. Key sets and new dialing devices can be introduced at customers' stations and operator positions by readily feasible modifications of registers and senders. New pulsing schemes can also be introduced as they are developed as evidenced by the introduction of multi-frequency pulsing over the past few years. Nationwide customer dialing, now under development, can be readily introduced in existing common control systems by economical modifications without the use of either directing codes or second dial tone. Step-by-step systems require at least partial senderization to provide equivalent service. In short, the flexibility of common controls and the concentration of the control elements in a relatively few circuits makes the addition of new service features easier and more economical than in direct dial systems.

MAINTENANCE ASPECTS

Experience has shown that switches with a large amount of motion, especially those with brushes which wipe over bank terminals, tend to wear excessively and require considerable maintenance effort and even replacement, at times. On the other hand, switches with short motions and relay-like action require little maintenance and tend to have long life. Furthermore, the switches which employ wiping brushes mostly use base metal contacts, whereas relay-like switches can readily be equipped with precious metal contacts—and in most cases are so equipped—with the elimination of the transmission noise to which base metal contacts are subject. The crossbar switch is a relay type of switch with precious metal contacts and considerations such as those mentioned influenced its adoption. The advantages of relay type switches are not necessarily limited to common control systems since such switches have been used in direct dial control systems. The first use of the crossbar switch in Sweden was in a step-by-step system, for example. However, economical arrangements for using such switches in large systems require markers. This is because economy must be achieved by having more than one call occupy a switch at a time and marker control is necessary to attain this

Important maintenance advantages have been introduced in systems using decoders and markers. In this category are the self-checking features, second trials with changed order of preference, and trouble reporting features. In No. 5 crossbar the ability to report the location of a line with a permanent signal by perforating a trouble recorder card has eliminated the need for tracing permanents.

A number of schemes are employed to detect troubles in markers and decoders and in circuits which connect to them. These include detectors for wrong sequences of operations, wrong combinations of relays, excessive current, false potential and lack of continuity. These are generally introduced at small cost since the circuits to which they are applied are small multipliers. However, some of them do a major job of testing since they reach out and test the numerous elements of the switching system to which markers have access. In this category are the tests of the crossbar linkages for opens, false grounds and double connections, tests of the switch crosspoints for continuity, tests of lines for false grounds, and for receivers off the hook on coin first coin lines.

To obtain clear trouble records, markers are designed with interlocked progress signals. This has made trouble analysis easier and has tended to improve design by eliminating relay races.

Starting with the panel system tests have also been introduced in senders for detecting open and reversed trunks. These tests have been of considerable help in maintaining outside plant and in detecting conditions that could lead to false charges.

DISADVANTAGES OF COMMON CONTROLS

Up to this point the stress has been mainly on the advantages of common controls. There are also some disadvantages. One of the major ones is the substantial getting started cost due to the necessity of providing a minimum amount of common equipment. This minimum is provided to maintain operation in case of trouble and during intervals when, for example, cross-connections require change because of changed or added routes. The minimum requirements establish economic barriers which tend to prohibit the economical use of common controls for small isolated systems.

Another disadvantage is the performance of common control systems under severe and protracted overloads. Experience with these systems indicates that although they compare quite favorably to direct dial control systems with respect to capability of handling moderate overloads, they are not able to handle severe overloads as well. In part this is a consequence of the fact that elements in common control systems are used at high efficiency and hence there is relatively less free equipment at full load for soaking up an overload than there is in systems that operate with smaller and less efficient groupings. Whenever the number of calls presented to the system exceeds the capacity of the common control elements provided, the excess calls are delayed. The things which customers, operators and connecting switching machines do when they encounter delays tend to aggravate the overload. The reactions of operators and customers to delays can be illustrated by two examples.

The first is taken from the operation of a network of No. 4 toll crossbar systems when one of the No. 4's is heavily overloaded. Operators placing calls through the overloaded system encounter, let us say, an abnormal number of "no circuit" conditions in the outgoing trunks. This causes them to make additional attempts to get circuits. These additional attempts plus the excessive number of first attempts overload the markers. Sender holding time is then increased because of delays in connecting to the markers and this, added to the abnormal number of sender usages, results in a further shortage of senders. Operators trying to place calls through the system are therefore slowed down because of slow "sender attached" signals. (These are the signals which tell the operators that they can start keying or dialing.) Senders in connecting systems are also delayed waiting for senders to become idle in the overloaded office. The overload therefore tends to spread to all connecting systems.

However, it is possible to provide remedies which limit the reaction to the overloaded system. These remedies are arrangements to rapidly clear out senders waiting for senders ahead. Automatic alternate routing is also useful in routing traffic around overloaded systems.

The second example is taken from local systems. Here the reaction of customers to delays compounds the overload. A severe overload results in a shortage of senders, much as described above. A shortage of senders in a local system causes dial tone delays. There are always some customers who either do not listen for dial tone or who will not wait very long for it, and who start to dial before senders are attached to their lines. The result of such dialing is either a partial digits condition under which the sender waits for a considerable interval for a full complement of digits, or a wrong number when the first digit is clipped. The delays reduce sender capacity still further and the wrong numbers further increase the attempts. The load "snowballs" and the ability of the system to handle calls degenerates.

Here again arrangements are available to control the overload. These include features for blocking calls before they reach the senders and markers, and for returning paths busy signals with a minimum of common circuit holding time.

While there is, then, a somewhat greater capacity for overloads in step-by-step because of less efficient use of equipment, common control systems do a good job of handling moderate overloads and, by provision of load control features, can operate satisfactorily even with severe overloads.

From a maintenance standpoint, a disadvantage of common controls is the relative complexity of the circuits. While this has introduced a training problem, maintenance forces have had no difficulty in acquiring the knowledge needed to do a competent maintenance job.

CONCLUSION

The full fledged common control systems exemplified by the crossbar local and toll systems have a number of important advantages over systems where the switches are driven directly by the customer's dial. The advantages arise largely from the ability to store digits, to translate them, use them flexibly for switching within the office, and transmit as many of them as desired to distant points for subsequent switching operations. The digits can be converted to others of different value whenever it is advantageous to do so. The inherent flexibility of common control equipment makes it possible to adopt any kind of numbering plan for a local area or a nationwide network that is best suited for the purpose without regard to the manner in which calls will be trunked from one point to another. Codes can be assigned at will to represent destinations and the best route for the call can always be taken. The best route may in some cases involve tandem operation or even a half-dozen switches in tandem. It may be the route selected as an alternate after previous trial of one or more other routes. A connection may be set up between offices of different types and over trunk groups requiring different forms of pulsing. These conditions may be met by common control equipment and the ability to meet such conditions makes it possible to provide cheap step-by-step equipment in places for which it is best suited, compensating for some of its deficiencies with common control equipment in other places.

With marker type common controls, trunk groups out of an office can be of any desired size regardless of the switch design. The individual crossbar switch, for example, gives access to only ten or twenty outlets as normally wired but full access single trunk groups of hundreds of trunks can be employed in some crossbar systems.

Schemes for recording billing data, aside from the relatively simple ones where metering equipment is associated with the customer's line and operated once per call, make use of common control equipment. This seems to be necessary where detail records must be made on individual calls for charging purposes.

As improvements in the art are made they can more readily be incorporated in common control systems than in step-by-step systems. For example, new subsets which may employ keys or other sending devices different from the dial can be accommodated by provision of proper facilities in senders and registers. Also, improved high speed pulsing arrangements can be easily incorporated in systems which do not require the switches themselves to be directly driven by pulses from the calling device.

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