TELEPHONE COMMUNICATION SYSTEMS

VOLUME I
EARLY SYSTEMS AND STATION EQUIPMENT
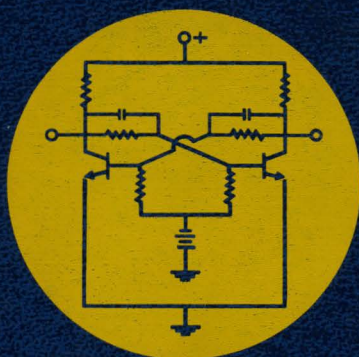
GRADUATE ENGINEERING
AND
INFORMATION SYSTEMS EDUCATION

TELEPHONE

COMMUNICATION SYSTEMS

VOLUME I

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PREFACE

Connecting any two phones among the millions of subscribers is accomplished by telephone switching systems. The process, although not simple, is normally taken for granted in our everyday use of telephone services. This is indeed a compliment to the Bell System people who have developed, engineered, and maintained the many types of telephone systems. The switching equipment in the Central office is considered by many to be the heart of the telephone highway, for without it the telephone never would have progressed to the highly developed and integrated entity it is today.

Although the switching equipments may be considered the "heart," the other parts of the telephone network are equally important. For without the connecting wires and cables, the subscribers' equipment and the power plant, there could be no universal telephone network and no Direct Distance Dialing.

Switching is a highly dynamic field. From the first crude switching arrangements developed by the Holmes Electric Company in Boston in 1877 to the highly sophisticated No. 1 ESS system developed by the Bell System Laboratories in the early 1960's, the telephone switching system has indeed come a long way. What the future holds can only be speculated upon: on the horizon, we now see new developments, such as the use of satellites, lasers, and holography in communications.

Each subject covered in this text could be developed much more extensively; however, our objective is not to print a comprehensive treatise on telephony, but rather to treat each subject briefly presenting a general technical explanation of its operation and function.

This text has been prepared for Graduate Engineering Education courses presented at the Western Electric Corporate Education Center. Its contents are the result of over 12 years of development, starting from a group of handouts given to students and leading to the book we have today. Although much of the material and ideas were taken from various Bell System sources, a great deal of the book can be attributed to the members of the Graduate Engineering Education staff. Acting as writers, instructors, and editors, each diligently worked in assembling a well organized telephone communications text. Their collective efforts are sincerely appreciated, and are hereby gratefully acknowledged.

J. E. GARRETT
Manager, Graduate Engineering
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Corporate Education Center
Hopewell, New Jersey

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CHAPTER 1

BRIEF HISTORY OF COMMUNICATIONS

1.1 INVENTION OF THE TELEPHONE

As is commonly known, the telephone business was founded on inventions of Alexander Graham Bell, which grew out of experiments in telegraphy begun in Boston in 1873. Perhaps less well known is that Bell was not an "electrical man," but that instead, his training was predominantly in music, speech, elocution, and anatomy of the vocal and auditory organs. Bell first became interested in telegraphy in 1867, and this led him also to investigate electricity, mostly on a home-study basis.

In 1870, Graham Bell, as he preferred to be known, migrated with his father from England, to Brantford, Ontario. In April, 1871, Graham visited Boston, substituting for his father who had been requested by the Board of Education to experiment with his Visible Speech method of teaching the deaf to speak. After similar work in other New England towns, Graham Bell was appointed Professor of Vocal Physiology at Boston University, in 1873. His preoccupation with professional duties made it necessary to conduct most of his electrical experiments after university hours.

Bell's first interest in electrical communication was to develop a harmonic telegraph which, he hoped, would transmit several Morse messages over the same circuit simultaneously. After abandoning the use of paireo tuning forks late in 1873, Bell considered the use of paired tuned-reed instruments. Early models made by himself proved unsatisfactory; this led him to place an order for instruments with Charles Williams, Jr., whose shop facilities and services attracted inventors.

Some of the delivered instruments had not been made in accordance with Bell's intentions, and one day, early in 1874, he strode through the office of Williams' shop and went to the work bench of the young mechanic, Thomas A. Watson, who had worked on the instruments. Although this was a rather unconventional procedure, Bell wanted to talk the job over directly with Watson, whom he had not met previously. Charles Williams continued to assign Watson to Bell's work; Watson also assisted Bell in his experiments after work hours.

Financial assistance soon was needed by Bell, who found the cost of his experiments to be quite burdensome. Fortunately, Gardiner G. Hubbard, who was interested in the problems of the deaf, and Thomas Sanders, whose deaf son had benefited from instruction by Bell, came forward, in the fall of 1874, with an offer to supply the needed money. These informal arrangements were embodied in a written agreement on February 27, 1875. Accordingly, Hubbard and Sanders, each, were to furnish one-half the money needed by Bell, and all three were to share equally in any patents which might be obtained.

While concurrently studying two very early types of acoustically actuated mechanical oscillographs...

These were the "Manometric Capsule" of Koenig, and the Phonautograph of Leon Scott, with improvements by Morey. Bell also obtained a human ear specimen and modified it to work about the same as the much larger phonautograph. Oscillograms recorded by Bell on smoked glass plates with this modified specimen in 1874 are in the Bell Telephone Laboratories' historical collection...

...as a possible means of improving his Visible Speech technique, and experimenting with his tuned-reed harmonic telegraph instruments, Bell conceived the basic principle of the telephone. He outlined it to Watson, for the first time, early in 1875 as follows:

"If I can get a mechanism which will make a
 current of electricity vary in its intensity
 as the air varies in density when a sound is
 passing through it, I can telegraph any
 sound, even the sound of speech."

Bell's tuned-reed harmonic telegraph instruments were constructed and intended to function, according to Watson, as follows:

"1. The transmitter has an electromagnet with a reed
 made of steel clockspring mounted over it and an
 adjustable contact screw like that of an
 ordinary electric bell. The receiver had a
 similar magnet and spring reed but needed no
 contact screw."

"2. The operation also was very simple. The reed of
 the transmitter, kept in vibration by a battery
 connected through the contact screw, interrupted
 the battery current the number of times per

second that corresponded to the pitch of the reed. This intermittent current, passing through the telegraph wire to the distant receiver, set the reed of that receiver into vibration sympathetically if it was of the same pitch as the transmitter reed. If the two reeds were not of like pitch, the receiver would not respond to the current."

"3. If six transmitters with their reeds tuned to six different pitches were all sending at once, their intermittent currents through the magnets of six distant receivers with reeds tuned to the same pitches, each receiver would, theoretically, select from the mix-up its own set of vibrations, and ignore all the rest."

A. EARLY EXPERIMENTS

Bell and Watson continued to experiment with models of instruments made by Watson as described above. In one room they set up:

1. Three circuit breaking transmitters, tuned to different pitches, each provided with a telegraph key to connect it with a battery and the line wire as desired, and

2. A set of three tuned-reed receivers having the same pitches as the transmitting instruments.

In the other room, designated as the receiving station, another set of three tuned-reed receivers, identical with the three receivers in the sending room, were connected to the far end of the line. Working with this experimental arrangement on June 2, 1875, Bell, at the receiving station at the far end of the line, made the critically controlling discovery, reported by Watson as follows:

"I had charge of the transmitters as usual, setting them squealing one after the other, while Bell was retuning the receiver springs one by one, pressing them against his ear.... One of the transmitter springs I was attending to stopped vibrating and I plucked it to start it again. It didn't start and I kept on plucking it, when suddenly I heard a shout from Bell in the next room, and then out he came with a rush, demanding: 'What did you do then? Don't change anything! Let me see?' I showed him. It was very simple."

The contact point of the transmitter which Watson was trying to start evidently was screwed too hard against the spring, so that when he snapped the spring the circuit had remained unbroken. Continuing with Watson's report:

> "...that strip of magnetized steel, by its
> vibration over the pole of its magnet, was
> generating that marvelous conception of
> Bell's -- a current of electricity that
> varied in intensity precisely as the air
> was varying in density within hearing
> distance of that spring. That undulatory
> current had passed through the connecting
> wire to the distant receiver which, for-
> tunately, was a mechanism that could trans-
> form that current back into an extremely
> faint echo of the sound of the vibrating
> spring that had generated it, but what was
> still more fortunate, the right man had
> that mechanism at his ear during that
> fleeting moment, and instantly recognized
> the transcendent importance of that faint
> sound thus electrically transmitted. The
> shout I heard and his excited rush into
> my room were the result of that recogni-
> tion. The speaking telephone was born at
> that moment."

After trying many variations of their first success-ful transmission, with and without a battery in the circuit, Bell instructed Watson late on June 2, 1875, to build a new instrument, the one which has since come to be known as Bell's first telephone. A stretched parchment diaphragm. which had been contemplated by Bell while working with the human ear specimen in the summer of 1874, was now added to the previous type of coil and reed receiver assembly, with certain modifications. This first telephone, a "Gallows Frame" Magneto (Figure 1-1) was tried out, as a transmitter on the night of June 3, 1875, the receiver being one of the tuned-reed harmonic telegraph instruments used previously. Later on, two of the new telephones were used as trans-mitter and receiver. Whereas the harmonic telegraph tuned-reed instruments, when used in pairs, were found capable of transmitting and receiving the fundamental and harmonics of a vibrating spring, the new telephone was capable of trans-mitting and receiving speech sounds which were more complex, but it still was not good enough to transmit intelligible speech.

B. PATENT APPLICATIONS

During the latter part of 1875, and early in 1876, Bell prepared his specification for a patent application, including both the harmonic telegraph tuned-reed device and a stretched-diaphragm-type instrument. In these instruments the "undulating current" was generated by magnetic induction. "Almost at the last moment" Bell included in his specification a claim which also provided for the variable-resistance method of producing electrical undulations in current supplied by a battery. This application, completed on January 20, 1876, was filed in the Patent Office February 14, 1876. Patent #174,465 registered as an Improvement in Telegraphy, was issued to Bell on March 7, 1876 which happened to be his birthday. He was then 29 years old; Watson was not yet 22.

Although three additional patents were obtained by Bell during his association with Messrs. Hubbard and Sanders, Patent #174,465 has been considered to be the cornerstone of the Bell System of intercommunication. This original group of four patents was assigned in later years to "parent companies" which followed the original three-man association.

In the spring of 1876, Bell pursued further the variable resistance method of producing the desired undulating current. After abandoning other methods, he decided to employ a variation of a method used by him in his previous development of a spark arrestor. A crude device of this type, used in the early days of March, 1876, brought the two experimenters close to their objective. At Bell's request, Watson then built an improved liquid transmitter, consisting essentially of a diaphragm capable of vibrating at voice frequency, and having attached to it a small wire which moved up and down in a liquid conductor (acidulated water), thus varying the resistance in the closed circuit including a battery, at voice frequency.

On the night of March 10, 1876, with Watson stationed at the far end of the line to which one of the harmonic telegraph tuned-reed receivers (Figure 1-2) had been connected, Bell was completing the last wire connection to the new liquid transmitter (Figure 1-3) when he spilled battery acid on his clothes, and he summoned Watson with the now famous call for help, "Mr. Watson, come here, I want you!" Watson excitedly reported that he heard every word -- distinctly, and in this way the feasibility of transmitting and receiving intelligible speech was fully established.
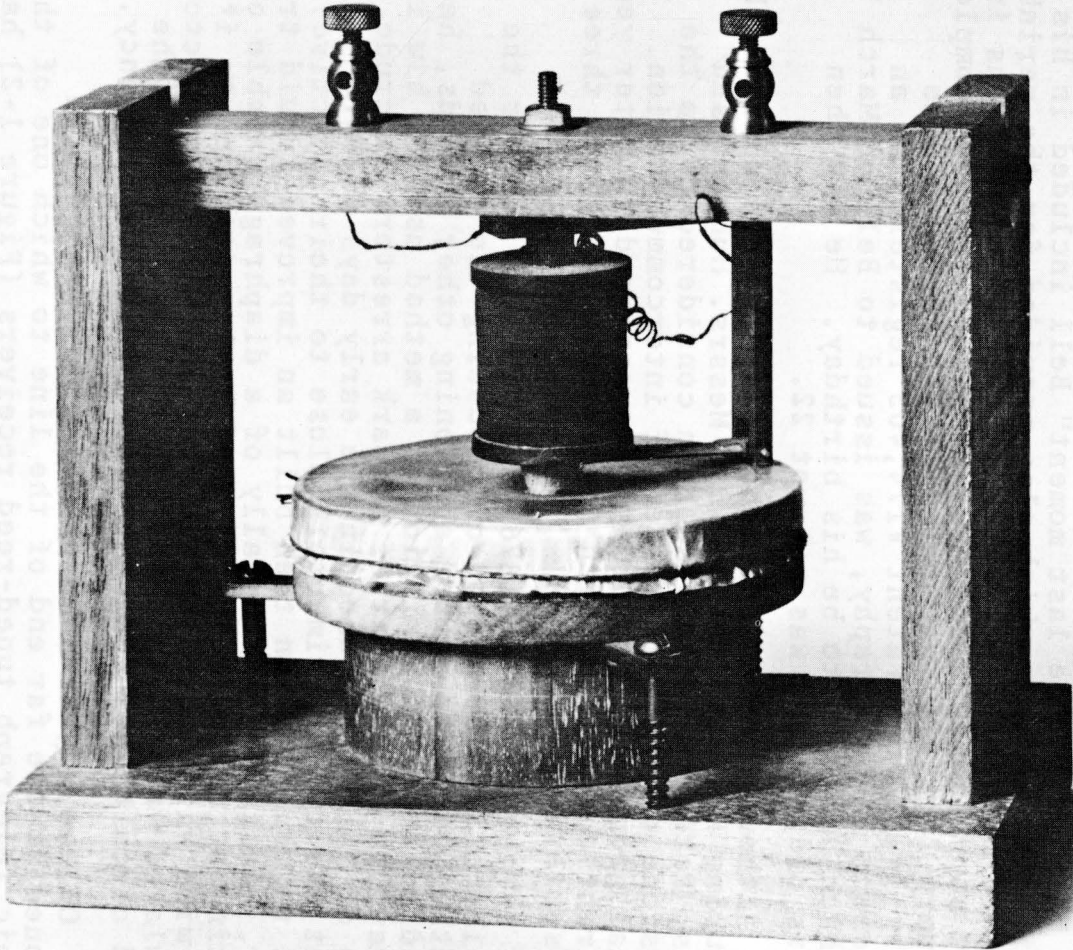
Figure 1-1   Gallows Frame Magneto Phone
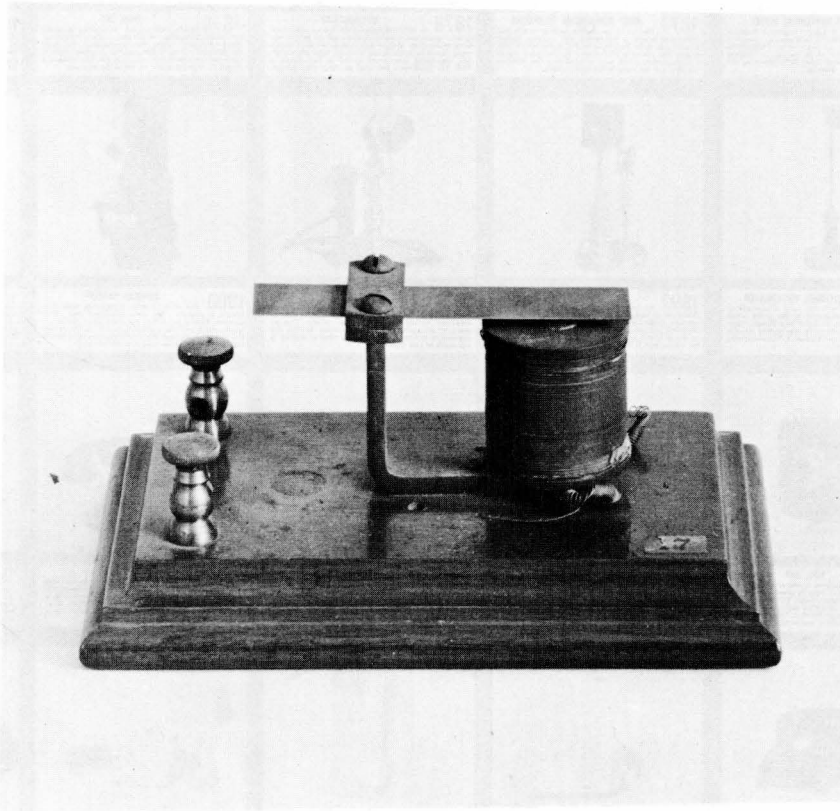
Figure 1-2 Vibrating Reed Receiver

1.7

The Telephone Story

THE STORY OF THE TELEPHONE is the story of change, of the relentless search for new methods and materials to transmit the human voice. Much of the progress achieved has been in terms of cables and switching equipment invisible to the user who is more familiar with the instrument he sees. Here is what the telephone has looked like over the years . . . .

Figure 1-3

1.8

The first commercial telephone (Figure 1-3) of 1877 was enclosed in a box with a round camera-like opening serving as transmitter and receiver and needing mouth-to-ear shifts.

Telephones were sold in pairs (one for you and one for the person you wished to talk with).

To use those early phones was simplicity itself. First you placed one telephone in your own home or business, and the other in the home or business of whomever you wished to talk with. Next, you somehow had to connect the two phones. The first telephone advertisement announced, quite helpfully, that you had two choices as to method. One possibility was to purchase the necessary wire and telephone poles yourself and to hire a "mechanic" to install the poles, string the wires, and connect them to the telephones. If this was to be your decision, that first ad gave you the necessary specifications,

> "...No. 9 wire costs 8-1/2 cents a pound,
> 320 pounds to the mile; 34 insulators at
> 25 cents each...."

and even calmed you as to any doubts you may have had with the cheery encouragement that

> "...any good mechanic can construct a line...."

or, if you weren't very good at construction projects, the Bell people offered to do the construction for you and give you a "firm" quotation such as the following, which is also taken from the first telephone advertisement:

> "...The price (of poles and setting) will
> vary (in every locality)...from $100 to
> $150 a mile...."

(Small wonder that the telephone was at first considered a rich man's toy!)

Once your two phones were connected, you were ready to use them. Now there was a problem at this point - how to signal the person in whose home or office the other phone was installed that you wished to speak with him. (There was no signal bell attached to those early phones.) Here again, the Bell Company was thoughtful enough to provide you with two choices. If you had strong lungs, you could

simply shout into your phone to draw the other party's attention. In fact, in that historic first telephone ad, the Bell people assured you that

> "...Any person within ordinary hearing distance can hear (your) voice calling through the phone...."

As an alternative to this method, if you were willing to pay an extra $5 installation charge, the Bell Company offered to attach a "thumper" just below the mouthpiece of your phone. When operated, this device activated a hammer within a chassis of the phone, making a loud thumping noise that was transmitted to the other phone.

The following year, Alexander Graham Bell designed the "Butterstamp" (Figure 1-3) the first set with a combined receiver and transmitter that could be held in the hand. Made of wood, it resembled a dairy butterstamp and hence its name.

The platinum-carbon contact transmitter (Figure 1-3), the receiver induction coil, the receiver and transmitter in a common handle, the receiver-operated switchhook, and Watson's polarized two-gong ringer actuated by a hand cranked magneto were thought of, or patented, or actually in use by 1878.

About this time, a young Bostonian named Francis Blake invented the variable contact transmitter (Figure 1-3). Capable of transmitting voice with extreme clarity, this instrument, every bit as good as those of Western Union, was offered with patent rights to the Bell Company in return for some of the Bell stock. His offer was quickly accepted. The Blake transmitter placed the Bell Company on even footing with Western Union and became a standard for years to come.

In 1897, one of the most important patent cases in the United States was decided by the Supreme Court. In its decree, it established Emile Berliner, whose formal schooling ended at age 14, as the inventor of the microphone transmitter. This transmitter gave the Bell System, holders of the patent, an advantage over the highly-competitive telephone systems of the day.

By 1900, telephone customers were benefiting from a common battery at the central office for talking and signaling, a bi-polar hand receiver, and some even had Almon Strowger's rotary dial.

New materials have come into play in the evolution of telephone sets. These range from magnetic materials, used in the receivers, to plastics that have made possible the long-life, nonfading, almost-everything-resistant, colored telephones.

Between 1878 and 1919 the telephone saw many changes both as a wall set and as a desk set. Then the deskstand-with-dial of 1919 became a "settled" design. It was followed in 1927 by the "French phone" comprising the receiver and transmitter in one "handle." In 1937, the Bell System began to produce the "300" type desk set where-in the bell was taken off the wall and put in the base of the telephone.

In 1950, the first of the present-day "500" series came into use and soon thereafter began to appear in a variety of colors. With color came an avalanche of new designs and new accouterments to the basic telephone.

Later additions to the Bell Telephone family are shown in Figure 1-3.

Of recent vintage are the Touch-Tone^R Trimline^R set (Figure 1-4) and the Picturephone^R (Figure 1-5). The former combines in one attractive hand-held instrument the receiver, transmitter and push buttons which enable customers to tap out phone numbers quickly. The latter on the other hand, makes possible not only the transmission of the human voice but also charts, drawings, products, processes and, if need be, the image of those conversing. Indications are that this service may have industry-wide usefulness in the carrying on of day-to-day business.

C. THE FIRST SWITCHBOARD

While the first switchboard used manually operated rotary switches to connect subscriber lines, many of the early switchboards contained jacks connected to each sub-scriber's line. The operator had a supply of flexible wires with plugs on both ends. To connect two parties, the operator plugged the ends of a cord into the two jacks associated with the lines; auxiliary devices produced the signaling service for ringing and disconnect. The manual switchboard positions were arranged so that additional positions could be placed side by side to obtain larger capacities. One operator could reach over three positions which could serve 150 subscribers. As the number of

Figure 1-4

1.12
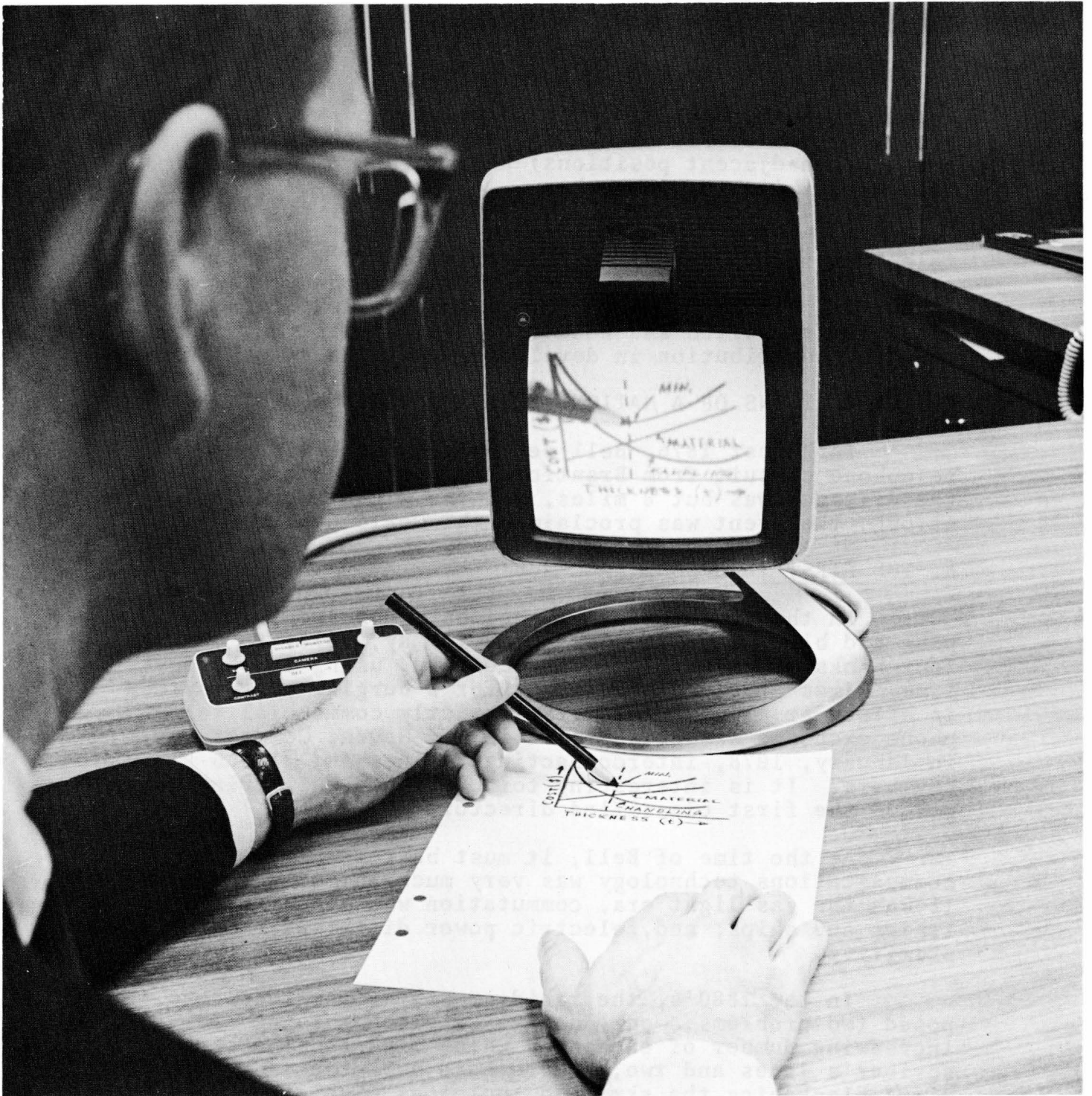
Figure 1-5

The Bell System's new Model II PICTUREPHONE set can be used
to transmit drawings or charts by setting the camera focus
at one foot. In the photograph, the "self-view" option is
being used to position the graph while it is being transmitted.

subscribers increased, a multiple of three switchboard positions was added. Trunking (permanent connections between nonadjacent positions) added a new dimension to telephone switching networks.

Much of the progress in the design of the early telephone switchboards can be attributed to the efforts of one of the most prolific inventors in telephony, Western Electric's Charles E. Scribner. Responsible for the "Jack-Knife" switch and holder of 441 patents, he made his greatest contribution in developing multiple switchboards.

1.2 THE ORIGINS OF A NATIONWIDE COMMUNICATIONS NETWORK

In August 1876, Bell set up a successful one-way telephone circuit from Brantford to Paris, Ontario. Though the distance was but 8 miles, and the signal none too strong, the event was proclaimed the world over.

A. THE FIRST TELEPHONE EXCHANGE

In the office of E. T. Holmes, in Boston, a simple plug and block apparatus was used in May, 1877, to connect four banks and a manufacturing concern, using in the day-time, wires provided previously for a burglar alarm system in effect at night. The first strictly commercial telephone exchange was established in New Haven, Connecticut, in January, 1878, interconnecting 8 lines and 21 subscribers. It is interesting to note too, that during this period the first classified directory was issued.

At the time of Bell, it must be remembered the communications technology was very much in its infancy. It was the gas light era, commutation was slow: trolleys, trains and ships; and, electric power distribution was primitive.

In the 1880's, the rapid growth of the telephone posed two problems: one, how to interconnect the ever-increasing number of exchanges which tied together sub-scriber's lines and two, how to hold back the tide of wires blackening the sky; and, poles as high as 90 feet carrying 30 crossarms and 300 wires. The answer to the first problem came in a statement by Theodore N. Vail, the first President of the American Telephone and Telegraph Company, when he remarked, "This linking of city to city, state to state and nation to nation has greater possibili-ties than we know of yet." The idea of a nationwide net-work of communications was born.

On June 2, 1880, a telephone line from Boston to New York was authorized. This line was put into service on March 27, 1884. On May 9, 1883, lines were authorized from New York to Philadelphia and Washington, and from New York to Albany. These events marked the beginning of the Long Lines System.

B. PHANTOM CIRCUIT

The answer to the second problem came in the practical application in 1886 of John J. Carty's "Phantom Circiut," a method of transmitting three conversations simultaneously over two pairs of wires which, via careful balancing methods, reduced the number of wires needed. Mr. Carty was also responsible for the adoption of balanced pairs of telephone wires instead of single wires with return through the ground, thus eliminating much of the interference from other telephone wires and power lines. He also developed the first theory of transportation whereby it was possible to balance out the crosstalk that accumulated over long distance from one pair of wires into other pairs.

C. INDUCTIVE LOADING

In 1889, George A. Campbell discovered, simultaneously with Professor Michael I. Pupin, an electro-physicist of Columbia University, that the benefits of inductive loading the adding of inductance - could be realized by locating "loading" coils at specified intervals along Transmission lines. This discovery led to the doubling of the distance that could be reached over open wires on poles, and the tripling or quadrupling of the distance over pairs of wires in cables. It wasn't long before, Campbell extended his circuit theory to the invention of the wave filter which, in turn, led to multichannel telephony.

In 1911 the New York-Chicago line had been extended an additional thousand miles to Denver. The line was built with large copper wires (No. 8, - almost as thick as a lead pencil), and was inductively loaded. There were two pairs of wires, giving two two-way telephone channels (a two-way telephone channel is called a "circuit"), plus a third circuit obtained by phantoming. These heavy wires - more like rods, really - were strung on thousands of poles stretching across the plains and the desert - a big and venturesome project and, for its time, a triumph of engineering and construction unsurpassed.

But Denver was the end of the line - the point of exhaustion. There was nothing left. The engineers who planned that long and slender route hoped it would somehow extend ultimately to the Coast, but they knew that this would depend on developing some kind of amplifier that might respond to the voice currents before they became too feeble, and build them up to a level where they could be projected on to more distant points. Bell people had been working on this, and there were already amplifiers of several sorts - mechanical amplifiers, mercury arc amplifiers - that demonstrated this possibility, but they were either too crude and cumbersome, or too imperfect in response, to be really promising for practical use in a long system.

D. VACUUM TUBE

It was in 1906, when the need was critical, that the "audion" or primitive tube, was being perfected by Lee Deforest. Basically, this device magnified electrical signals which heretofore were too weak for transcontinental projection. Recognized by the Bell System scientists as a technological breakthrough of extreme importance, a concentrated research and development effort was initiated to adapt the vacuum tube to large scale telephone communications.

In 1913, construction began on the route from Denver to Salt Lake City. Vacuum tube repeaters were installed at Philadelphia, Pittsburgh, Chicago, Omaha, Denver, Salt Lake City and Winnemucca, Nevada. In mid-'14 the first trial conversations were held from coast to coast. And, in January of 1915, Alexander Graham Bell, from an office in New York, placed the first official transcontinental call to Thomas Watson in San Francisco - the Watson who had been his assistant in the attic laboratory in Boston where the first telephone was made nearly forty years before. In the same year, speech was transmitted for the first time by radio telephone from Arlington, Virginia, across the continent to San Francisco, to Hawaii, and across the Atlantic to Paris.

The telephone has come a long way since that historic call in 1915. From a single transcontinental line, furnishing three circuits, the capacity for simultaneous coast-to-coast conversations has grown to many thousands. The time for setting up a call has dropped from about a half an hour to a small fraction of a minute.

The quality of transmission too, has improved tremendously. All of this did not happen by chance. The needs of the fast growing communications industry had veritably marked major areas for technological and financial effort.

E. NEGATIVE FEEDBACK

In the 1920's, when multiplex was moving ahead fast, and transmission engineers were interested in long-haul systems with hundreds of channels, the problem of ridding amplifiers of distortion, which accumulates as the telephone lines lengthen, and more and more amplifiers are added, seemed incapable of being overcome. One day in 1927, Harold S. Black, a Bell Telephone Laboratory scientist on his way to work, who too had pondered long on this very same problem envisioned the answer. Using an accidental blank page, he recorded equations that led to a solution destined to completely revolutionize the art of signal amplification over long distances. Known as "Negative Feedback" principle, it was employed in amplifiers used commercially in 1936 between New York and Philadelphia and made possible the installation of a 12 channel carrier system - operating in nonloaded cable pairs - in 1938, between Toledo, Ohio and South Bend, Indiana.

Later, George C. Southworth, a Bell Telephone Laboratory research engineer, transmitted television, radar and other broad-band signals through hollow pipes and dielectric wires, a discovery that led to the development of the Microwave Radio Relay System.

1.3 SWITCHING SYSTEMS - LOCAL DIAL CENTRAL OFFICE EQUIPMENT

In switching, new concepts and applications have made their impact felt in step-by-step panel, crossbar with its centralized intelligence and the stored program of the Electronic Switching System (ESS). The following are brief descriptions of these systems prior to their presentation in the chapters that follow.

A. NO. 1 STEP-BY-STEP AND 350A, 355A, AND 356A COMMUNITY DIAL SYSTEMS

Once started, the telephone network grew rapidly. Engineers began to think in terms of completing calls without the aid of an operator by using switches in the connecting network and a dial for the subscriber. A

Kansas City undertaker, Almon B. Strowger, in 1889 invented a rotary stepping switch that formed the basis for much of the telephone switching equipment now in service. Automatic switching systems had been patented as early as 1879 but the Strowger System, developed by A. E. Keith and others of the Automatic Electric Company, was the first commercailly feasible system. Step-by-Step switches are electromechanical devices usually activated by dial pulses. These switches are mounted on shelves in such a manner that in the establishment of the talking path through the office, the contact brushes of each switch move over a series of terminals arranged in semicircular stacks - an array of 10 rows of 10 sets of contacts.

As the name Step-by-Step implies, the connection of a telephone call is established progressively through a series of such switches. Upon dialing the first digit or letter, a selector steps up to the level indicated by the dial pulses and at that level hunts for a vacant trunk to another selector. This process is repeated at each selector. The dialing of the final two digits operates one of the connectors serving the called line. The next to the last digit dialed steps the switch up to the level indicated and the last digit rotates the switch to the terminal associated with the called subscriber's line. The last switch, known as the connector switch, in addition to making a connection, rings the subscriber, sends a busy tone back if the line is busy and places a busy condition on the called line.

In 1892 the first Step-by-Step office (automatic telephone exchange) was unveiled in La Forte, Indiana by the Strowger Automatic Telephone Exchange. Today, approximately 44% of all lines are still being served by a step-by-step office. Depending upon the type of office, step-by-step systems may accommodate anywhere from 100 to 10,000 subscribers.

B. PANEL DIAL SYSTEM

The first panel dial office units were placed into service in 1914 at the Mulberry and Waverly offices in Newark, New Jersey.

The panel system was developed for use in large metropolitan multioffice areas where, in most cases, the fully mechanical step-by-step system could not be used advantageously. Although this equipment is still being used, it has been superseded by the more efficient crossbar and electronic systems.

In the panel system, the digits, which the sub-
scriber dials, have no direct relation to the groups of
trunks to which the various selectors move in completing
the call, and the selectors do not move in unison with the
dialing. Therefore, it is necessary to provide equipment
which will receive the dialing from the subscriber, record
it, hold it, change it as necessary, and transmit it to
the various selectors to control their movements and di-
rect them to the proper setting. This mechanical operator
is called the sender and generally speaking, acts as the
control in setting up a call through a Panel office.

Terminals, over which the selector switches move,
are arranged in flat vertical rows in multiple banks. The
selectors are moved by electric motors rather than
electromagnets. As noted above, there is no direct control
of selections by the subscriber's dial, but rather, the
dialing is registered in a sender which controls and oper-
ates the selector circuit. This allows for greater flexi-
bility, more efficient trunk groups and permits dialing
over a more complex and extensive trunking arrangement
than is possible with the use of the direct control.

C. NO. 1 CROSSBAR DIAL SYSTEM

No. 1 Crossbar, like Panel, was developed for use
in large metropolitan areas. A common control system,
using extensive logic circuits for the first time, it
replaced panel dial for new installations.

In the No. 1 Crossbar system, mechanical motion,
which is utilized in the Panel and Step-by-Step systems
for hunting in the various switching functions, has been
reduced. The Crossbar switch is the principal switching
element and it is, briefly, a device employing horizontal
and vertical members, each magnetically operated. The
operation of a vertical member, in conjunction with a
horizontal member, will cause a particular set of contact
springs associated with the vertical member to close and
to remain closed as long as the magnet of the vertical
member remains in operation.

To set up a call in this system, an idle path going
in the proper direction is found, seized and immediately
used to progress to the next diverging point, where this
operation is repeated. Calls are set up on a "marker"
basis, under which each step is "marked" before any of the
intervening paths are actually seized. When the connec-
tion is completed, the common equipment, consisting of
senders, markers, connectors, etc., drop out of the call

and proceed with another call. This reduces the amount
of equipment tied up during the period of conversation
and hastens the setting up of a call. The primary advan-
tages that Crossbar has over Panel are the provision for
alternate routing calls and less maintenance.

Some offices are equipped with the Automatic Message
Accounting (AMA) System, for billing of 7-digit calls with-
out the assistance of an operator. Others, not so equipped,
obtain automatic billing through Crossbar Tandem with
Centralized Automatic Message Accounting (CAMA).

The addition of auxiliary senders to the No. 1
Crossbar (non-AMA type) and Panel offices, permitted 10-
digit direct distance dialing to other numbering plan areas
through the Crossbar Tandem or No. 4 type toll Crossbar
offices with 10-digit CAMA. No. 1 Crossbar offices with
local AMA were similarly arranged.

Another feature, Automatic Number Identification
(ANI) enabled local offices, using CAMA, to identify a
calling number and pass this information along to the
CAMA machine for billing. Before this, operators were
required to manually record this information. ANI is
designed to identify one and two party subscribers in
No. 1 Crossbar, Panel and Step-by-Step local office areas.
The first No. 1 Crossbar system, President 2 Office in
Brooklyn, New York, was cut into service on February 13,
1938.

D. NO. 5 CROSSBAR SYSTEM

The No. 5 Crossbar Office is a common-control local
and/or toll telephone switching system designed for use in
areas having more than 2000 lines. It operates with all
local, tandem and toll switching systems and can serve as
a combination local and tandem or toll center switching
office. No. 5 can be readily arranged for Direct Distance
Dialing (DDD), by operators or customers, and for Automatic
Message Accounting (AMA) or centralized Automatic Message
Accounting (CAMA). It has been designed to operate with as
few as 4 digits in a subscriber number or as many as 11.
No. 5 provides the following features essential to the
expansion of operator and customer toll dialing:

1. 10-11 digit capacity
2. Alternate routing
3. Code Conversion
4. Marker pulse conversion and
5. Six-digit translation

The first No. 5 Crossbar Office went into service on July 11, 1948 at Media, Pennsylvania.

1.4 SWITCHING SYSTEMS - TOLL DIAL CENTRAL OFFICE EQUIPMENT

A. TOLL APPLICATION

Crossbar equipment can be used for switching toll traffic as well as local traffic. In the toll switching application, toll lines or trunks are switched to other toll lines or trunks, whereas in local switching, subscribers' lines are switched to other subscribers' lines or trunks. Long distance operators and, in many areas subscribers, can complete calls directly to subscribers in other distant areas on a dialing basis. For example, an outward toll operator in New York can dial a subscriber's number in any other city which has appropriate switching arrangements. No intermediate or end operator is required. With Direct Distance Dialing (DDD), no operator is needed at the originating end on certain types of calls.

The general toll switching plan divides the United States and part of Canada into many numbering plan areas. Switching systems employing No. 4 Crossbar, Crossbar Tandem, No. 5 Crossbar and, in some cases, Step-by-Step Intertoll are provided at strategic points in each area.

B. NO. 4A/4M TOLL SWITCHING SYSTEM

This is a Crossbar Common Control Switching Point (CSP) system that provides 4-wire paths for establishing connections electromechanically on a nation-wide basis, between intertoll trunks, or between intertoll and toll connecting trunks. Operating on a destination route basis, it is capable of routing a call over a preferred route or any one of as many as six predetermined alternate routes automatically without operator assistance. The 4A System and its predecessor the 4M have the same features and operating capabilities. The No. 4 System uses multi-frequency (MF) pulsing, that considerably shortens the time required for transmitting pulses controlling the switching equipment. Features essential to the operation of the No. 4, and to Direct Distance Dialing (DDD) are:

1. Crossbar switches, arranged on incoming and out-going link frames, together with the necessary trunks and toll terminal equipment, care for the switching path.

2. Common control equipment (consisting of senders, connectors, decoders, card translators and markers) determines routing, sets up switching paths, and receives and sends the pulsing and signaling information required for completion of the call.

3. Selection of routes in rapid succession accomplished by the electromagnetic card translator.

4. Predetermined and alternate routing is punch coded on metal cards.

Philadelphia, Pennsylvania was the recipient of the first Toll Switching installation in 1943.

C. CROSSBAR TANDEM SYSTEM

Crossbar Tandem is a two-wire switching system using Crossbar switches and other apparatus. Originally developed as an intermediate mechanical switching office for large metropolitan areas with Panel and No. 1 Crossbar local offices, it provides three functions for the local office:

1. Permits economical trunking by combining small volumes of traffic into larger volumes which are routed over common trunk groups.

2. Translates almost any type of inpulsing to any type of outpulsing, thereby connecting otherwise incompatible local offices.

3. Permits centralization of equipment and services.

With the advent of Extended Area Customer Dialing and Direct Distance Dialing (DDD), the following switching features have been developed for Crossbar Tandem to accommodate interzone trunking:

1. Intertoll traffic
2. Alternate Routing
3. Storing and Sending Forward Digits as Required
4. Code Conversion
5. 6 digit Translation

1.5 SWITCHING SYSTEMS - ELECTRONIC

In Crossbar Systems, electromechanical switching was developed to the fullest extent feasible. Major advances are now taking place in Electronic Switching.

The Bell System's Electronic Switching System (ESS) is a stored program system which utilizes the high speed of electronic devices to perform the basic functions of telephone switching.

High operating speed permits a very small number of control circuits to serve a very large number of lines and trunks. System control is accomplished by subdividing the work, required to process each call, into segments and time-sharing the segments of other calls. The system's actions are determined by a program stored in semipermanent memory. Variations in features of different offices are accomplished in the stored program rather than in apparatus, wiring and equipment options. Office units, which are traffic dependent, are accommodated by a plan which minimizes engineering and installation efforts required for new offices and additions to existing offices. Wide use is made of transistors and other solid-state devices which operate more than 1000 times faster than conventional switching apparatus. The system's high speed and special equipment make possible a variety of new services which greatly increase the value and flexibility of each customer's telephone. Although ESS uses electronic components, it is comparable in many ways to the present common control switching systems, especially No. 5 Crossbar.

A. NO. 1 ELECTRONIC SWITCHING SYSTEM (NO. 1 ESS)

Succasuna, New Jersey was selected for the Bell System's first full-scale commercial electronic central office "Cutover" in May 30, 1965. It is a very sophisticated common control switching system which can serve as many as 65,000 station lines. Highly reliable and compact, this office has high-speed solid state devices that provide unlimited flexibility, great dependability and economy in every phase of its operation. A stored program that utilizes magnetic memory devices to direct the system, provides such unique "customer calling services" as:

1. Two and three-digit dialing for frequently called numbers

2. Automatic routing of incoming calls to another phone when the original called line is busy

3. Dialing a code to forward incoming calls to another telephone when the customer is away from home, and

4. Dialing a third telephone into an existing telephone conversation.

Taking full advantage of its data processing capabilities, this system has been programed for Automatic Message Accounting operation.

B. NO. 101 ELECTRONIC SWITCHING SYSTEM (NO. 101 ESS)

The first commercial trial for an electronic PBX, Centrex and other modern subscriber service features was inaugurated in November 1963 at Cocoa Beach, Florida. As in the No. 1 ESS, this system also utilizes high-speed solid-state electronic components in conjunction with a binary stored program control. Among the new features of this system are:

1. Abbreviated dialing in which frequently called outside numbers, either local or long distance, may be reached by dialing three digits.

2. Touch-Tone dialing in which extensions can be equipped with numbered touch buttons instead of a rotary dial.

3. Call transfer in which calls from the outside can be switched from extension without going through the switchboard operator.

4. Conference calling in which as many as two additional parties can be dialed into an existing conversation by the party originating the conversation.

1.6 CARRIER SYSTEMS

The carrier principle is a method of converting voice frequencies of a communication channel to a corresponding band of frequencies centered about a particular frequency beyond the voice range, known as the carrier frequency. By suitably spacing such carrier frequencies over a comparatively wide range, several communication channels may be combined to transmit signals or voice over a single pair or wires without interference from another channel. Thus, the carrier system is used to increase the capacity of open wire, cable conductors and microwave for carrying telephone, telegraph and video messages.

Early carrier systems provided up to three or four additional channels, as well as the original voice-frequency channel, on each pair of wires. The number of channels which a carrier system can accommodate is limited by the band of frequencies which can be transmitted economically over the conducting wires.

As a result of continuous improvements to carrier systems, we cannot realize utilization of the carrier principle which will permit the transmission of 3600 telephone conversations over a pair of coaxial cable conductors in the L-4 Carrier System. Yet, with the potential now offered by solid-state devices (repeaters using transistor amplifiers), it is possible that even wider band coaxial systems than the L-4 will be designed.

1.7 A NATIONWIDE AND WORLDWIDE COMMUNICATIONS NETWORK

Today, as the result of the efforts by Long Lines - the long distance operating unit of the A.T.& T. - which builds, operates and maintains the interstate network of circuits and other facilities in the United States that make possible nationwide and world wide communications, telephone users in the United States can be connected with almost all the telephones in the world.

A. LONG DISTANCE OPERATIONS

There are in the United States 2100 cities in which there are operating offices for handling long distance calls. These cities are called toll centers.

In order for a long distance call to be made, the call must travel from the local exchange at which the call originates to a nearby toll center, then (directly or indirectly) to toll center near the exchange at which the call terminates, and then to that local exchange itself. To facilitate the connection of any two of the 2100 toll centers, there is a special set of 210 toll centers that are called switching points and that perform a function in connecting the toll centers that is comparable to the function of a central office switchboard in connecting the subscribers whose lines are connected to that switchboard.

Each toll center is connected directly with at least one of these switching points. In turn, each switching point is connected, directly or indirectly, with each of the other switching points.

B. DOMESTIC TELEPHONE MESSAGE SERVICE

Long Lines' responsibility is to handle interstate calls which originate in the territory of one Associated Company and terminate in the territory of another. Long distance calls other than the type just defined are handled by the Associated Companies.

Consequently, most intrastate long distance calls
are handled by the Associated Companies. Also, most
interstate long distance calls that originate and terminate
within the same Associated Company are handled by the
Associated Companies.

In general, the Long Lines Department provides
circuit facilities for the longer haul interstate traffic
of the Bell System. During 1966, long distance interstate
telephone messages - jointly handled by Long Lines and the
Associated Companies - totaled 1,780,300,000. This traffic
amounted to 5,706,000 messages per average business day.
To assure a smooth flow of communication - particularly in
times of especially heavy traffic, disaster, or equipment
failure, the Long Lines Department and the Associated
Companies have established twelve regional network control
centers as well as an overall control center in New York.

Each of the twelve regional centers is divided into
several sectional centers, then, in turn, into smaller
areas called primary centers and, finally, toll centers
containing the switching machines where calls first enter
or leave the long distance network.

Together, the staffs at these centers act as a
network management team, handling the interstate network
of circuits and switching equipment that serves customers
with about 95,000,000 telephones - and about 55,000
teletypewriter machines.

Under a master switching plan, the network, like a
computer, is programmed to handle calls in a systematic,
economical manner with alternative routes provided when
normal ones are not available. It is seldom that a
"no-circuit" tone or announcement must be made in order
to ask the customer to try his call again later.

The success of this management of the flow of calls
depends upon automatic switching equipment, a system of
alternative routings, and full knowledge of the second-by-
second state of the network as noted briefly in the
material on communication systems.

C. OVERSEAS SERVICE

The Long Lines Department furnishes service by
means of ocean telephone, satellite, radiotelephone, and
over-the-horizon radio to countries and territories
overseas and by radiotelephone to ships on the high seas
and to airplanes. The volume of overseas messages handled

by Long Lines was about 10,000,000 during 1966. Overseas telephone service, together with service to points on this continent, makes it possible for telephone users in this country to reach more than 97 percent of the telephones in the world.

Overseas telephone facilities are also used in transmitting television and radio programs to and from countries abroad. Long Lines also makes circuits available to the international telegraph carriers for their use for their own customers. Many of the underseas telephone cables were laid across the ocean floor by the Bell System cable ship, C.S. LONG LINES (Figure 1-6).

In addition, circuits for overseas communications are leased from the Comsat Corporation, which provides the service via orbiting satellites. The Bell System pioneered communication by earth satellites with the Echo balloon and TELSTAR^R satellites.

1.8 THE BELL TELEPHONE LABORATORIES

The Bell Telephone Laboratories has the reputation of being the finest industrial laboratory in the world. A large part of this reputation is due to the work of the scientists noted thus far. Further indication of the importance of the research work can be found also in the fact that Bell Laboratories is an industrial labortory whose researchers have won two Nobel prizes. One was awarded to Clinton J. Davisson in 1937 for the codiscovery of electron diffraction and the wave properties of electrons. Another, in 1956, went to William Shockley, John Bardeen, and Walter H. Brattain for their investigations into semiconductors and for the discovery of the transistor effect.

The invention of the transistor opened the era of modern electronics, an era in which Bell Laboratories has played a significant role. Another invention was the solar battery, which has been the source of power for many long-lived earth orbiting satellites. The principles of the laser were first described by a Bell Laboratories researcher, Dr. Arthur Schawlow, working with Dr. Charles Townes of Columbia University. Later, the first continuously operating gas and solid-state (ruby) lasers were created by Bell Laboratory scientists.

Figure 1-6   C.S. Long Lines

Communications achievements which have come from Bell Laboratories include: two-way transoceanic radio-telephone service, the coaxial cable, microwave radio relay systems, the nationwide television network, over-the-horizon microwave transmission, transoceanic telephone cable systems, direct distance dialing, and electronic switching systems.

The concept of communications by satellite was first proposed scientifically by Dr. John R. Pierce of Bell Laboratories. Later, the TELSTAR experimental communications satellite, which stirred the world when it first spanned the Atlantic with live television in 1962, was engineered, constructed, and successfully tested by Bell Laboratories development engineers. They continued their experiments with the second TELSTAR satellite, which was put into orbit in 1963.

1.9 NEW DEVELOPMENTS

A. HOLOGRAPHY

Recently, the Bell Telephone Laboratories have been pioneering in Holography which holds great potential for important communications functions. Holography, sometimes called "lenseless photography" of "wavefront reconstruction photography" is a way of recording the unfocused light reflected or transmitted by an object or objects. The recording, called a hologram, is usually made by exposing a photographic plate to light reflected from a subject and a reference source. The subject and the reference source (often a mirror) are illuminated with laser light. Two aspects of holography that are of primary interest at the Laboratories are:

1. The recording and transmitting of pictoral information, including possible uses in PICTUREPHONE and television services; especially, the three dimensional imaging capability of holography.

2. Utilization as a memory device.

Holography is still in its infancy. The advent of the laser, with its intense, coherent output (light waves) has given great impetus to its progress. Its potential however, in the final analysis, to the communications media must be evaluated in terms of its economic feasibility.

1.10 DIGITAL COMMUNICATION

Transmission systems carrying all types of communications in a digital pulse stream are gradually being introduced into the Bell System. Eventually, they will be connected together in a digital hierarchy to form a nationwide digital communications network.

For some years Bell Telephone Laboratories has been planning a digital network that will carry all types of communications signals, including:

1. Voice

2. Digital Data

3. Facsimile

4. PICTUREPHONE Service

5. Television

These signals will be mulitplexed together and transmitted on high-speed pulse streams.

Although the complete concept of a digital communications network includes digital switching as well as transmission facilities, most of the effort has been on the latter. Tl Carrier, the first digital transmission system to be designed, is now used commercially in many of the more heavily populated areas. At present, a medium-speed system and a commercial high-speed system are being developed. An experimental high-speed system has been built. The domestic communication satellite system, recently proposed by the Bell System to the FCC, would employ digital transmission and would be interconnectable with the digital network.

With the rapid development of solid state electronics and its application technologically to digital transmission, it may not be too far in the future when a digital network will be capable of:

1. Operating over any distance, and

2. Carrying several thousand calls, several television channels, or many data signals on a single pulse stream.

As time goes on, digital communication systems are expected to assume an increasingly important role in the Bell System, but analog systems will continue to provide the bulk of communication for many years.

1.11 FUTURE TRENDS

The past history of communications has been studded with developments that have contributed significantly to man's progress. At the turn of the century, the Bell System mobilized its resources to bring about a nationwide telephone network. It was a period in which the ground work was prepared for the transition from the manual system to the switching system. Later, we saw the advent of the solid state era in which the transistor, communication satellite and the computer made their entries. Today too, we are witnessing the increase in the variety and number of products, systems and services.

What will be the demands of the future? The following are comments by two world-renowned Bell Telephone Laboratory scientists.

Dr. John R. Pierce - Executive Director, Research Communications Sciences Division:

> "I see a great extension of satellites using radio frequencies for both domestic and foreign communication. It's a way of getting a lot of circuits quickly. And of course television is now extending through the ultra-high frequency as well as the high frequency. Ultimately, you run into an end as the air waves become full. But you never run into an end in the demand for communication. Thus, I think that communication--even mass communication--will eventually outgrow the air waves. We will have more and more of it by wire, or by millimeter waves going through hollow tubes called waveguides, or through laser beams that can carry tremendous amounts of communications, but which will have to be protected from the weather by pipes. I think that ultimately a large fraction of communications, even those that now ordinarily go by radio, will probably have to go by some guided means."

Dr. William O. Baker - Vice President, Research:

"In the coming years we must prepare to anticipate
and meet customer needs for communications facili-
ties of ever-increasing quality and quantity ...
which will involve the transmission of new
magnitudes of communications, including intermixed
batches of data, works and graphics beyond anything
conceived hitherto ....

"The new technology should enable us to enhance
the usefulness of all our service offerings."

CHAPTER 2

STATION APPARATUS

2.1 INTRODUCTION

In considering the various types of communication facilities, we will start with the basic apparatus at each end of the circuit and then, in separate chapters, discuss the equipment available for connecting the two. Normally the equipment at each end of the circuit is considered customer station equipment, or even more briefly, the customers telephone. It has the triple function of permitting talking, listening and signaling. Simply stated, however, the telephone is defined as an instrument for converting the mechanical energy of the speaker's voice into electrical energy having similar characteristics and then in turn converting the electrical energy back into similar sound waves at the listener's end.

2.2 SOUND

Since the primary source of the electrical signals transmitted over a telephone system is a speech sound wave and the end product of the transmission system is the reproduction of the original sound wave, a knowledge of the characteristics of sound will aid in the understanding and operation of our communication facilities.

The word sound has two distinct meanings. A physiologist or psychologist defines sound as a sensation produced by certain types of atmospheric disturbances. The physicist uses sound to define the disturbances rather than the sensations they produce.

These disturbances have been found to be waves in the air much like the waves produced when a stone is tossed in a pond. Sound waves travel in concentric spheres and expand at a definite rate of travel which has been found to be approximately 1075 feet per second varying somewhat with altitude and atmospheric conditions.

Sound waves are produced by the vibration of some source, such as a tuning fork or the human vocal chords. The rate of vibration of the source determines the frequency of the sound. A rapidly vibrating source will produce a tone of high pitch while a tone of low pitch will be produced by a slowly vibrating source. The frequencies of audible waves are in the range of about 20 to 20,000 cycles per second.

Audible sound is thus defined as a disturbance in the atmosphere whereby a form of wave motion is propagated from some source at a velocity of about 1,075 feet per second with a frequency range of 20 to 20,000 cycles per second.

Fortunately, in telephone transmission, which is essentially a problem of conveying "intelligibility" from the speaker to the listener, we are not seriously concerned with sounds having either fundamental or harmonic frequencies that extend throughout the entire scale of audibility. The sound frequencies which play the most important part in rendering the spoken words of ordinary conversation intelligible are the band of frequencies within the audible scale ranging from approximately 200 to 3,500 cycles per second.

2.3 THE SIMPLE TELEPHONE CIRCUIT

The original telephone, as invented by Bell in 1876, consisted of a ruggedly constructed telephone receiver, which at that time served as both transmitter and receiver. The telephone circuit in its simplest form consisted of two wires terminated at each end by such an instrument but without transmitter or battery and without signaling features. Figures 2-1 and 2-2 shows such a circuit.
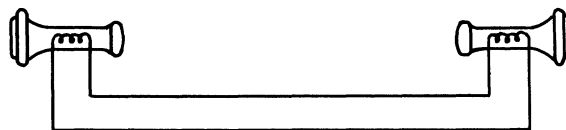
Figure 2-1 Elementary Telephone Circuit

At the speaker's station, the sound waves of the voice strike the metal diaphragm of the telephone receiver, and the alternate condensations and rarefactions of the air on one side of the diaphragm establish in it a sympathetic vibration. Located behind the diaphragm is a permanent bar magnet whose magnetic field is crowded in the vicinity of the metal diaphragm. The vibration of the diaphragm causes a corresponding change in the number of magnetic lines passing through the receiver winding, resulting in the turns of the winding being cut by the building up and collapsing lines. This establishes a varying electric voltage and current in the winding of the telephone receiver, having wave characteristics similar to the characteristics of the sound wave. This varying current passes over the connecting wires and through the receiver winding at the distant end. There it alternately strengthens and weakens the magnetic field of the permanent magnet, lessening and increasing the pull upon the receiving diaphragm, and causing it to vibrate in unison with the diaphragm at the transmitting end, although with less amplitude. This vibrating diaphragm reproduces the original sound, conveying intelligibility to the listener at the receiving end.
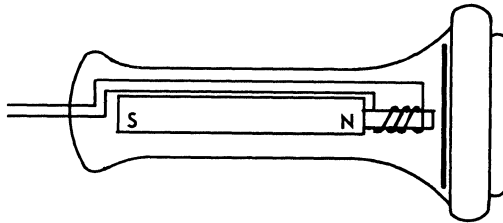
Figure 2-2 Bar-Magnet Transmitter-Receiver

This instrument contains no source of power, but relies entirely on the power generated by the talker's voice, the strength of the field of flux set up by the permanent magnet, and the resistance of the connecting wires. "Voice powered" type sets still exist today (with greatly improved magnetic structures) and are frequently used in the military and in explosive atmosphere environments.

2.3

Later developments and improvements in the subsets brought about the splitting of the transmitter and receiver into separate units.

2.4 THE TELEPHONE TRANSMITTER

Although the principle of Bell's original telephone applies to the present day telephone set, it was appreciated in the early stages of telephone development that the electrical energy generated by a diaphragm vibrating in a comparatively weak magnetic field was insufficient for the transmission of speech over any considerable distance. The energy could, of course, be increased by using stronger magnets, louder sounds, and the best possible diaphragms, but even with any ideal telephone receiver that might be perfected, voice transmission would be limited to comparatively short distances. One year after the invention of the original telephone, the Blake transmitter was introduced. It worked on the principle of a diaphragm varying the strength of an already established electric current, instead of generating electric energy by means of electromagnetic induction. It thus became possible to establish an electric current with an energy value much greater than that conveyed to the instrument by a feeble sound wave. The battery in this case was the chief source of energy and the vibration of the diaphragm acted as a means for regulating or modulating this energy supply, rather than as a generating device.

The principle of the transmitter is illustrated by Figure 2-3. The battery establishes a direct current in a local circuit consisting of the primary winding of an induction coil, and a cup of carbon granules. One side of
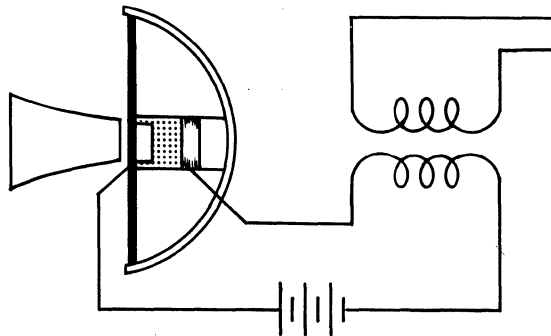
Figure 2-3 Principle of the Telephone Transmitter

2.4

this cup rests against a small carbon disc rigidly connected to the transmitter diaphragm. The vibrating transmitter diaphragm varies the pressure on the carbon granules, which causes the resistance of the electric circuit through the carbon granules to vary correspondingly, thereby causing fluctuations in the value of the direct current maintained in the circuit by the battery. These fluctuations, represented by varying direct-current values, establish an alternating emf in the secondary winding of the induction coil. This, in turn, sets up an alternating current through the local receiver, over the line, and through the distant receiver. The operation of the distant receiver is the same as has been explained previously.

The remarkable feature of this unit is the fact that the device is an exceedingly efficient converter from acoustic energy to electric energy. Numerically, the ac power is in the order of one thousand times greater than the acoustic power actuating the unit. The additional energy results from the battery associated with the transmitter.

Figure 2-4 shows a cross section of a standard transmitter unit for subscriber's telephone sets. It is of the "direct action" type; the movable element attached to the diaphram, which activates the granular carbon, is an electrode that serves the dual purpose of contact and pressure surface.
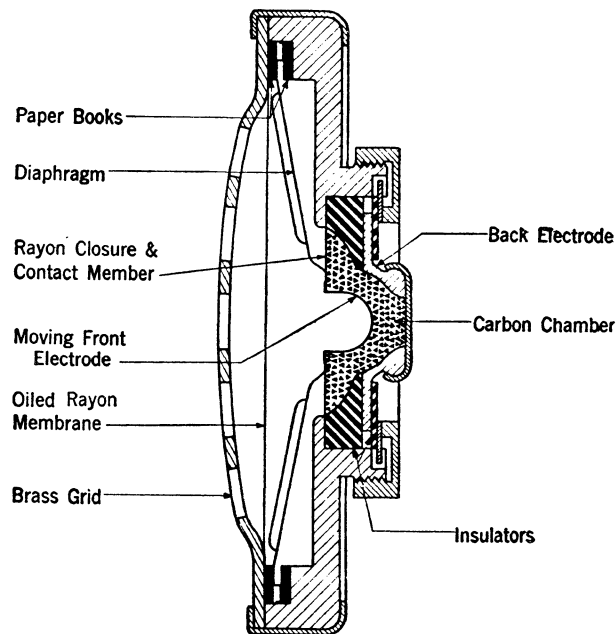
Figure 2-4 Cross-Section of Transmitter Unit

2.5

2.5 THE TELEPHONE RECEIVER

The earliest forms of telephone receivers were made with a permanent bar magnet as shown in Figure 2-2. The efficiency of the receiver was later greatly increased by the use of a horseshoe magnet as shown in Figure 2-5. This permitted the lines of magnetic force to pass in a much shorter path from one magnetic pole to the other through the iron diaphragm. The principle of operation of receivers currently in use in the telephone plant does not differ fundamentally from that of the original type although the receivers themselves are generally quite dissimilar in physical appearance.
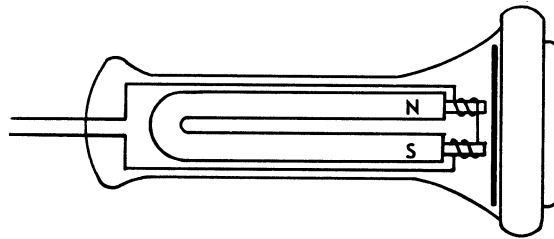
Figure 2-5 Horseshoe-Magnet Receiver

In the receiver the permanent magnet is important not only because it increases the amplitude of vibration of the diaphragm when the voice current is flowing through the windings, but also because it prevents the diaphragm vibrating at twice the voice frequency. This is illustrated in Figure 2-6. When a piece of soft iron is held near an electromagnet, it is attracted by the magnet regardless of the direction of the current in the windings. Thus, an alternating current in a winding on a soft iron core will assert an attraction during each half cycle, which in the case of the receiver diaphragm will establish a vibration with a frequency twice that of the current. If, on the other hand, a permanent magnet is used, the alternating current establishes a vibration of the same frequency as the current by merely increasing or lessening the pull already exerted on the diaphragm.
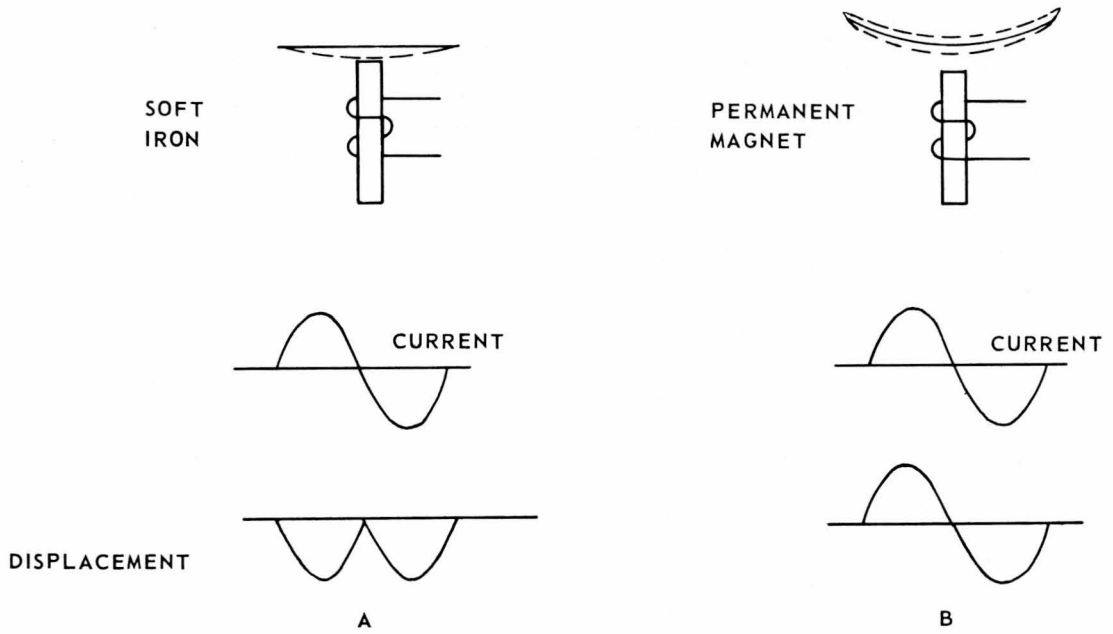
Figure 2-6 Receiver Diaphragm Displacement
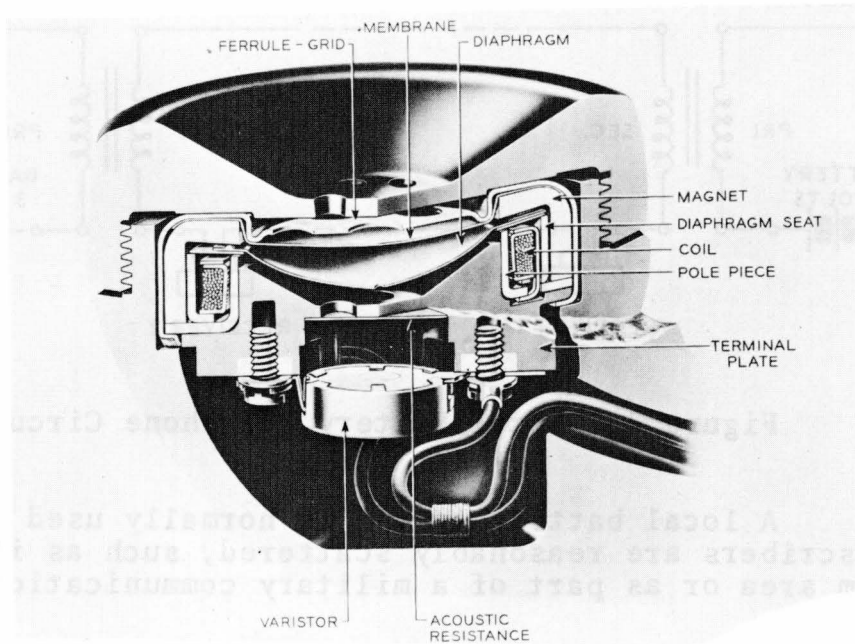
Figure 2-7 Ring-Armature Receiver

The above basic principles also apply to today's re-ceivers, of which a cross section of one of recent design is shown in Figure 2-7. This receiver is known as ring-armature receiver. The diaphram structure is driven like a piston under the influence of the magnetic fields existing in the air-gap across the inner edge of the armature ring.

2.6 THE TELEPHONE SET

A. Local Battery

Figure 2-8 illustrates a local battery telephone circuit. When the magnetic field is established by the fluctuating current through the primary of the induction coil, an alternating current is induced in the secondary of the coil. This current flows through the receiver at the same end of the circuit, giving "sidetone," which will be discussed later in this chapter, to the receiver at the home station. It is also transmitted to the distant station operating the receiver at that point.
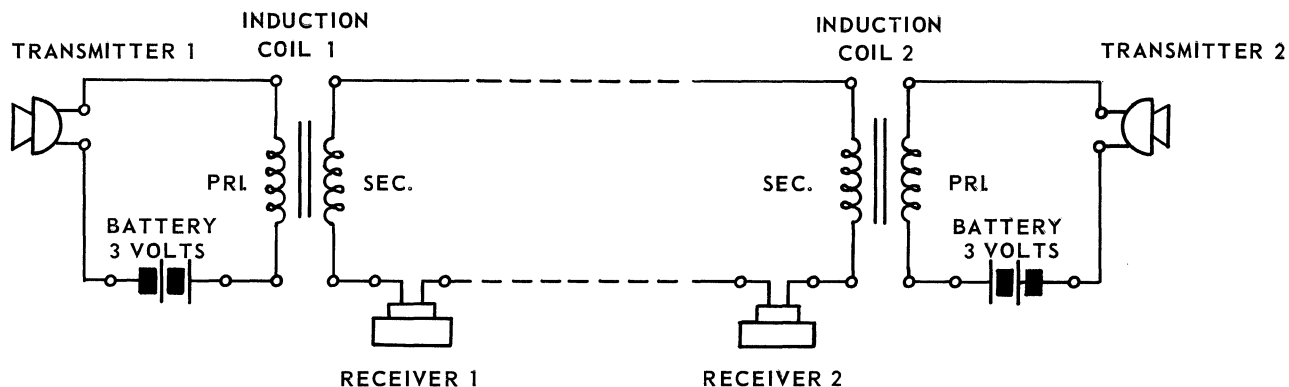
Figure 2-8 Local Battery Telephone Circuit

A local battery system is normally used where the subscribers are reasonably scattered, such as in a rural or farm area or as part of a military communication system.

Like any other communication equipment a local battery telephone system has certain definite advantages and disadvantages. Some of the advantages of the system are:

1. Satisfactory speech transmission is possible over long high resistance lines because there is only alternating current on the line and that of a relatively small value.

2. This means that the wire lines, commonly called the outside plant, can be of a poorer quality and can be constructed more economically and in less time.

3. The switchboard for this system is less complex, less delicate, and less costly.

However, the list of disadvantages for this system far outweighs the advantages. Some of these disadvantages are:

1. The life of the dry cell battery is short. It deteriorates even when standing idle and the voltage varies radically between the time of installation and exhaustion. This means that from the economic viewpoint dry cells are one of the most expensive sources of electrical energy.

2. The batteries must be checked at frequent intervals and exhausted cells replaced. Thus a repairman must visit each subset location no matter how widely scattered or isolated.

3. As the voltage of the battery decreases, the output of the telephone will decrease which will be noticed at the receiving end as a decrease in the volume of the received signal. Consequently, uniform transmission cannot be obtained from all subsets or even from one subset.

4. Some means of signaling the operator or other customers must be incorporated in the subset. This is accomplished by a hand generator or magneto which requires effort on the part of the user and also increases the size of the subset.

5. If the party using the phone does not ring off when through talking, it means more work for the operator since it is then necessary to monitor the circuit to determine when to disconnect. This also tends to reduce the availability and thus the traffic carrying capacity of these circuits.

6. If the switchboard drops are the manual restoring type, this further adds to the operator's work.

7. It can only be used for manual switching systems and not for mechanical switching systems.

B. Common Battery

Figure 2-8 showed a simple telephone connection between two telephone sets, each equipped with a transmitter, receiver, induction coil and its own battery for supplying talking power. In most modern telephone station installations, talking battery is supplied to each subset from a common battery at the telephone central office to which each subscriber line is connected. The simplest subscriber station circuit arrangement under these conditions is shown schematically in Figure 2-9. When the receiver is lifted to close the contacts of the switchhook, and the line is picked up at the central office by an operator or mechanical device, the central office battery is connected in series with the primary winding of the induction coil and the transmitter, and current is sent over the line. Varying currents set up by the transmitter, when it is talked into, add to or modulate the direct current flowing from the central office battery. The varying transmitter currents (which are fundamentally alternating rather than direct) induce a flow of current by transformer action in the secondary of the induction coil through the receiver and causes "sidetone."

The pulsating dc, with its corresponding voltage, variations, are impressed upon transmitter No. 2 and the primary of induction coil No. 2. Transformer action takes place from the primary to the secondary of this induction coil thereby impressing voltage variations upon receiver No. 2 which results in sound in the receiver. The voltage variations across transmitter No. 2 serves no useful purpose.
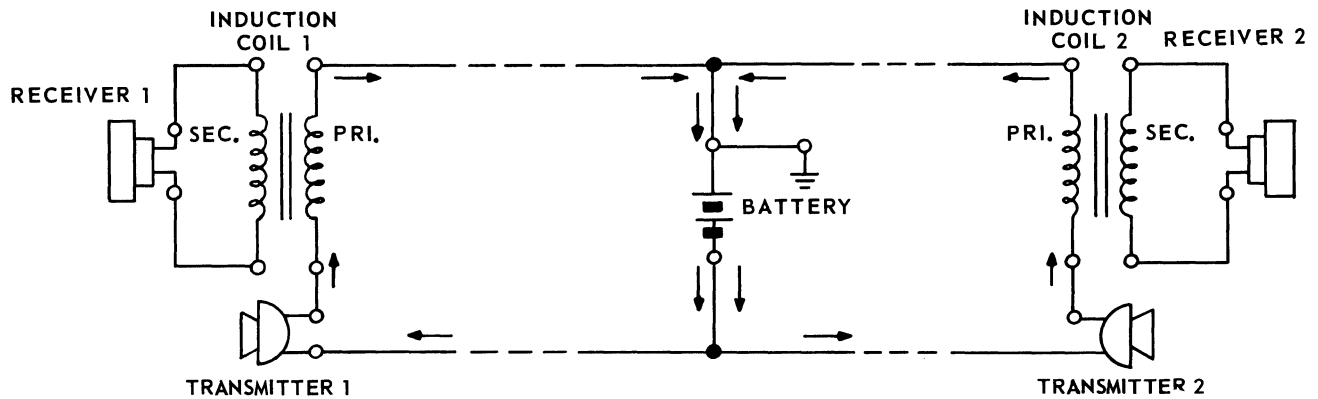
Figure 2-9 Common Battery Telephone System

The common battery system is used where there is a high concentration of customers. Practically all of the telephones in operation today are of the common battery type. This includes all of the telephones associated with the mechanical switching systems.

The use of a centrally located battery overcomes most of the disadvantages listed above for the local-battery system. For example:

1. By furnishing all current from a centrally located battery, the drain on it is such as to warrant the use of storage batteries which are easier and more economical to maintain. Recharging energy for a storage battery costs a great deal less than does the purchase of dry cells - the service requirements being the same.

2. The talking current for the subsets is supplied from the storage batteries which hold their current constant, thus the output of the subset is not affected by battery deterioration.

3. The battery supply being at a central location eliminates the necessity of visiting subsets to test and renew batteries.

2.11

4. The switchboard operator, or the mechanical line locating equipment, is signaled by removal of the handset from the switchhook of the subset. This allows direct current to flow in the line which lights a lamp in front of an operator or operates a relay in the mechanical systems. The elimination of the magneto together with the removal of the dry cells means that the subset equipment is smaller and simpler.

5. The operation of the switchhook, when the receiver is removed - or switchhook signaling - not only simplifies the routine for placing calls, but affords a prompt means of indicating completion of the conversation to the operator.

6. A single operator can handle many more lines on a common-battery switchboard than one at a local-battery switchboard and also give better service.

As with any system there are also a few disadvantages connected with the common-battery telephone system.

1. The outside plant must be of higher quality in order to reduce voltage leakage from the lines.

2. Any unbalance in the wire lines of the outside plant will seriously affect quality of transmission and distance over which transmission of speech is possible.

3. The inside plant equipment is far more complex, expensive and delicate; therefore, a longer time is required for installation, and maintenance requirements are increased.

4. The resistance of the loop or line to the subset limits the distance over which transmitter and signaling current may be supplied to a subset.

2.7 SIDETONE

A telephone system connected per Fig. 2-9 on the previous page has a serious drawback in that the receiver picks up not only the signal from the remote transmitter but also from its own transmitter. This coupling is undesirable both in the talking and listening phase. When talking, the individual hears his own speech through his receiver at an uncomfortable loud level and when listening, the background noise in the listener's room is picked up by his transmitter and superimposed on the received signal which tends to mask the incoming speech.

This coupling effect between the transmitter and receiver is called sidetone. A circuit was developed to eliminate this coupling by utilizing a 3 winding induction coil as described below and illustrated schematically in Fig. 2-10. This circuit is called the antisidetone circuit.

The complete elimination of sidetone is, however, not desirable either, since in normal conversation one hears his own speech and talking into an instrument while not hearing anything in the receiver seems unnatural. Subjective tests have shown that some coupling must be allowed between the transmitter and receiver to provide a controlled amount of sidetone. Too much sidetone causes the talker to lower his voice, thereby reducing the volume which the listener receives; too little sidetone makes telephone conversation seem unnatural and tends to cause people to talk too loudly. The actual antisidetone circuit employs, therefore, a balancing network that can be adjusted to slightly mismatch the line impedence and thus, introduce a small amount of sidetone.

Figure 2-10 shows the equivalent circuit of the "anti-sidetone" feature of a present day 500 type telephone set.
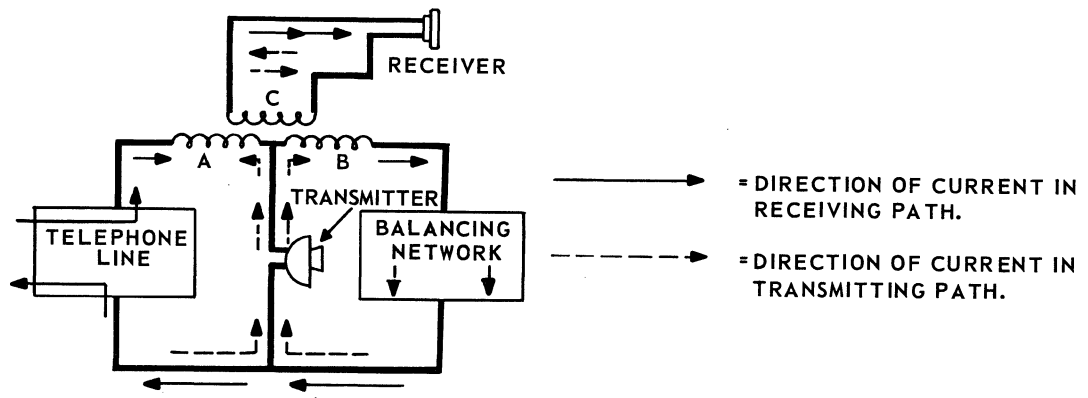
Figure 2-10 Antisidetone Station Circuit

In the transmitting phase, the signal generated by the transmitter goes through the A coil out on the line and through the B coil into the balancing network. These two parts of the signal induce a current into the C coil (receiver), however, since the currents are in the opposite direction and of equal magnitude (balancing network matches line impedence) they cancel each other out and therefore, no part of the signal generated by the transmitter appears in the local receiver - no side tone.

In the receiving phase both parts of the signal are in the same direction, they reinforce each other and appear as a strong signal in the receiver.

To introduce a small amount of sidetone, the balancing network is adjusted to mismatch the line impedence, thus the 2 parts of the transmitted signal do not balance out and the difference appears as sidetone.

2.8   DIAL

In a manual telephone system the subscriber tells the number he desires to an operator who either selects the number for him and connects his line to the line of that numbers, or, in larger systems, connects the line to a trunk to a distant office and repeats the number to another operator who selects the line for him. In automatic systems, the sequence of operations is somewhat similar but the operations are performed by electro-mechanical switches.

Since an electromechanical switch cannot respond to the voice of the subscriber as an operator can, it is necessary to provide a means by which the subscriber can convey to the switches what number he wants.
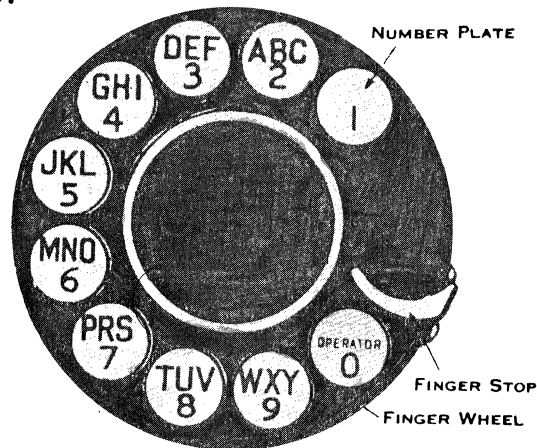
Figure 2-11   Telephone Dial (Front)

2.14

This mechanism is the "dial" (Figures 2-11 and 2-12). Most people are now familiar with the operation of the dial. The customer puts his finger in the hole of the dial in which appears the letter or figure which he wishes, pulls the rotating disc around until his finger strikes the stop and lets go.
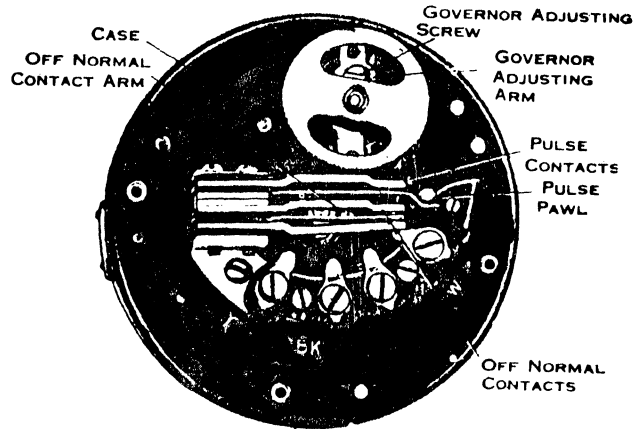
Figure 2-12 Telephone Dial (Rear)

A spring rotates the disc back to its normal position and in doing so simply opens and closes the circuit of the customer's line the number of times indicated by the number under the hole into which the customer puts his finger. It must be remembered that that is all the dial does -- it opens and closes the circuit of the customer's line a certain number of times. A little governor in the back of the dial controls the speed of the rotating disc and assures that the opening and closing of the circuit is uniform and regular. By performing this operation the proper number of times, the customer relates to the relays or switches the central office in which the desired line is located and the number of that line. It should be noted that rotating the disc with the finger in the hole marked "zero" opens and closes the circuit ten times.

If the customer wishes to reach the operator, the dial in restoring to normal will cause the pulse contacts to open and close ten times. The opening and clsoing of the dial pulse contacts will cause the "line pulsing relay" in the central office to release and operate ten times. In releasing and operating ten times the "line pulsing relay" conveys this information to the "pulse counting circuit" or "switch mechanism" and the automatic equipment functions to establish a connection to the zero operator. In a similar manner other call combinations can be established.

In order to eleiminate the dial clicks in the receiver when the dial is restoring to normal a pair of off-normal contacts in the dial break and the receiver is out of the circuit. After dialing is completed the off-normal contacts restore the circuit to normal.

The average customers dial is designed to operate at about 10 pulses per second. The circuit of the 500D type dial telephone set is shown in Figure 2-13. The 500-type set includes a mechanical dial with a precision pulsing mechanism,
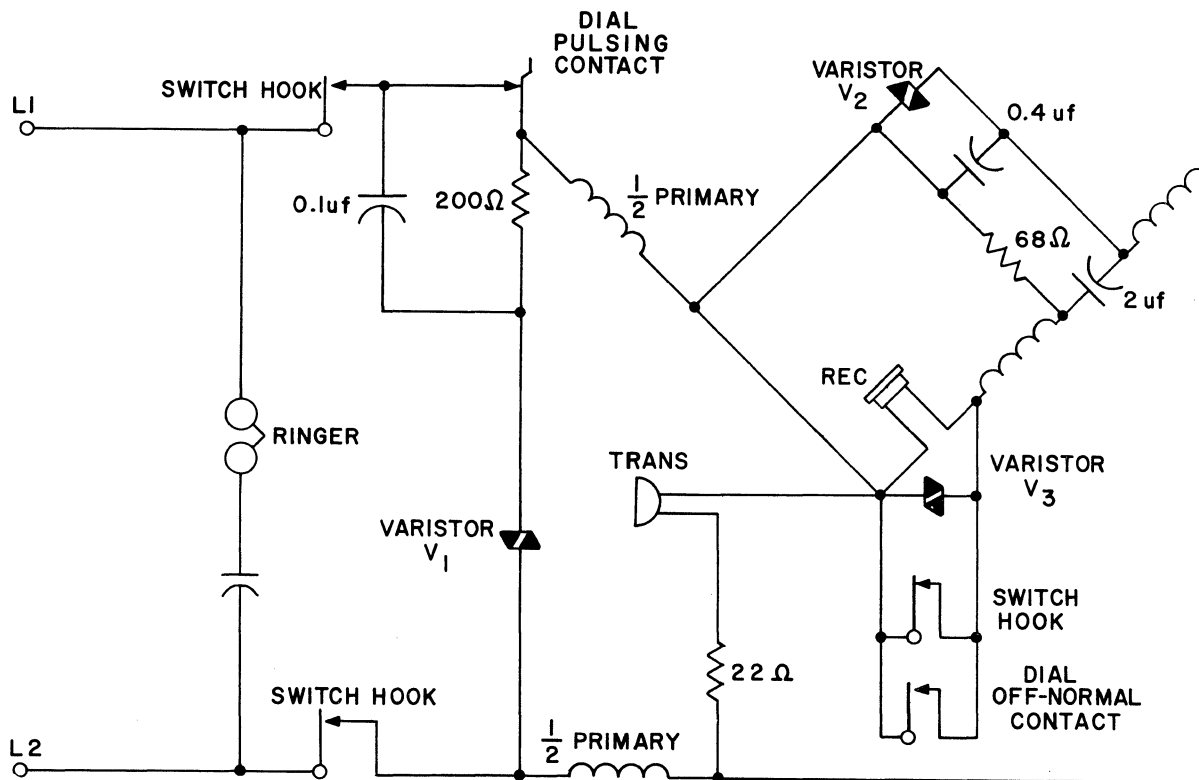
FIGURE 2-13 - Complete Circuit of Type 500D Telephone Set

and it is self adjusting in its speech transmission and sidetone
characteristics to match the length of subscriber line on which
it is used. Automatic control of transmission features is
accomplished through the variable characteristics of varistors V1
and V2 shown in Figure 2-13. Both the ac and dc resistance of
these varistors depends on the direct current passing through them
and the magnitude of this current is determined by the resistance
(length) of the subscriber loop. These circuit elements adjust
the speech transmission and sidetone characteristics of the
subscriber set as required for any type of telephone connection.
The 500-type set also has improved ringing features, compared with
earlier sets. A 500-type telephone set with the letters and
numbers appearing outside the dial is shown in Figure 2-14.
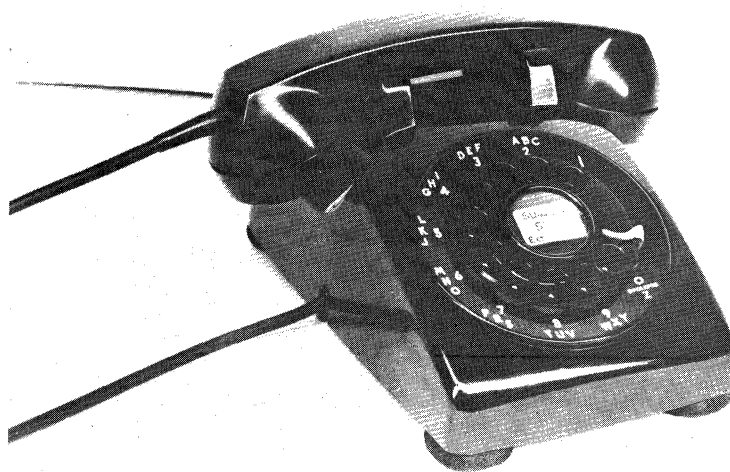
2.9 TOUCH-TONE

TOUCH-TONE dialing offers to the customer speed and
convenience through the use of a "pushbutton" rather than the
rotary type dial. Consequently, the telephone set contains a
set of "pushbuttons" rather than the dial of Figure 2-11.
Multifrequency tones are generated by depressing the pushbuttons
of the subset instead of direct current pulses being generated
by the pulse contacts of the dial.

The subset contains a double frequency transistorized
oscillator which is powered by the central office battery.
Depressing any pushbutton will generate two frequencies; one
from a high group and one from a low group. Each group consists
of four frequencies as follows; low group - 697, 770, 852 and
941 cps, high group - 1209, 1336, 1477 and 1633 cps.

```
          1209    1336    1477    1633
                                  (SPARE)

    697 ──┤ 1 ├──┤ 2 ├──┤ 3 │

    770 ──┤ 4 ├──┤ 5 ├──┤ 6 │

    852 ──┤ 7 ├──┤ 8 ├──┤ 9 │

    941 ──────────┤ 0 ·│
```
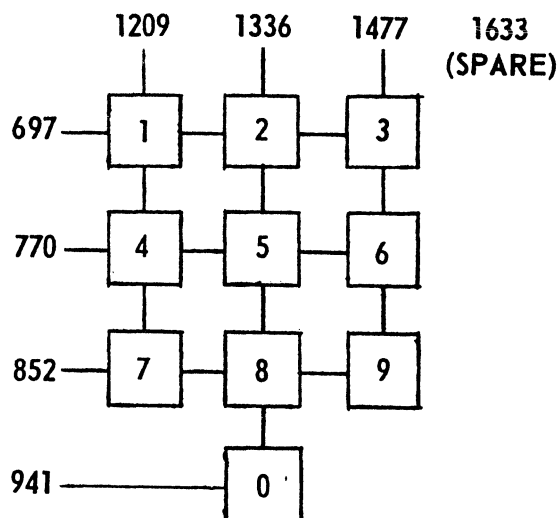
Figure 2-15   TOUCH-TONE Dialing Freq Combinations

The two frequencies generated will indicate a digit from 0 to 9 and two special service tones as shown in Figure 2-15. The combination of one low group frequency and one high group frequency gives 16 possible signal combinations. The extra four signals are for use with the special 16 pushbutton phones.

Depressing any pushbutton also operates the "Common Switch" which reduces sidetone to the receiver, opens the transmitter path and applies bias voltage to the transistorized oscillator.

2.10 RINGERS

The telephone ringer or "bell" is used to indicate the presence of an incoming call. Three types of ringers are in use today; the unbiased ringer, the biased ringer, and the harmonic ringer.

Unbiased ringers are intended for use on alternating current only. When alternating current passes thru the electromagnets, the magnetism set up by the permanent magnet is strengthened in one coil and diminished or overcome in the other on the first half cycle. The armature now tilts toward the core having the strongest magnetism and the clapper ball strikes one gong. As the current is reversed on the half cycle, the other coil has the greater attraction and the clapper ball strikes the other gong.

The biased ringer is used in all cases where superimposed current (direct current superimposed on alternating current) is used for ringing. The biased ringer is constructed like the unbiased ringer except that it is equipped with a biasing spring to hold one end of the armature against the respective magnet core. See Figure 2-16. A pulse of the proper polarity will overcome the pull of the spring and pull the armature against the other core, ringing first one gong and then the other as the armature is released and returned to the biased side by the biasing spring. Pulses of the opposite polarity would, of course, have no effect on the ringer. This makes it possible to ring either of two ringers on one wire by choosing the polarity of pulses to be sent out over the line.
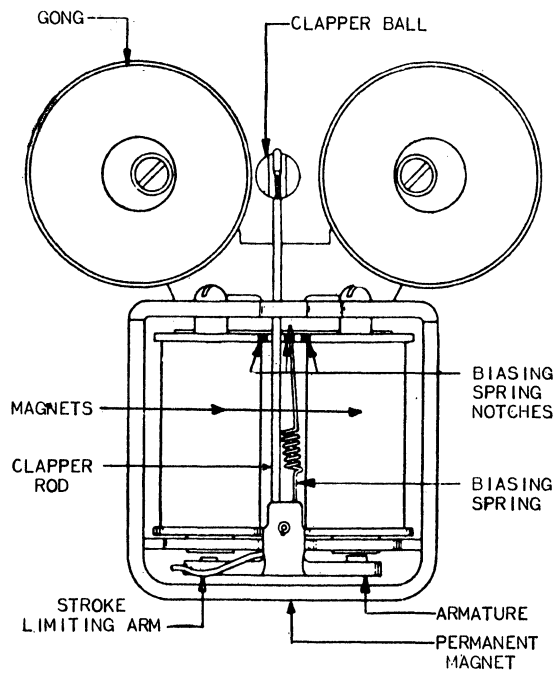
Figure 2-16 Biased Ringer

The harmonic ringer resembles the unbiased ringer in general construction. However, the armature of the harmonic ringer is secured to a stiff steel spring rigidly mounted between the two halves of the core yoke, instead of being pivoted by trunion screws. Thus, the armature and tapper are held normally in a median position. Each ringer is mechanically tuned so that it responds only to ac ringing of one frequency. The natural period of vibration is determined by the strength of the spring and the weight of the gong tapper. The four ringing current frequencies are: 16-2/3, 33-1/3, 50 and 66-2/3 cycles per second.

2.11 RINGING MULTIPLE-PARTY LINES

A. 2-Party Selective Ringing

In 2-party selective ringing, the ringers of the two parties are connected one from each side of the line to ground, instead of across the line as in individual lines. This is shown schematically in Figure 2-17, in which the subscriber stations, other than just the ringer portions, do not appear. Likewise, the tripping circuit is not shown, and the ringing circuit is shown only symbolically. Actually, the ringer is essentially the same as already indicated, but with a means for applying the ringing
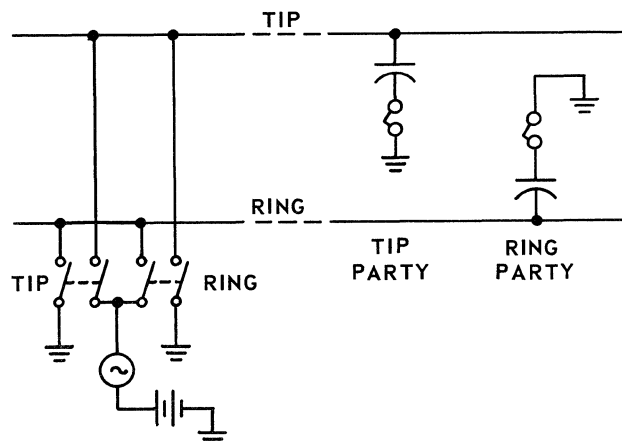
Figure 2-17 2-Party Selective Ringing

voltage to either side of the line at will, ground being applied to the opposite side in either case. If ringing voltage is applied to the tip side of the line, only the tip-party ringer will operate, as the ring-party ringer is then grounded on both sides. When ringing voltage is applied to the ring side of the line, the opposite occurs.

B. 4-Party Full Selective Relay System

The first successful 4-party full-selective ringing was accomplished by having a relay in series with a capacitor bridged across the line at each party's station. Operation of the relay applied ground to the ringer, as shown in Figure 2-18. In this diagram, two degrees of selection in the ringing are obtained, first by applying the ringing voltage to either tip or ring wire, as in the case of 2-party ringing, and further by changing the polarity of the battery current which is superimposed on the alternating current from the ringing machine. Thus four selective combinations are obtained, positive or negative direct current with alternating current on the tip wire, and positive or negative direct current with alternating current on the ring wire.
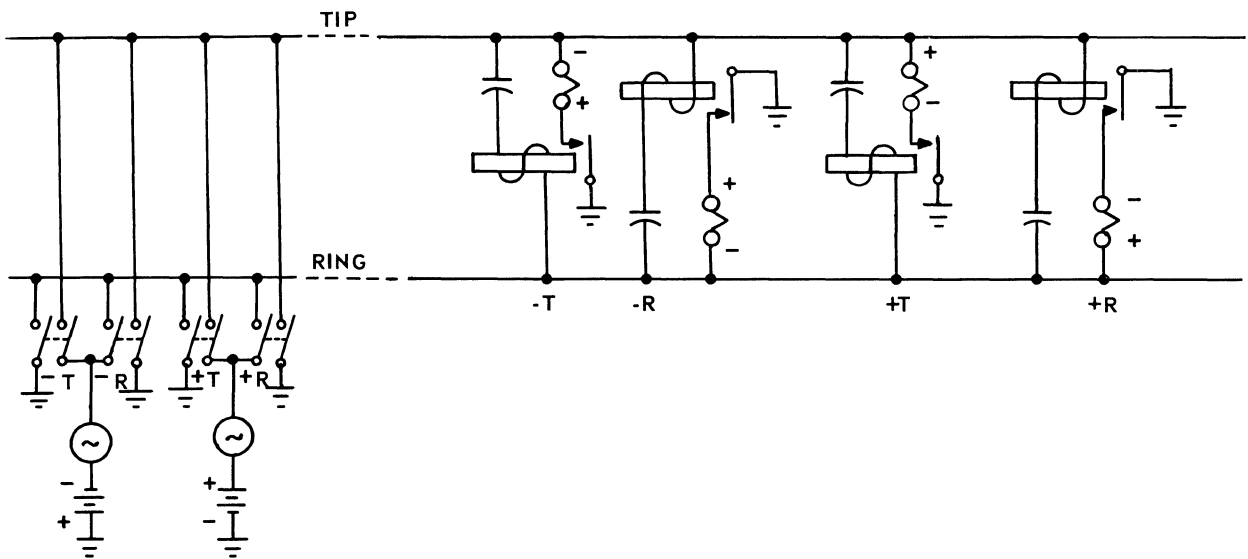
Figure 2-18 4-Party Full Selective Ringing Using Relays

When any one of the four combinations is applied (by throwing any one of the four switches in the diagram) all four of the relays operate, as there is no directional or polarity sense in the operation of the relays. Ground is thus applied to all four ringers, but only two of these are connected to the side of the line corresponding to the one switch thrown, thus eliminating the other two ringers. Which one of the two possible ringers operates, is determined by the polarity of the direct current and the bias of the ringer. The bias is obtained mechanically by means of a spring which pulls one end of the armature of the ringer to a stop position where it is nearly in contact with one of the cores of the ringer winding. Of the two ringers connected to the tip wire, one is biased to the side which requires positive direct current to overcome the pull of the spring (negative direct current only holds the armature more firmly against the core), and the other to the side which requires negative direct current. The two ringers connected to the ring wire are similarly biased for positive and negative operation. Thus only one ringer can operate when one of the switches shown in the diagram of Figure 2-18 is closed.

C. 8-Party Semiselective Coded Ringing

8-party semiselective ringing is obtained by doubling up on a 4-party full-selective arrangement. Two ringers operate for each of the four combinations of ringing. The final step in selection is achieved by code, for instance, one ring for one of the two selected ringers and two rings for the other.

D. Inverted Relay Biased Bell System

In order to overcome the difficulties experienced with ground potentials which seriously interfered with the operation of Relays in the Central Office, as well as causing substation "Cross-Ringing" or failure to ring, the position of the ringer and the relay was reversed to obtain the Inverted Relay Biased Bell System as shown in Figure 2-19.
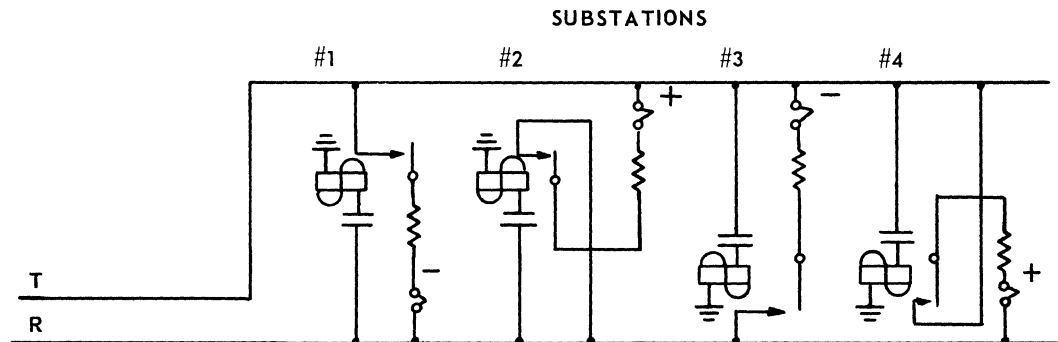
SUBSTATIONS

Figure 2-19 Inverted Relay Biased Bell System

Two (2) substation relay windings are connected from each side of the customer line to ground, each relay in series with a capacitor. When pulsating ringing current is applied to the called customer line, one side of the line is grounded. As a result, only two(2) substation relays operate - those two having their windings connected to the ungrounded side of the line. One of the two substation ringers, bridged across the customer line by operation of the two substation relays, is selected by applying pulsating ringing current of the proper polarity to the line.

When positive ringing pulses are applied to the tip conductor of the called customer line and ringing ground to the ring conductor, Substation #3 and #4 relays operate, bridging their respective ringers across the subscriber line. Only Substation #4 ringer operates as it is biased for positive ringing pulses.

E. 4-Party Full Selective Ringing Using Harmonic Ringers

In 4-party full selective harmonic ringing, each substation ringer is bridged across the customer's line, in series with a capacitor. A particular substation is signaled by the selection of one out of four ac ringing current frequencies: 16-2/3, 33-1/3, 50 or 66-2/3 cycles per second applied to the called customer's line. Only the ringer tuned to the frequency selected will operate.

2.23
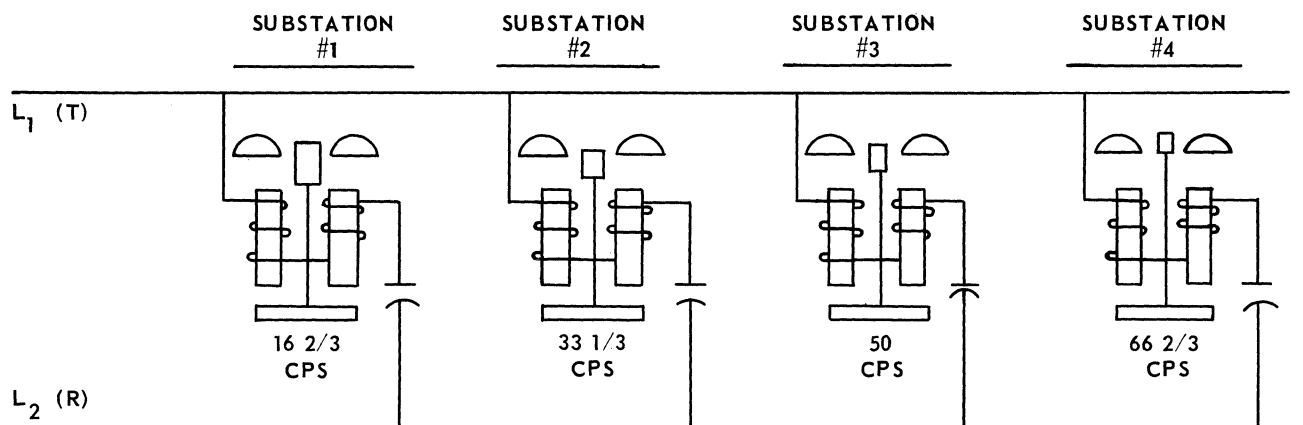
Figure 2-20 4-Party Full Selective Ringing
Using Harmonic Ringers

8-Party full selective ringing is then possible with the use of harmonic ringers. Four substation ringers are connected from one side of the line, and the remaining four ringers from the other side of the line, each to ground and each through a capacitor. Any one of the eight substations may be signaled, with the exclustion of all others, by applying ac ringing current of the correct frequency to the side of the customers line, tip or ring, to which that substation ringer is connected, utilizing ground return.

The harmonic ringer is not used too frequently in the Bell System. It is inconvenient to manufacture four different types of the harmonic ringers. It is simpler to manufacture a ringer with the biasing spring that can be positioned to operate on positive superimposed ringing, negative superimposed ringing or ac ringing current alone, by neutralizing the biasing spring.

F. **4-Party Full Selective Ringing Using 3-Element Cold-Cathode Tubes**

The present standard method of 4-party full selective ringing is one which employs 3-element cold-cathode tubes instead of the relay and capacitor. These are arranged as indicated in Figure 2-22. The tubes have a control anode and cathode which form a "control gap." This breaks down, or ionizes, when a potential of
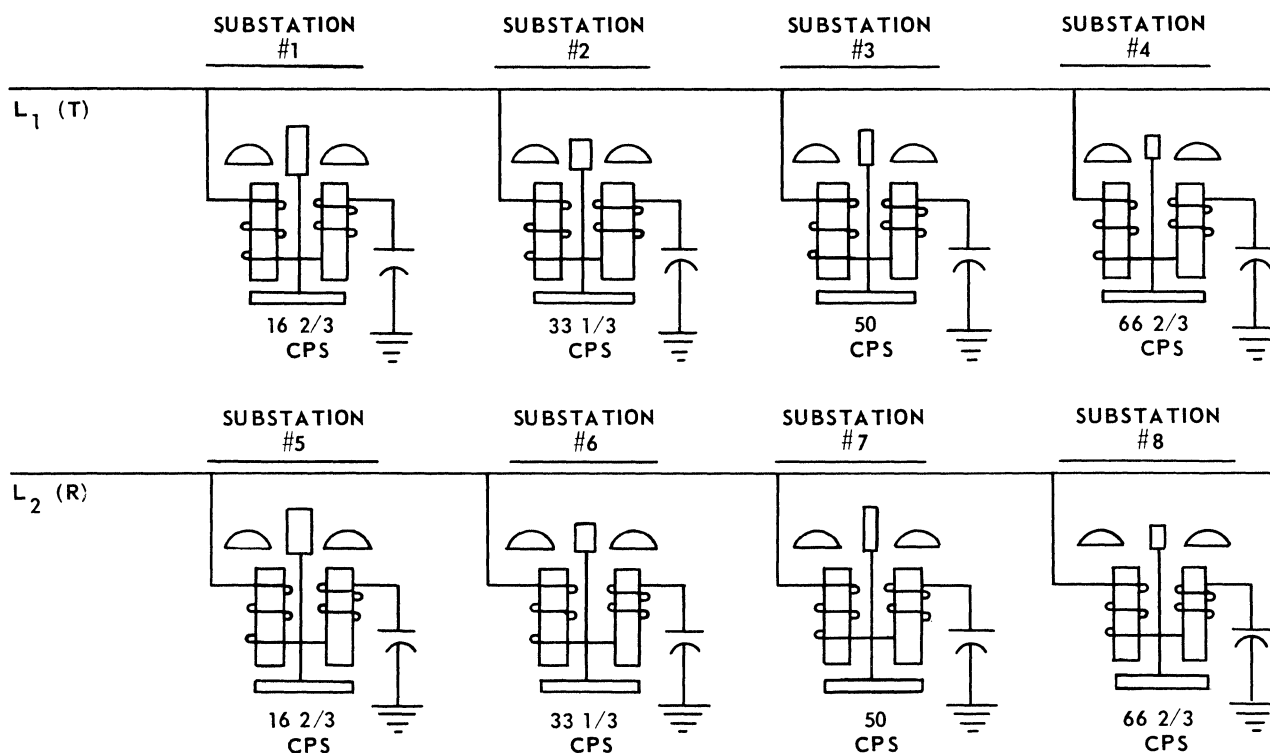
Figure 2-21 8-Party Full Selective Ringing
Using Harmonic Ringers

about 70 volts (of either polarity) is applied across it.
Ionization of the gas in the tube permits current conduc-
tion to occur in the main gap, provided the third element,
the main anode, is positive with respect to the cathode.
Current in the control gap is limited by a series resistor
to about one microampere, but the main gap can handle
currents as high as 30 milliamperes. Referring to
Figure 2-22, it will be noted that when any one of the
four switches is thrown, the control gaps of two of the
tubes will breakdown. The other two control gaps cannot
breakdown because both sides of the gaps are at ground
potential. For instance, if the -T switch is thrown, the
control gaps of the tubes for the -T and +T parties will
breakdown. The superimposed direct current has the correct

2.25
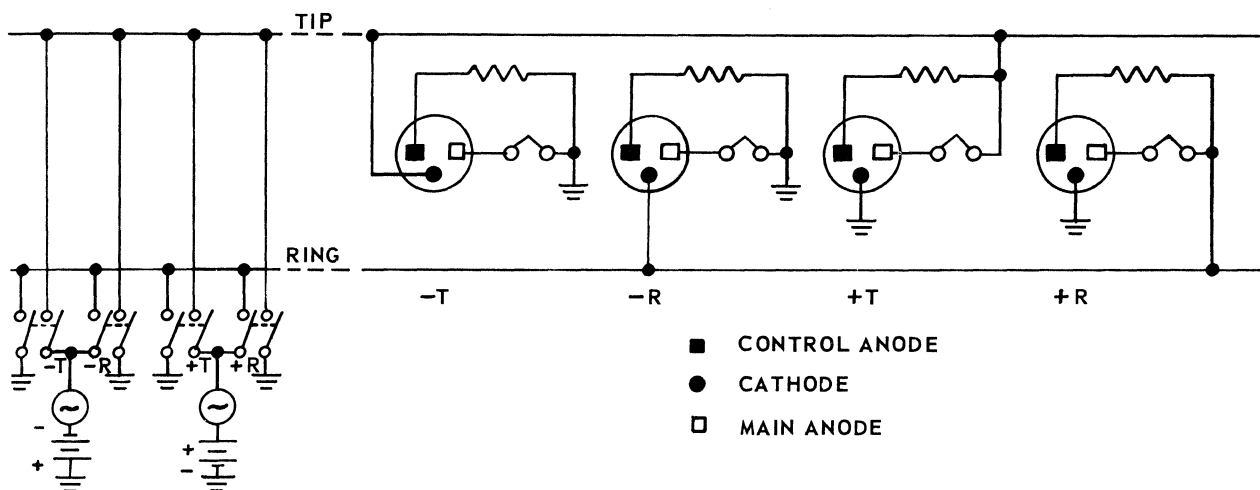
Figure 2-22 4-Party Selective Ringing Using
3-Element Cold-Cathode Tubes

polarity to cause conduction of ringing current in the
main gap of the -T party, but the wrong polarity for that
of the +T party. Hence the ringer of the -T party is the
only one of the four which operates. In the same way,
throwing any one of the other three switches operates only
the one corresponding ringer.

The tube subset has several advantages over the
relay type. With the relay type subset, ringing current
flows through 2 ringers and 4 relays. In the case of the
inverted relay biased system, ringing current flows through
2 relays and 1 ringer. However, ringing current flows
through only 1 ringer in the tube-type subset since the
electron tube will pass current in only one direction.
This arrangement reduced the voltage drop due to line
resistance, and permits an extended ringing range for
4-Party Service.

The electron tube also eliminates bell tapping
and false ringing sometimes caused by dialing or switching
operations.

In addition, the tube may be mounted in any position, while the relay must be mounted vertically to insure proper operation. Adjustment of the relay is also required to insure proper functioning of the relay type subset.

2.12 RINGING AND TRIPPING CIRCUITS

A simplified schematic of a ringing machine appears in Figure 2-23, which shows ringing and tripping circuits applied to an individual line, that is, to a subscriber line to which only one station is connected. It will be noticed that the commutator which supplies ringing current to the line is divided into two segments which correspond, respectively, to a ringing interval of about two seconds, followed by a silent interval of four seconds. During both ringing and silent intervals, direct current from a 45-volt battery is supplied. Alternating current is supplied only during the ringing interval.

Ringing is accomplished by closure of switch contacts, or, in dial offices, relay contacts as shown at the point marked C in the diagram. This causes the relay marked A to operate and relay B remaining unoperated since its winding is short-circuited. Operation of relay A applies ground to one side of the customer loop and the ringing commutator to the other side. Alternating current flows through the ringer at the customer station set during the ringing interval, and to ground back at the central office, thereby ringing the bell. As long as the customer does not lift the handset from its mounting, there is no dc path in the customer circuit.

The purpose of the tripping relay is to insure that the called subscriber cannot be "rung in the ear," whether he answers the call during the ringing interval or the silent interval. In other words, operation of the tripping relay is an indication that the customer has removed the handset from its mounting, and is presumably ready for conversation. The tripping relay is so designed that it cannot operate on alternating current alone, that is, as long as the direct current path is open. Removal of the handset closes the direct current path through the switch-hook, transmitter, and one induction coil winding at the subscriber station. The relay will operate firmly on direct current alone if the call is answered during the silent interval. If the call is answered during the
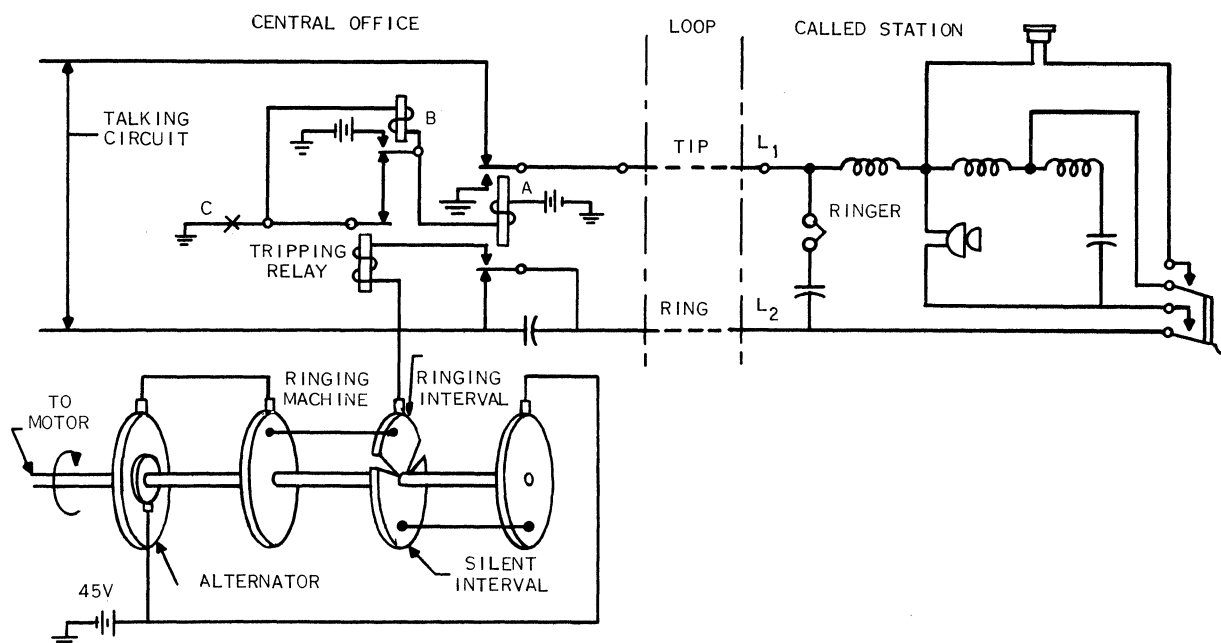
Figure 2-23 Superimposed Ringing and
Tripping Circuits

ringing interval when both alternating and direct currents
flow through the winding of the tripping relay, the latter
will tend to operate intermittently. However, at the first
operation of the tripping relay, the short-circuit is
removed from the winding of relay B, which operates and
locks up to battery through its contacts, thereby shunting
down relay A. This, in turn, restores the line to the
talking condition before the called customer can raise
the handset to his ear.

A condenser is shown in Figure 2-23 near the con-
tacts of relay A. When the circuit is in the talking
condition, with relay A nonoperated, the capacitor is
short-circuited. In the ringing condition, relay A removes
the short-circuit from the capacitor, which allows a small
amount of ringing current to flow back to the calling
customer, thus permitting him to hear the so-called
"audible ring."

CHAPTER 3

LOCAL MANUAL SYSTEMS

3.1 THE MANUAL SWITCHBOARD

A. History

On January 28, 1878, two years after Alexander Graham Bell was awarded a patent on his primitive telephone, the world's first commercial telephone exchange opened for business in New Haven, Connecticut. This enterprise was called the District Telephone Company of New Haven. It was a small beginning. There were only 21 subscribers, served by 8 lines with interconnecting service provided by the operation of two rotary switches. This was the first switchboard, a model of which is shown in Figure 3-1.

As more and more subscribers were added, switchboard designs had to be altered to enable the interconnecting of the steadily increasing number of subscriber lines. As local central office areas began to be established, each devoted to the interconnecting of a group of subscriber lines terminated on its switchboard, further alterations were required. It soon became necessary to enable a subscriber whose line terminated in one central office to be connected to a subscriber whose line terminated in another central office. With the ever increasing growth of subscribers, improvements in local central office switchboard designs were constantly made until they evolved into the manual switchboards described in this chapter.

B. Basic Switchboard Functions

A telephone switchboard is defined as the unit of central office equipment which requires an operator to perform the switching function necessary to provide the requested telephone service. In a manual office operators are required to switch all calls from one subscriber to another subscriber whose line is terminated in the same central office. Operators are also required to terminate calls received from another central office to any of its subscribers. Further, operators must also be able to connect any subscriber to a line terminated in another central office which will in turn connect him to one of the subscribers in that office or to another switchboard elsewhere.
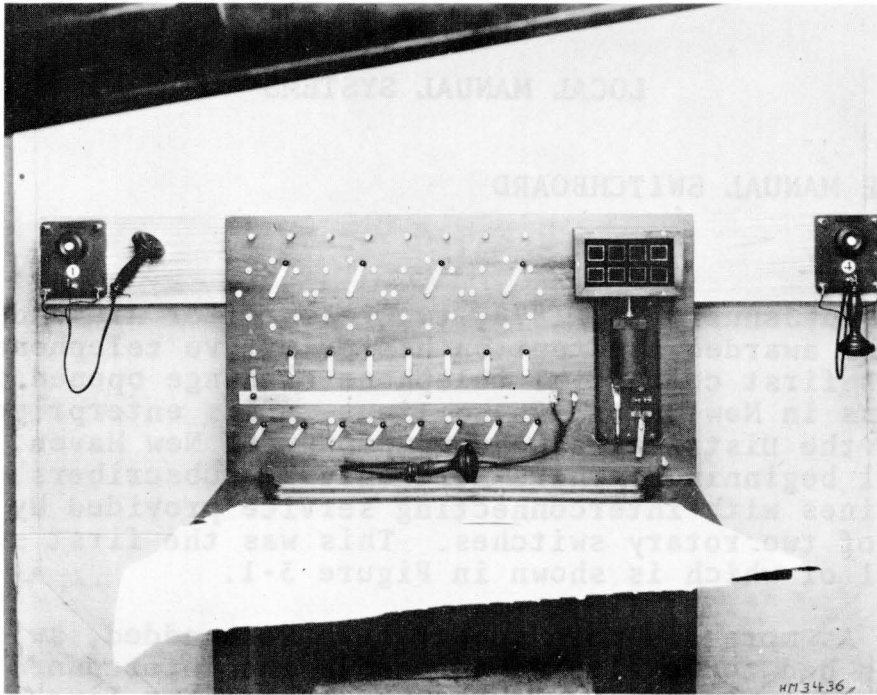
Figure 3-1 Model of First Switchboard

Thus a local telephone switchboard is designed to switch originating and terminating calls from and to subscribers in the local central office area. Originating calls are those made by subscribers which are answered by operators and completed to other subscribers in the same office or forwarded for completion in another office. Terminating calls are those incoming from other offices and completed by operators to subscribers in the local office.

The basic tool available to the switchboard operator and which she uses to establish any of the above connections is the cord circuit. Actually, each switchboard is equipped with a number of these cord circuits in order to enable the operator to establish the requested call connections while other previously established calls are still in the "talking" stage.

Each of these cord circuits is essentially a telephone line "bridge" with a plug at each end and a key in the middle for connection to the operator's telephone circuit. Since

each subscriber's telephone line is terminated in a jack
mounted in the upright portion of the switchboard (facing
the operator), the operator can establish a talking path
between any two such subscribers by inserting the cord
circuit plugs into the two subscriber line jacks and thus
establish a connecting "bridge" between the two lines.

Before this can be accomplished however, the operator
must be able to detect a subscriber's request for telephone
service and then determine the nature of the call. If it is
a call to another subscriber in the same central office, she
locates the called subscriber's line jack, rings the sub-
scriber and waits until she detects an answer. When the
conversation between the two subscribers has terminated which
she detects by means of the lit cord circuit lamps, she
removes both plugs from the subscriber's jacks. The cord
circuit is now available for the subsequent connection of any
other two subscriber lines. Each switchboard contains certain
basic equipment necessary for the completion of subscribers
calls. This is described in paragraph 3.2.

Switchboards are usually referred to as local or toll,
according to the type of traffic handled. The local switch-
board is designed for operators to switch calls between sub-
scribers in the same office, forward calls to another office
or to complete incoming calls received from other offices.
The toll switchboard is designed for switching calls between
local offices and calls to and from other toll switchboards.
In the more populated areas local and toll switchboards are
generally separate units although they may be located in the
same building. In smaller areas they may be separate lineups
in the same operating room or even part of the same lineup.
When part of the same lineup, the switchboard is sometimes
arranged so that operators can switch both local and toll
calls. This latter arrangement is called a combined local
and toll board or a single channel switchboard. Toll
Switchboards will be discussed in a later chapter.

3.2 SWITCHBOARD EQUIPMENT

Figure 3-2 shows the front equipment and keyshelf of
a typical local manual switchboard. In the figure, the keys,
lamps and plugs for 17 cord circuits are shown mounted on
the keyshelf. The relays and equipment associated with these
keys, lamps, and plugs are not shown in the figure, but are
mounted on a relay rack behind the keyshelf. The figure shows

the lower portion of the front equipment which contains the
subscriber line answering jacks and associated line lamps.
Above these jacks and lamps are the outgoing (O.G.T.) multiple
jacks and in the top portion, the subscriber multiple jacks
are shown.
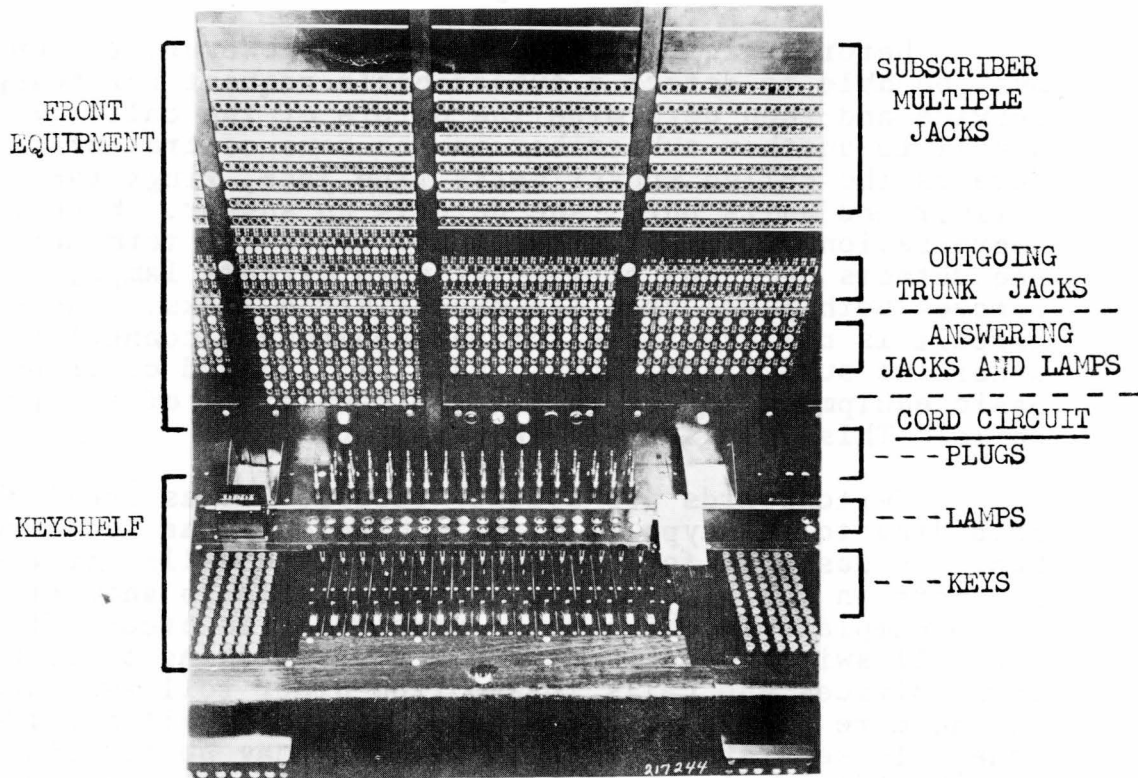
Figure 3-2   Front View of a Typical Manual Switchboard

A. Upper and Lower Units

The illustration shows only one switchboard position
(for one operator). Usually three such positions are
combined into one switchboard section. The front equipment
for all three positions is known as the upper unit. This
consists of the framework necessary for mounting the various
jacks and lamps described above, the shelf and brackets for
supporting the multiple cables, the answering jack cables
and other miscellaneous switchboard cable. There is one
lower unit for each position, and this consists of the key-
shelf and framework for the cord circuits and other apparatus
required by one operator.

B. Subscriber Answering Jacks

The subscriber answering jacks are not assigned to the subscriber's lines in numerical sequence but are assigned so as to equalize the originating traffic (the request for telephone service) among the various operators. Each operator, therefore, is responsible for a proportionate share of the traffic load.

C. Subscriber Multiple Jacks

The subscribers multiple jacks are used by the operators to complete connections to subscriber lines whose answering jacks terminate in other positions. Except in very small offices, each line appears in parallel (multiple) at other jack locations at repeated intervals along the various switchboard sections. This enables each operator to connect the calling subscriber (whose answering jack appears in the answering jack portion of her position) to the called subscriber (whose jacks appear in the multiple jack portion within her reach). Normally each operator is able to reach all the multiple jacks in her position, and the positions on either side. Thus, the principle of the multiple jacks switchboard enables one operator to answer any one of about 150 lines and connect it to any one of about 10,000 lines. A multiple jack switchboard is shown diagramatically in Figure 3-3.

D. A Subscriber's Call

If a calling subscriber, whose number is 109 in Figure 3-3, calls a party whose number is 567, the calling subscriber's lamp in position 1, that is associated with the answering jack for line 109, indicates a request for service. The operator, upon seeing the lamp light up, then plugs one end of the cord circuit into the associated jack (A). After finding out that the subscriber desires number 567, the operator then inserts the other plug of the cord circuit into the multiple jack (B) for line number 567 located in position 2.

On the other hand, if subscriber 567 called subscriber 109, the operator at position 3 inserts the cord circuit plug into the jack marked (C) in Figure 3-3 and then inserts the other cord circuit plug into the multiple line jack marked (D) in position 4.

Each operator guards against plugging into a busy line. If she hears a "click" in her receiver when she starts to plug into a jack the fact that the line is in use somewhere else in the multiple is indicated.

MULTIPLE JACKS

(B)

(D)

LINE 109

LINE 231

Pos. 1

Pos. 2

Pos. 3

Pos. 4

Pos. 5

Pos. 6

(A)

(C)

ONE SWITCHBOARD SECTION

LINE 567

ANSWERING JACKS & SIGNAL LAMPS
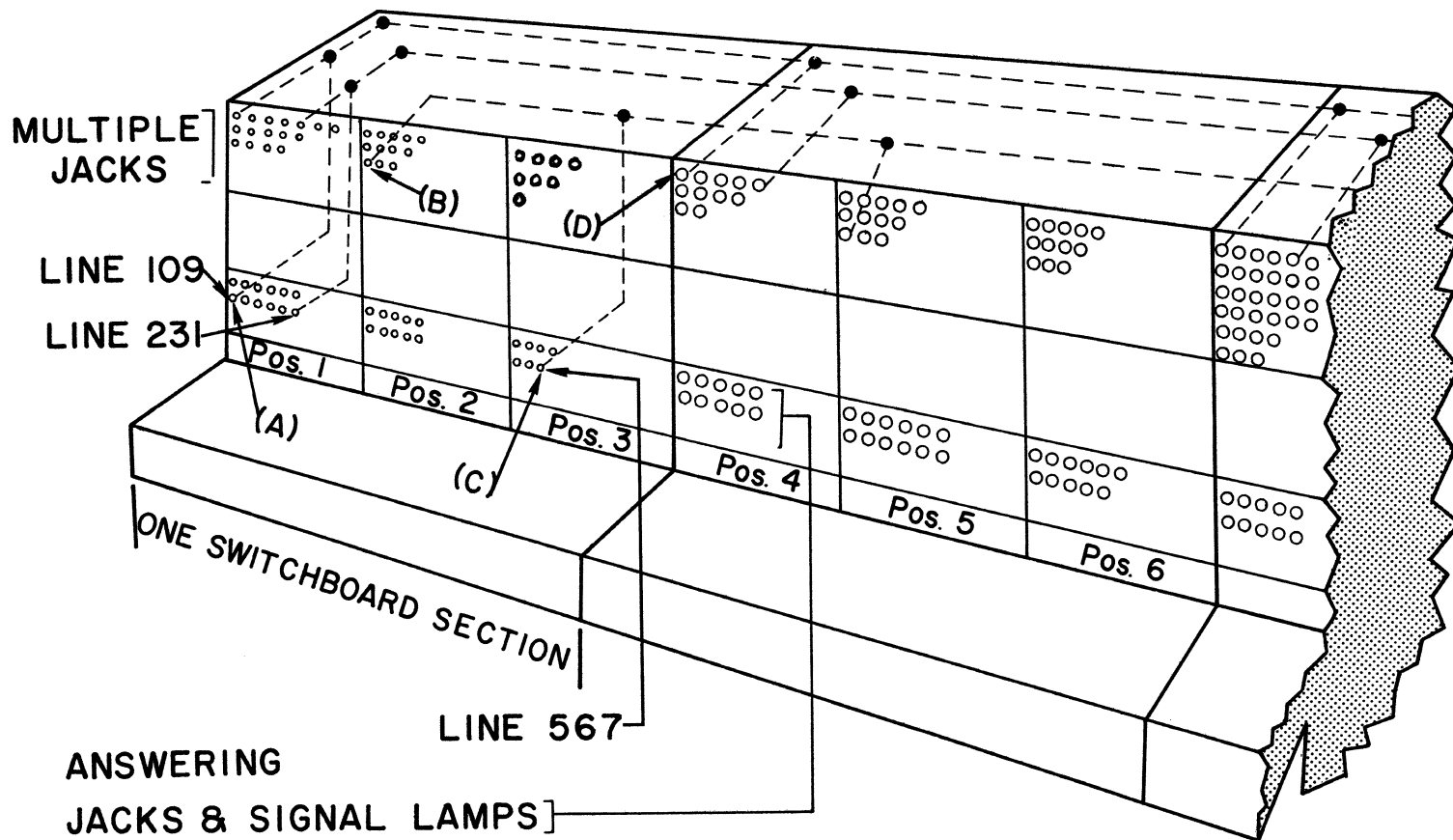
Figure 3-3   An example of a Multiple Jack Arrangement

3.3 SWITCHBOARD CIRCUITS

A. Subscriber Line Circuit

The evolution of the subscribers line circuit is illustrated in Figure 3-4. One of the circuits used in the early manual switchboards was the cut-off jack line circuit, Figure 3-4(a). When the subscriber removed his handset a circuit across the T and R leads was closed and the lamp lit. When the operator plugged into the jack with the answering cord, the plug physically opened the lamp circuit and at the same time connected the subscriber to the operator. The difficulty here was that different subscribers required different sizes of lamps depending upon the resistance of the subscribers loop due to varying lengths of line. Also, the jack cut-off springs were hard to adjust. An improvement was the line relay circuit, shown in Figure 3-4(b). The lamp was now replaced with a high resistance relay which operated regardless of the amount of loop resistance. The lamp circuit, controlled by the line relay, was office contained and in addition, all lamps were now of the same size. There was still one difficulty, which was, the jack itself. The jack was rather large and required the plug on the cord to physically break the circuit by the action of the plug in the jack. This was overcome by use of the line circuit with line and cut-off relays, shown in Figure 3-4(c).

Figure 3-4(c) shows that when the operator plugs into the jack of this circuit, the sleeve of the plug puts battery on the sleeve of the jack. This causes the cut-off relay to operate, releasing the line relay and extinguishing the lamp. There are fewer parts to this jack and it is smaller; since there is no required physical movement in the jack, the jacks can be located closer together, thus allowing more jacks to be placed in any switchboard position. There is another advantage to this circuit. When the operator plugs into this circuit she places battery on the sleeve of the jack. In a multiple switchboard this means that there is battery on the sleeve of every multiple of this jack. This allows other operators to test for a "busy" condition of a subscriber line. If a subscriber line is "busy," the operator will hear a click in her headset when she touches the tip of a cord circuit to the sleeve of the jack.

B. Cord Circuit

The cord circuit permits the operator to talk to subscribers, interconnect lines and trunks, ring the subscriber's telephone, supervise the connection and perform a number of other duties. It also provides talking battery for the subscribers.
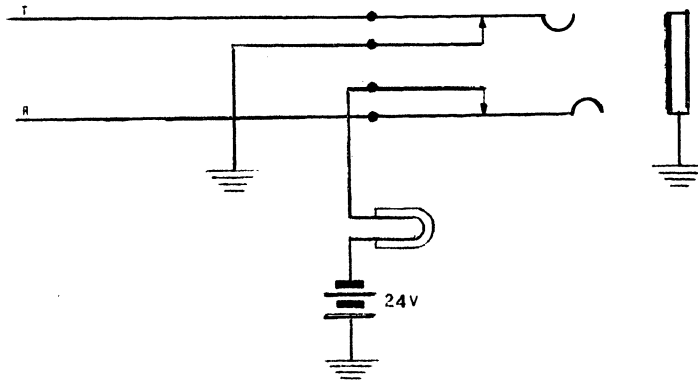
Figure 3-4(a)   Cut-Off Jack Line Circuit
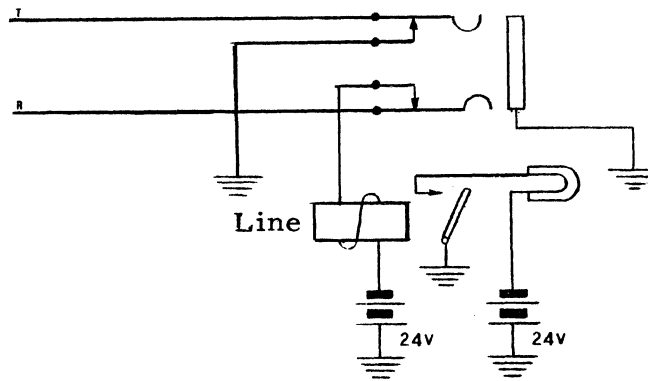
Figure 3-4(b)   Line Relay Circuit
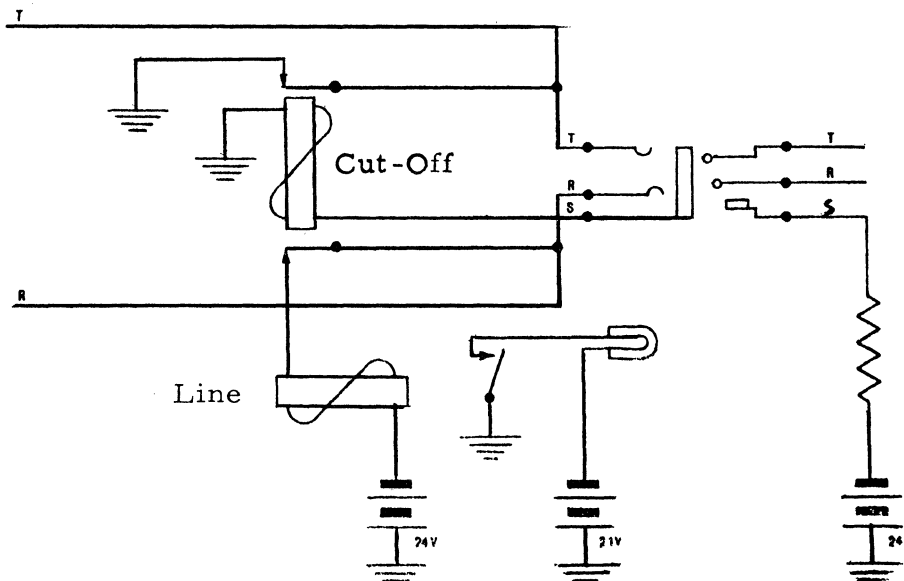
Figure 3-4(c)   Line Circuit With Line and
                Cut-Off Relay

A cord and its associated circuits is illustrated in Figure 3-5. This figure shows a telephone connection between two stations terminating at the same central office. Here the telephone circuit at each station is normally open when the receiver is on the hook, with the exception of the ringer which is bridged across the circuit in series with a capacitor. It is a function of the capacitor to close the ringing circuit for alternating current and open in so far as the subscriber's signaling the operator is concerned and is closed through the ringer in so far as the operator's ringing the subscriber is concerned. Thus, the circuit is in such condition that the subscriber may call the operator or the operator may call the subscriber.

The subscriber calls the operator by merely closing the line, which is accomplished by removing the receiver from the hook. The operator answers the call by inserting plug P_1 , into the answering jack associated with the lighted lamp and to which the line of the calling party is connected.

The operator learns the calling subscriber's wishes by connecting her telephone set to the cord circuit by means of the key K_1 . She talks over the two heavy conductors of the cord circuit through the windings of the repeating coil, which by means of transformer action induces current into the other windings of the same coil. This current flows back over the calling subscriber's line and induces a current in the secondary of the induction coil, which in turn, flows through the telephone receiver.

Answer Jack & Lamp

Repeating Coil

Subs. Line Jacks

Thru Pilot Lamp & Night Bell Relay

Calling Subscriber Sub-set

Thru Pilot Lamp & Night Bell Relay

Operator's Head Set

Called Subscriber Sub-set
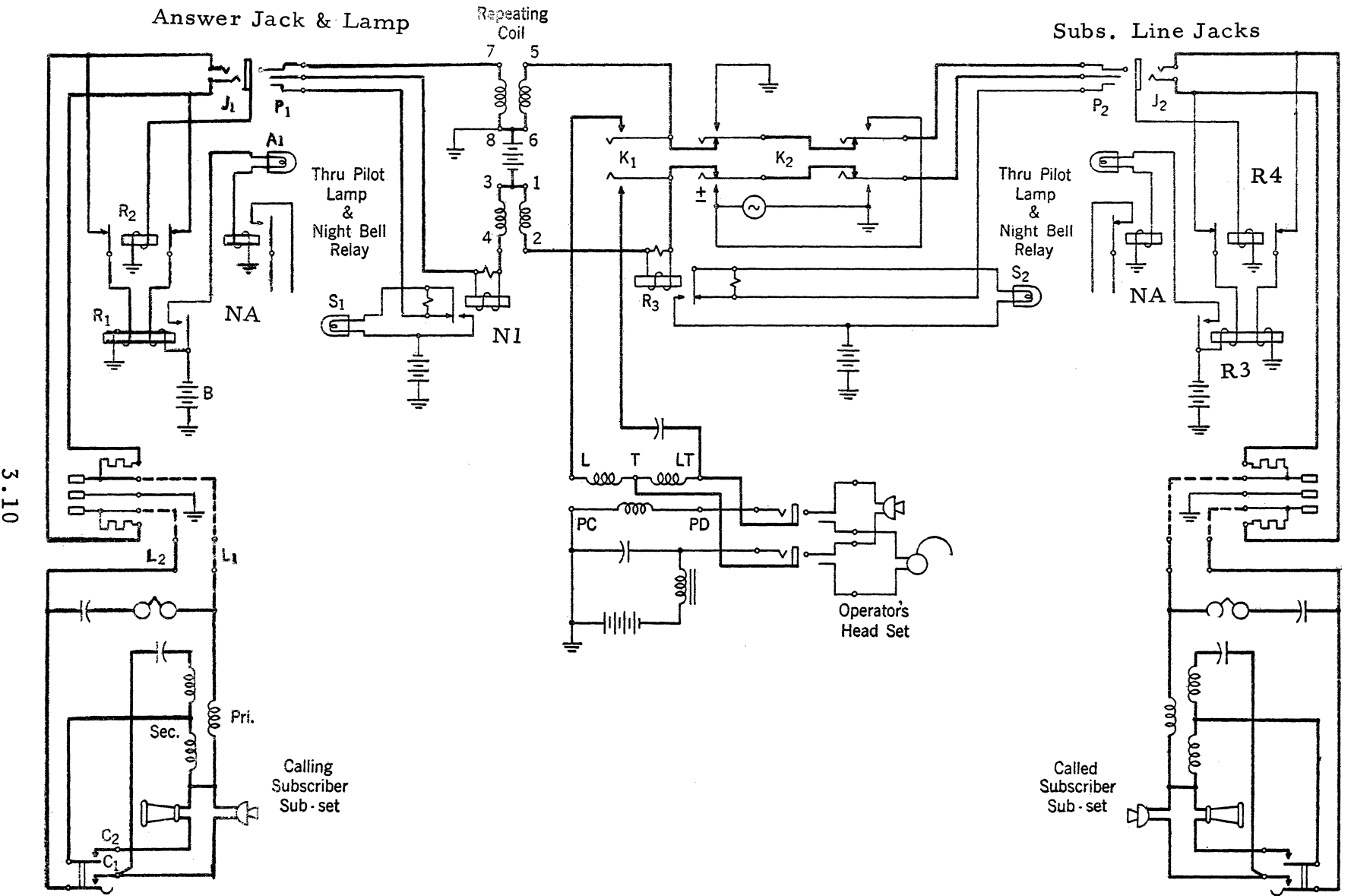
Figure 3-5   Telephone Connection Through Common Battery Exchange

Not only does the operator's voice current flow from the central office cord circuit to the subscriber's receiver, but there is direct current furnished by the central office battery through two of the four windings of the repeating coil of the cord circuit, over the line and through the subscriber's transmitter. This permits the subscriber to talk by virtue of the transmitter carbon resistance varying the strength of the current, which, by means of the repeating coil windings at the central office, induces an alternating voice current across to the opposite side of the cord circuit.

C. Trunk Circuits

A "trunk" is a telephone line which connects one central office with another central office. In the case of a local manual system, when a subscriber calls a subscriber whose line terminates in another central office, the local switchboard operator connects him to a trunk line which routes his call to that office. The operator accomplishes this by inserting the cord circuit plug into one of the outgoing trunk jacks (O.G.T.) mentioned previously. The trunk jack is part of the trunk relay circuit. The number

and types of trunk relay circuits required depend upon the
type of facilities, type of signalling, and nature of the
distant office to which the particular trunk line is
connected. In a similar manner, trunk circuits are also
used to complete calls arriving from distant offices. These
are called incoming trunks. Trunk circuits also enable
operators stationed at different switchboards in the same
office to communicate with each other. Some of these intra-
office trunks are described later on in this chapter.

3.4 LOCAL SWITCHBOARDS

The use of switchboards containing multiple sub-
scriber line jacks made it possible for one operator to
service a great number of lines. However, as more and more
telephones were installed, it became impossible to put
enough multiple jacks within the reach of each operator.
To solve this problem the local manual switchboard function
was divided into two types of switchboard sections, the
"A" subscribers section and the "B" trunk section. This
brought about central offices with lineups of "A" type
switchboards cabled to lineups of "B" type switchboards.
These two different types of switchboards were usually
located in different parts of the building.

A. "A" Switchboard

The subscriber or "A" switchboard is composed of
three basic elements required to perform its switching func-
tions. These are the subscriber line circuits, the trunk
circuits over which connections are established, and the
cord circuits which are used by operators to establish the
desired connections. Although varying in appearance,
characteristics and capacity, the different types of "A"
switchboards all have these basic features.

B. "B" Switchboard

The incoming trunk or "B" switchboard requires only
two basic elements to perform its switching function of
completing incoming or terminating calls to subscribers.
These elements are the subscriber line jack and the incoming
trunk circuits.

The subscriber line jacks in the "B" board are a
continuation of the multiple jacks in the subscriber line
circuits of the "A" board.
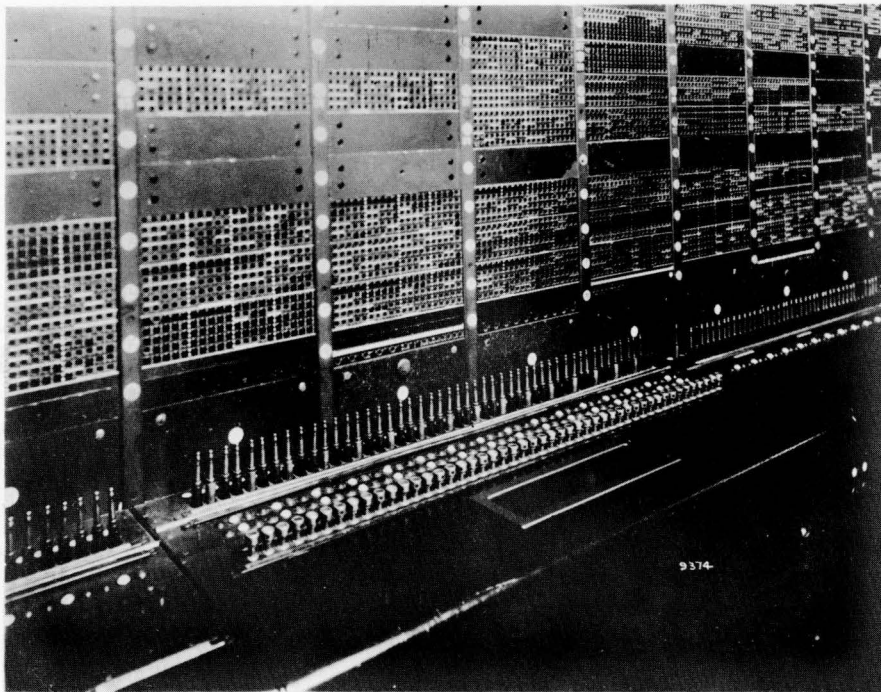
Figure 3-6   Front View of a "B" Switchboard

Incoming trunks at a "B" board handle calls specifi-
cally directed for completion to subscribers in the local
office. This feature makes it practicable to terminate the
trunks on single plug ended cords. Lamp signals are
associated with each cord and operators complete calls
directly to the subscriber multiple jacks. Since the
average number of calls per trunk is comparatively high it
has been found that from 30 to 48 trunks will generally
furnish enough traffic for one operator. Accordingly, "B"
position keyshelves are arranged for 30 to 48 incoming
trunks.

Only the cords, keys and lamps of the trunk circuits
are located in the switchboard. The trunk circuit relays
and position control equipment are located on relay rack
bays. Figure 3-6 shows a typical "B" board keyshelf and
jack field.

3.13
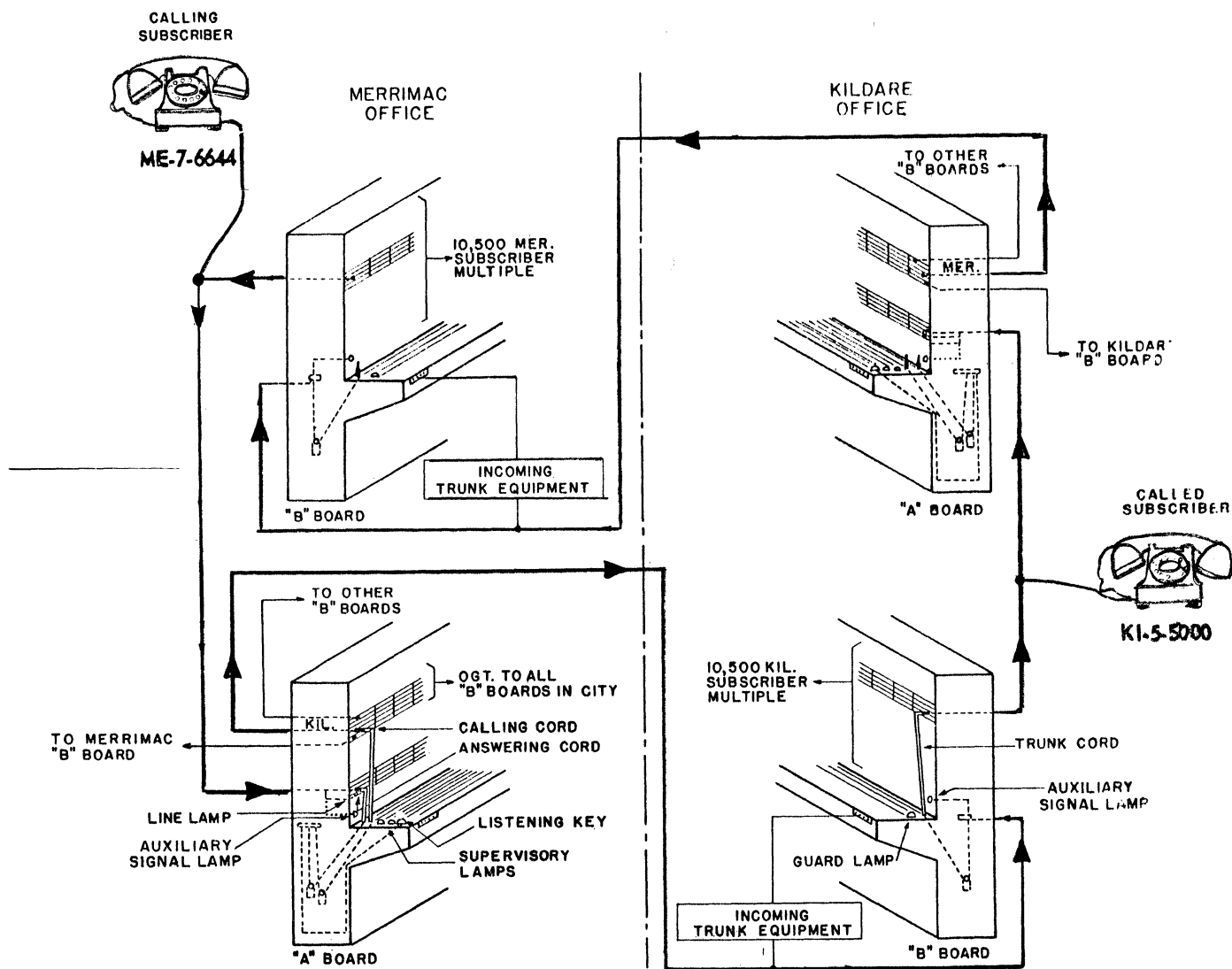
Figure 3-7   Completing Manual Call
(Straightforward Trunking
Method)

3.5 METHOD OF OPERATION

There are two general methods by which telephone calls may be completed in a central office containing "A" and "B" switchboards. One, the earlier method, uses "call circuit" trunks and the other or newer method, uses "straight-forward" trunks.

A. Call Circuit Trunk

When a call circuit trunk is used, the number called is passed by the "A" operator to the "B" operator over a separate circuit, known as a call circuit. The trunk to be used for the connection is assigned by the "B" operator. The "A" operator then plugs the calling cord into the out-going trunk and the "B" operator plugs the cord on the other end of the assigned trunk into the desired subscribers multiple jack.

B. Straightforward Trunk

When a straightforward trunk is used, the number called is passed by the "A" operator to the "B" operator over the trunk to be used for the connection. In this case the trunk used is selected by the "A" operator. The call circuit is, therefore, not required.

It should be noted from the above comparison that the straightforward method entirely eliminates the call circuit. This has several advantages, among which are: elimination of interference between "A" operators, who use the same call circuit (each call circuit is multipled to a large number of "A" positions); the clearing of the keyshelf of the large number of call circuit key buttons (in large central office districts the number of buttons required is above one hundred); and the service rendered to subscribers is somewhat improved.

Straightforward trunks are divided into three classes, knows as:

1. Key listening
2. Automatic Listening
3. Jack listening

1. Key Listening Straightforward Trunks - This class of straightforward trunks is so called because each trunk has a key associated with it at the "B" board which must be operated before the "B" operator can be connected to it to receive the number of the line being called.

There are several types of key listening straight-forward trunks, which differ mainly in the operation of their lamp signals; however, the CITS (Call Indicator Temporarily Straightforward) trunk will be the only one considered herein. The general description given below should furnish a basic understanding of key listening straight-forward trunks.

A call is answered in the "A" switchboard in the usual way by an "A" operator plugging an answering cord into the calling subscriber's answering jack. After the "A" operator has received the subscriber's order, she leaves the listening key operated, and using the associated calling cord, tests in the usual way for an idle outgoing trunk to the office in which the called subscriber is located, by touching the tip of the cord to the sleeves of the outgoing trunk multiple jacks. Having selected an idle trunk and plugged the calling cord into it, the "A" operator waits on the connection for momentary tone signals signifying that the "B" operator's telephone set has been connected to the trunk. The "A" operator then tells the "B" operator the desired number. In the meantime, the calling party, while waiting for the connection to be established, can hear the number passed and can correct it if necessary. The "A" operatore then restores the listening key and handles the call in the same manner as for call circuit trunks. When the called subscriber answers, the supervisory lamp of the cord connected to the trunk is extinguished.

In the "B" switchboard a key listening straightforward trunk terminates at the "B" switchboard in a cord and plug. Associated with this cord and plug are an assignment lamp, a disconnect lamp and key, all located in the keyshelf at the "B" switchboard. The relays associated with the trunk are located on a relay rack in the terminal room.

When a cord is plugged into a trunk at the "A" switch-board, the assignment lamp of this trunk is lighted at the "B" switchboard, thus indicating to the "B" operator that a call is waiting on that trunk. The "B" operator's telephone set is connected to the trunk when she operates the associated key. The operation of this key also sends momentary tone signals over the trunk to the "A" switchboard so that the "A" operator knows when the "B" operator is ready to receive the number called. In addition, the operation of the key changes the steady assignment lamp to a flashing signal. This indicates to the "B" operator the trunk to which she is connected.

After the "B" operator learns the number of the called subscriber, she tests the called line in the usual way by touching the tip of the plug to the sleeve of the called line multiple jack. If the line is idle, she inserts the plug in the multiple jack and the ringing starts automatically. If the line is busy, she inserts the plug in the busy back jack which returns a busy tone to the calling subscriber and flashes the supervisory lamp at the "A" switchboard.

Insertion of the plug into any working jack extinguishes the flashing assignment lamp and disconnects the "B" operator from the trunk. The operator is now ready to take up a call on another trunk.

Although both subscribers control supervisory signals (the lighting of the lamps) at the "A" switchboard, neither subscriber has any control over the disconnect signal associated with the trunk at the "B" switchboard. This signal is entirely controlled by the "A" operator.

The "A" operator disconnects from the trunk by removing the calling cord from the trunk jack. This causes the disconnect lamp to light. The "B" operator removes the trunk cord, extinguishing the disconnect lamp. Should the "B" operator fail to remove the cord before the trunk is selected for another call, the assignment lamp will relight together with the disconnect lamp, but ringing current will not be placed on the trunk. In such a case the operator must remove the cord, and extinguish the disconnect lamp. If this is not done, her telephone set will not be connected to the trunk when the key is depressed.

Several assignment lamps may be lighted simultaneously, each indicating a call waiting on the associated trunk; however, only one trunk can be connected to the operator's set at a time. In order to facilitate handling calls when traffic is heavy, the equipment may be arranged to permit the operator to overlap her calls, that is, operate a second key to disconnect her set from a trunk to which she is con- nected and cause her set to be connected to the second trunk while she is completing the connection for the first trunk. It is necessary for the operator to remember the number wanted on the first trunk until she completes that connection.

3.17

2. Automatic Listening Straightforward Trunks - This class of straightforward trunk is so called because the "B" operator is automatically connected to a trunk on which a call is waiting. This is the most generally used type of straightforward trunk.

The operation of the "A" switchboard is the same as described above for "Key Listening" operation. An automatic listening straightforward trunk terminates at the "B" switchboard in a cord and plug. Associated with the cord and plug is a trunk lamp which acts as both a guard and a disconnect signal and sometimes as an auxiliary signal lamp.

When a cord is plugged into a trunk at the "A" switchboard, the trunk lamp at the "B" switchboard lights steadily as a guard signal, indicating a call waiting on the trunk. The circuits are so arranged that the operator's set is automatically connected to the trunk.

When the trunk lamp lights, momentary tone signals are sent over the trunk to the "A" switchboard so that the "A" operator knows that the "B" operator is ready to receive the number called. This changes the steady guard lamp to a flashing signal to indicate to the "B" operator the trunk to which she is connected.

As an example of this type of call, assume that a subscriber in the Merrimack office, whose number is 6644, removes his handset to originate a call (Figure 3-7). This lights the subscriber line lamp and a panel auxiliary signal lamp on the Merrimack "A" switchboard. The Merrimack "A" operator operates the listening key of a cord circuit, inserts the plug of the answering cord into the associated answering jack, extinguishing the line and auxiliary signal lamps, and says, "Number Please." The calling subscriber at MErrimack - 7-6644, gives the number of the party being called, "KIldare - 5-5000". The Merrimack "A" operator says, "Thank you," and using the calling cord plug tests for an idle outgoing trunk (O.G.T.) to Kildare office. This test is made by touching the tip of the calling cord plug to the sleeve rim of the outgoing trunk (O.G.T.) jack. (When idle trunk indicating lamps are used the operator selects the idle trunk visually by means of the spot of light over the (O.G.T.) jack.) Having selected an idle trunk, the Merrimack "A" operator then inserts the plug of the calling cord into the O.G.T. jack, causing the calling cord supervisory lamp at the Merrimack "A" switchboard to light.

Current from the calling cord at the Merrimack "A" switchboard operates relays in the Kildare incoming trunk circuit which causes the associated guard and disconnect lamp and the auxiliary signal lamp to light at the Kildare "B" switchboard. If no other calls are waiting to be answered at the Kildare "B" switchboard, the control relays in the associated "B" switchboard position operate, causing the guard and disconnect lamp to flash and automatically connect the "B" operator's telephone circuit to the trunk, at the same time sending out two momentary "order" or "Zip" tones which are heard by the "B" operator, the Merrimack "A" operator, and the calling subscriber. The Merrimack "A" operator hearing the order tones knows that the Kildare "B" operator is connected and says "5000" and then releases the listening key. The Kildare "B" operator picks up the trunk cord plug associated with the flashing guard and disconnect lamp and tests line 5000 in the multiple by touching the tip of the trunk cord plug to the sleeve of the jack. If the line is found idle, she inserts the plug into the jack. This causes trunk relays to operate which extinguish the guard and disconnect lamp and auxiliary signal lamp, connect ringing current to the called line, and disconnect the operator's telephone set from the trunk.

The calling subscriber hears ringing induction, as an indication that the called party's bell is being rung. When the Kildare-5 subscriber "5000" answers, relays in the incoming trunk circuit operate disconnecting the ringing current and extinguishing the calling cord supervisory lamp at the Merrimack "A" switchboard. While the subscribers converse, battery is being furnished by the "A" and "B" board cord circuits. When they have finished and replaced their handsets the answering and calling cord supervisory lamps on the Merrimack "A" switchboard light up.

The Merrimack "A" operator then removes the answering and calling cord plugs from the jacks, again lighting the trunk guard and disconnect lamp at the Kildare "B" board. The Kildare "B" operator removes the associated trunk cord plug from the multiple jack extinguishing the guard and disconnect lamp and equipment is again normal.

There are some Special Features associated with these trunks. For instance, several guard lamps may be lighted at the same time, each indicating a call waiting on the associated trunk, but only one trunk can be connected to the operator's set at a time. Each trunk on which a call is waiting will be connected in rotation, the lowest number cord first, then the next higher, etc.

In order to facilitate handling calls, each position is provided with a button, called "master release key," mounted on the keyshelf. The operation of the release key permits the operator to overlap her calls, that is release her telephone set from a trunk to which it is connected and connect it to the next trunk on which a call is waiting while she is completing the connection on the first trunk. If an "A" operator plugs into a trunk but disconnects before the "B" operator is connected to the trunk, the guard signal will remain lighted and the "B" operator will be connected to the trunk in regular sequence as for a call. The "B" operator in such a case may release her set from the trunk by operating the release key.

Although both subscribers control supervisory signals at the "A" board, neither subscriber has any control over the disconnect signal associated with the trunk at the "B" board. This signal is entirely controlled by the "A" operator. When the "A" operator disconnects from the trunk by removing the calling cord from the trunk jack, it causes the lamp associated with the trunk to light as a disconnect signal. The "B" operator removes the cord, extinguishing the disconnect lamp.

Should the operator fail to remove the cord before the trunk is selected for another call, the trunk will be connected to the "B" operator's set in regular sequence and the lamp will flash as soon as the trunk is so connected, regardless of whether or not the trunk is still up in a multiple jack. Under this condition, however, the sub-scriber will not be rerung.

3. Jack Listening Straightford Trunks - This class of straightforward trunk is so called because the "B" operator connects her set to any trunk on which a call is waiting by plugging the trunk into a listening jack. After learning the number wanted, the "B" operator removes the cord from the listening jack and disposes of the call in the usual way.

3.6 LOCAL MANUAL SWITCHBOARDS TODAY

The conversion of local offices from manual to various electromechanical (Step-by-step, Crossbar #5, etc.) offices and eventually to electronic (No. 1 ESS, etc.) offices did not entirely eliminate the need for Local Manual Switchboards. Such a switchboard is still required to handle the originating and terminating traffic which the automatic equipment is unable to complete, or in certain areas where the installation of automatic equipment is as yet not economical.

CHAPTER 4

STEP-BY-STEP SYSTEMS

4.1 INTRODUCTION

The Step-by-Step System of automatically establishing telephone connections, is the oldest of the several types of machine switching systems which comprise the modern telephone plant. Its invention is generally credited to Almond B. Strowger in 1889; hence, it was originally known as the Strowger Dial System.

Step-by-Step Systems are quite flexible in that they may be used for local dial service in communities requiring about 100 lines, or for large central offices requiring 10,000 lines or more. Various types of PBX's also use a Step-by-Step System.

When intertoll dialing service was first introduced, the Step-by-Step configuration was readily adapted to it. However, recent Crossbar Systems, with their many advantages, have replaced some of the larger Step-by-Step intertoll systems. Most of the future intertoll systems will be of the crossbar and electronic variety except for certain situations such as small isolated toll centers, or toll centers with local Step-by-Step systems where Step-by-Step intertoll arrangements may be installed for economy reasons.

All Step-by-Step systems are somewhat alike; however, the circuit requirements vary with the size of the system. Also, some features which are desirable in larger offices are unnecessary in smaller, less complicated units. Because of this, various types of systems have been developed to provide adequate yet economical service. Figure 4-1 shows typical Step-by-Step office equipment.

The term "Step-by-Step" is not only descriptive of the intermittent motion of the principal switches used in the system but it is also descriptive of the manner in which a call progresses, one stage at a time, from the input terminal, through a tree-like structure of switches and trunks, to the output terminal. It is a progressive control system and distinct from a common control system which first determines the input and output terminals,

Figure 4-1   Typical Step-by-Step Dial Office Equipment

and then on the basis of this determination, causes a path to be established between them through a grid like network.

Progressive control systems are classified as <u>direct progressive</u> or <u>register</u> progressive control. Direct progressive control is defined as a system in which the switching network is under the immediate and direct control of the subscriber's calling device. A register progressive control system, on the other hand, interposes a circuit between the subscriber and the switching network that accepts and <u>registers</u> signals from the subscriber and which in turn controls the succeeding switches. Usually this circuit is called a register, although the registration function may be incorporated in other circuit units. The Step-by-Step system was originally a direct progressive control system. Recent developments, however, have provided various means of modifying it to a register progressive control system.

4.2 SWITCHES

In any switching network three fundamental aspects must be considered; these are the switch, the network and the control. While they are closely related and the nature of one influences the nature of the others, the Step-by-Step switch had a tremendous influence on the development of the system.

The Step-by-Step switch as shown in Figure 4-2, is the most important switching device in the system. Other switches, such as the "Plunger" type and simple <u>rotary</u> type, have been used for various minor concentrating jobs in early offices. The rotary type, which has shown itself to be a reliable switch, is still in use.

A. <u>STEP-BY-STEP SELECTOR SWITCHES</u>

Essentially the <u>Step-by-Step switch</u> is a two-stage rotary switch, and is shown schematically in Figure 4-3. The principle mechanical parts of this switch are shown in Figure 4-4.

The terminals are physically arrayed in banks, each bank consisting of 10 horizontal levels with 10 positions per level - a total of 100 positions as shown in Figures 4-5
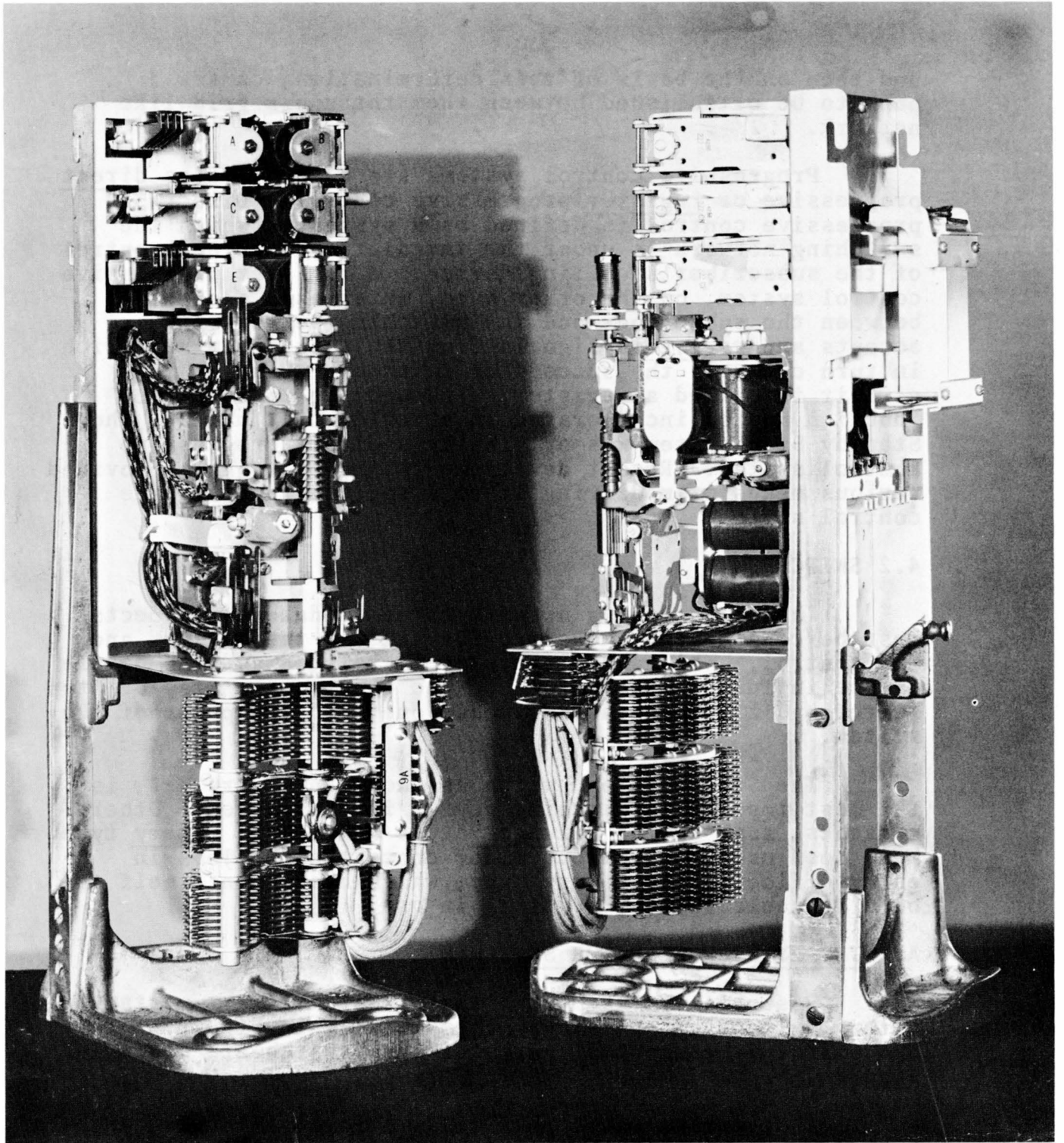
Figure 4-2 A Typical Step-by-Step Switch
with Cover Removed

and 4-6. Some terminal banks have two terminals, insulated from each other, at each position, while others have only one terminal at each position. With each bank there is associated an assembly of two brushes, which are rigidly connected to a vertical shaft that is driven upward while the brushes are clear of the banks. Rotating the shaft horizontally brings the brushes into contact with the bank terminals of one horizontal level.

Two control magnets actuate the shaft and brushes during the establishment of a connection; a vertical magnet steps the shaft upward to the desired level and a rotary magnet steps the brushes along the terminals on that level. Both magnets are coupled to the shaft by means of pawl and ratchet assemblies. In both vertical and rotary stepping, the brushes move when a magnet is energized. The deenergization of the magnet permits the stepping mechanism to return to normal, preparatory to the next stepping action. As the shaft is rotated over the terminals, a helical spring located at the top of the shaft is wound up to provide a restoring torque.
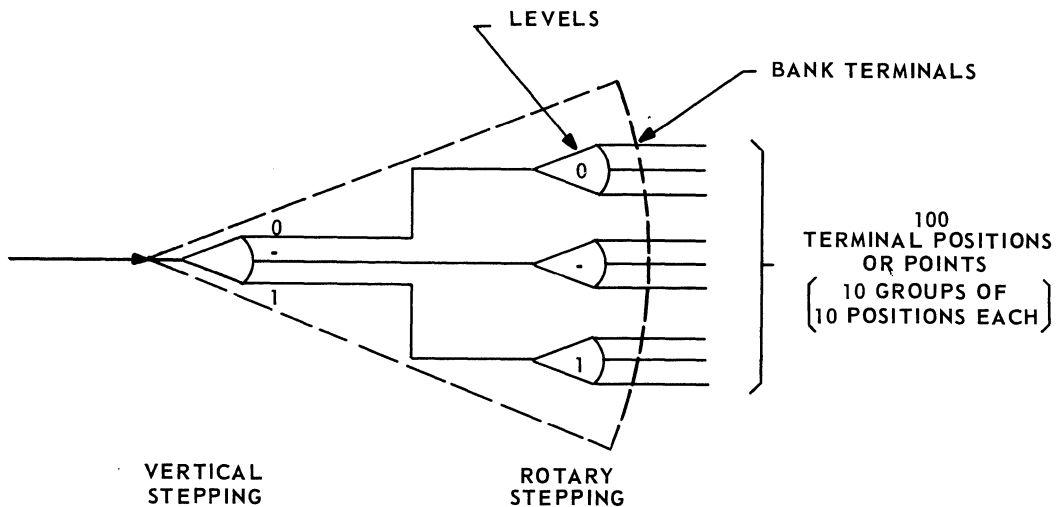
Figure 4-3   Equivalent Diagram of a Step-by-Step Switch
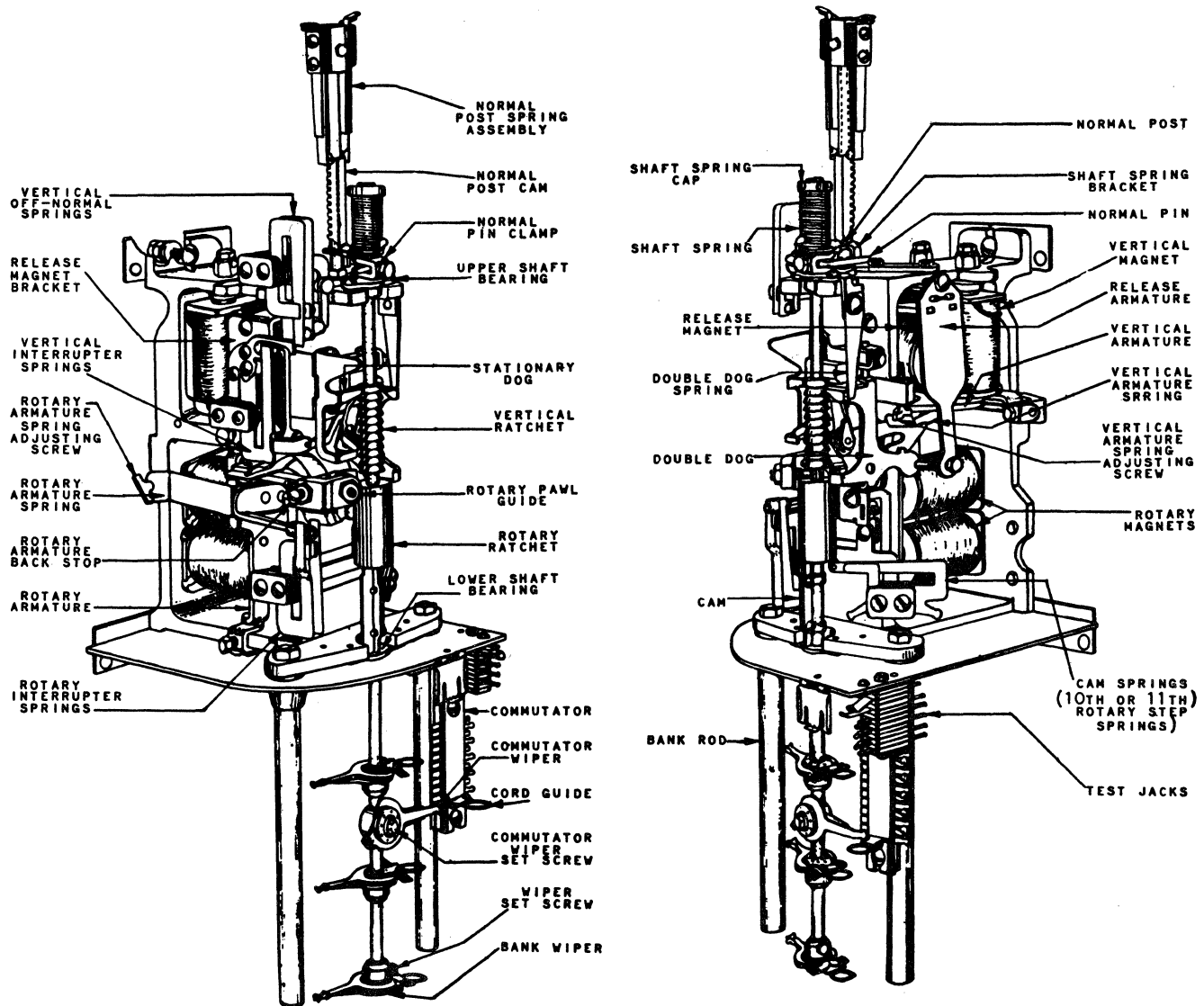
Figure 4-4   Line Finder Switch
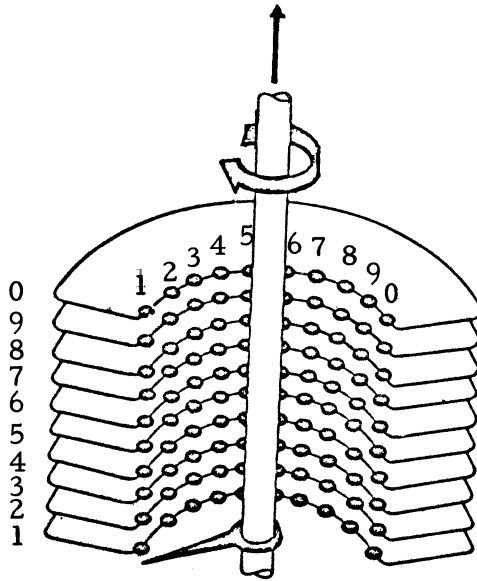
Figure 4-5 Representation of a 100-Point Bank Assembly
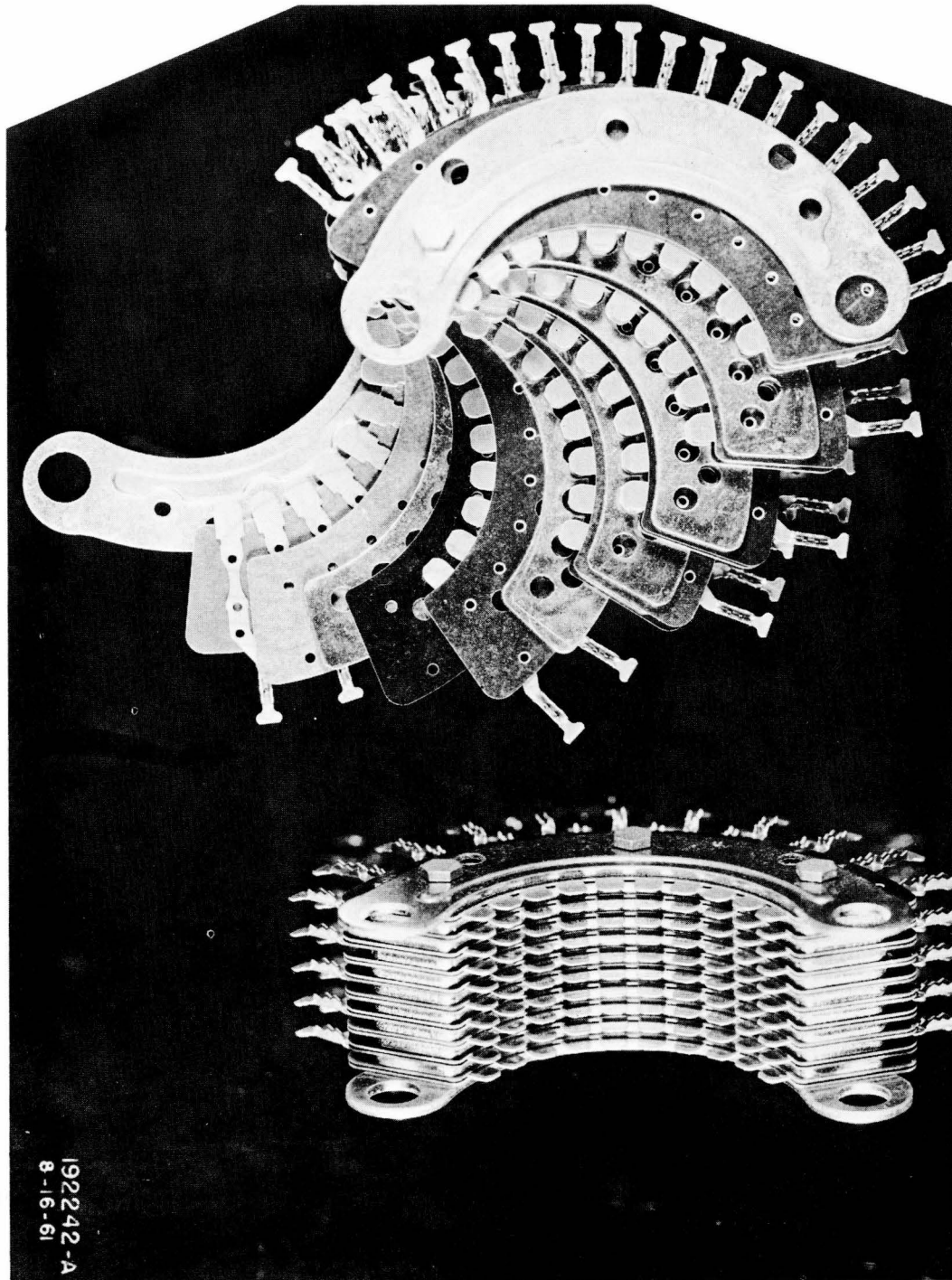
Figure 4-6   Typical 100-Point Bank

The shaft and brush assembly is restored to normal by energizing a release magnet which withdraws restraining fingers from the vertical and rotary ratchets. The helical spring is thus permitted to rotate the shaft back to its normal rotary position. Thereupon gravity drops the shaft to its normal vertical position.

Since a switch bank is limited to two terminals per position, a separate bank and brush assembly must be provided for each pair of conductors to be cut through the switch. Switches may be furnished with as many as four switch banks to cut through eight leads. The switch in Figure 4-2 is equipped with three banks.

Various contact arrangements controlled by the switch magnets and brush shafts are provided where needed to aid in controlling the switch. Interrupting contacts permit both vertical or rotary self-stepping, hunting feature. When the switch steps past the tenth and final rotary bank position, a set of contact springs are activated. The operation of these springs is referred to as making the "11th rotary step" which indicates a failure to find a desired terminal.

Since the basic step-by-step switch can be operated in one of two modes: select or hunt, it is theoretically possible, for a two-stage switch to operate in one of four modes; select-select, select-hunt, hunt-hunt and hunt-select. Actually step-by-step switches utilize only the first three modes, select-select, select-hunt and hunt-hunt.

B. ROTARY SWITCHES

Rotary-type selector switches consist, primarily, of arcs of terminals over which associated wipers pass. An electromagnet mounted on the switch assembly provides power to move the wipers from one terminal position to the next; each separate energization and deenergization cycle of the magnet causes the wipers to move one position. There are two basic types of rotary switches: forward-action or direct driven switches, which step from one terminal to the next terminal on the energization of the magnet; and back-acting or spring driven switches, that step on the deenergization of the magnet. The control magnet of either type of switch is known as the "step magnet."

When the step magnet of a forward-acting switch is energized, a pawl coupled to the magnet armature is forced against the teeth of a ratchet wheel on the shaft supporting the wipers, causing the shaft to rotate through a small angle, thus moving the wipers from one terminal to the next. A detent engaging the ratchet wheel insures that the wipers remain on the terminal just reached when the magnet is deenergized. In the case of a back-acting switch, energization of the step magnet pulls a pawl away from the ratchet wheel on the wiper shaft, against the force of a spring attached to the frame of the switch. When the magnet is deenergized, the pawl is pulled back by the spring, engaging a tooth on the ratchet wheel and advancing the wipers a single step.

Some rotary switches may be caused to step continuously in the same rotary direction over the same set of terminals, whereas others, after stepping their wipers over the associated arcs, must be returned to a normal position before the wipers can again be moved over the arc terminals. These two types of switches are designated nonhoming and homing, respectively. Switches of the homing type are normally equipped with a second magnet, a release magnet, which allows a spring to restore the wipers to the starting position.

Wipers may be either of two types: bridging, in which adjacent arc terminals are short-circuited by the wiper as it steps from one to the other; and nonbridging, in which the wiper leaves one terminal before it makes contact with the next.

Illustrated in Figure 4-7 is a back-acting rotary switch consisting of six arcs of 22 terminals each. The wipers are double-ended so that, when one wiper end has passed over the half-circle of 22 terminals, the other end is in position to start stepping over the same 22 terminals. Occasionally, single-ended wipers mounted in pairs staggered 180 degrees apart are utilized on a similar switch so that two adjacent arcs of 22 terminals may be employed as a continuous bank of 44 terminals. The switch may be driven by external circuit pulses at a rate of up to 25 or 30 steps per second; a rate of 50 or 60 steps per second may be realized if the switch runs under self-interrupted control by using the break contact of the stepping magnet.

A forward-acting ten-terminal two-arc switch is illustrated in Figure 4-8. In addition to the stepping magnet, this switch is furnished with a release magnet, shown in the lower left corner. In the normal position, the wipers stand in the position just preceding the first terminal. The switch may be driven at speeds up to 25 steps per second.
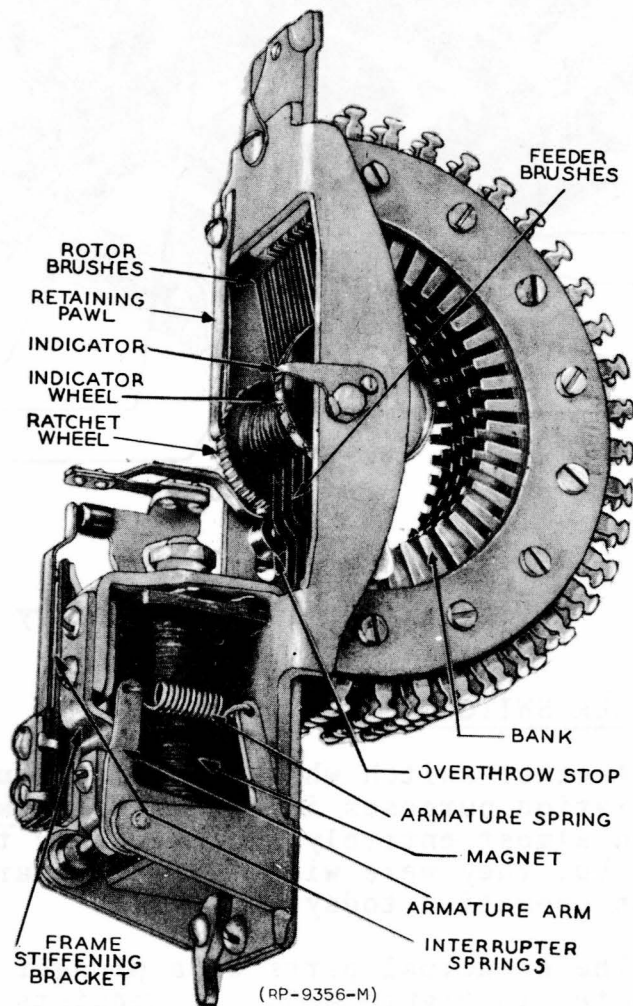
Figure 4-7 22-Point Rotary Selector
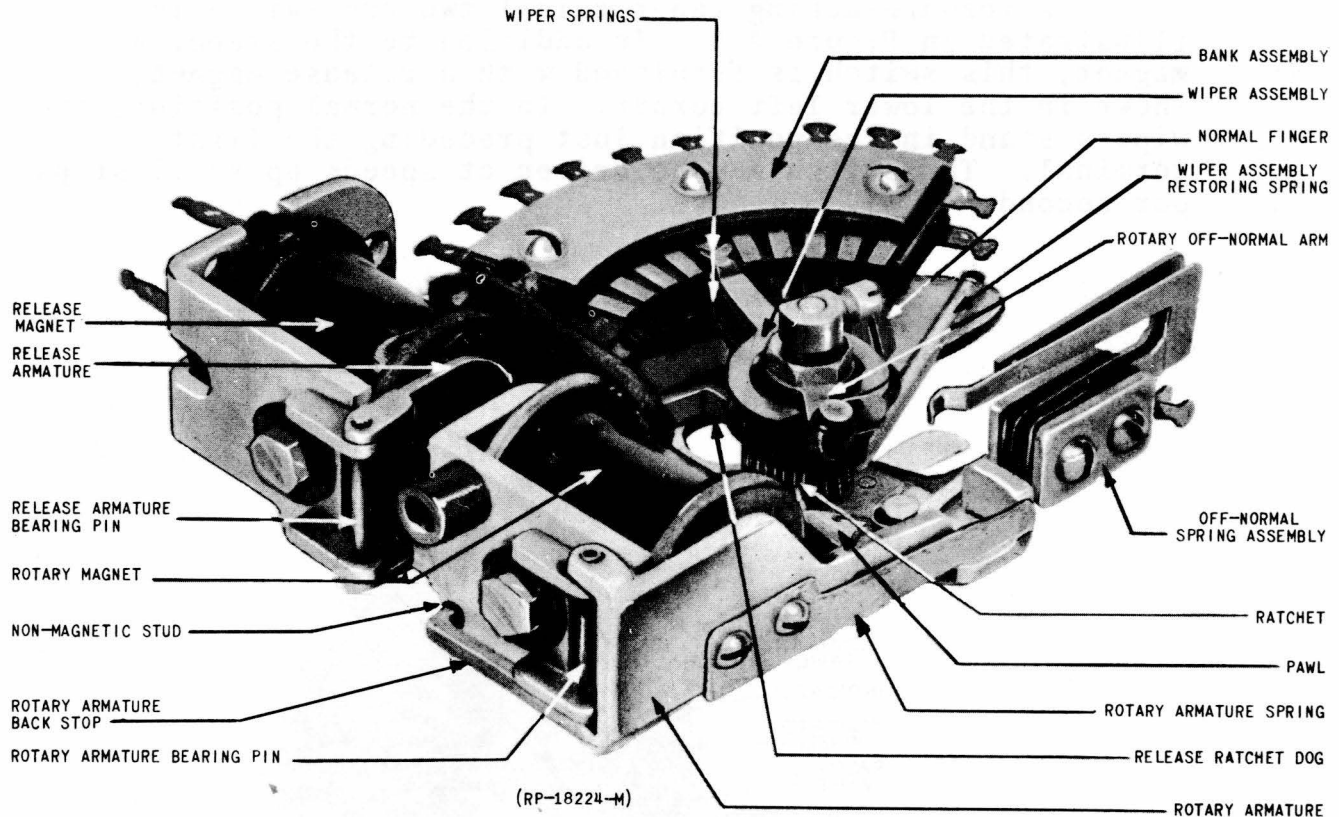
Figure 4-8   10-Point Rotary Selector

C. PLUNGER SWITCHES

Another switch which was widely used for concentration purposes is the plunger switch. This switch has been almost entirely superseded by the line finder switch, but they were widely used in early offices and are still in operation today.

The principal parts of a plunger switch is represented in Figure 4-9. It consists of a relay (not shown), a magnet, a plunger and a segment of a bank having ten sets of terminals arranged in an arc. The fixed contacts of the ten sets of terminals are multipled to a single input, while the flexible contacts each connect to a separate output.

SOLENOID

MASTER SWITCH
AND BANK

(2)
LINE SWITCH
AND BANK

(1)
LINE SWITCH
AND BANK

PLUNGER
GUIDE SHAFT

SUB. 2

SUB. 1

MULTIPLED TO
ALL TEN SET OF
BANK TERMINALS

SELECTORS
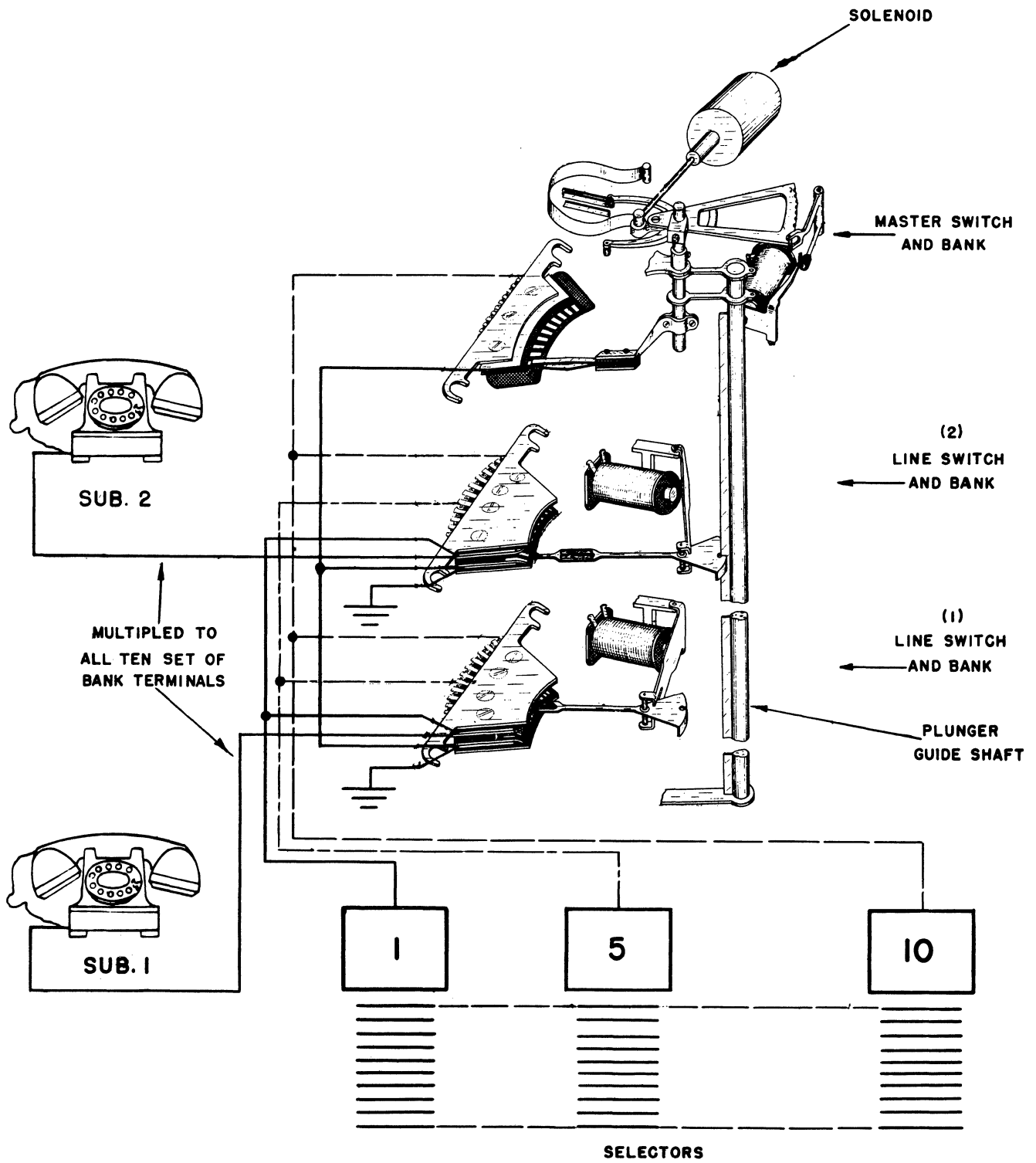
Figure 4-9   Plunger Switch

The "wing" of the plunger is slotted and engages a guide shaft which is capable of being oscillated through about 40 degrees. The motion of the shaft enables the plunger to be aligned with any one of the ten sets of terminals.

When an input demands attendance, the relay is energized which in turn energizes the magnet causing the switch to "plunge in" and extend the input to an output. While the switch actually is a crosspoint switch, it is convenient to consider it to be a 10-point rotary hunting, backward-facing switch. In this particular case the inputs are on the bank terminals and the output is via the wiper.

A number of plunger switches are associated with the same group of trunks by multipling the outputs, as shown in Figure 4-10, and by controlling the plungers with the same guide shaft as shown in Figure 4-9.
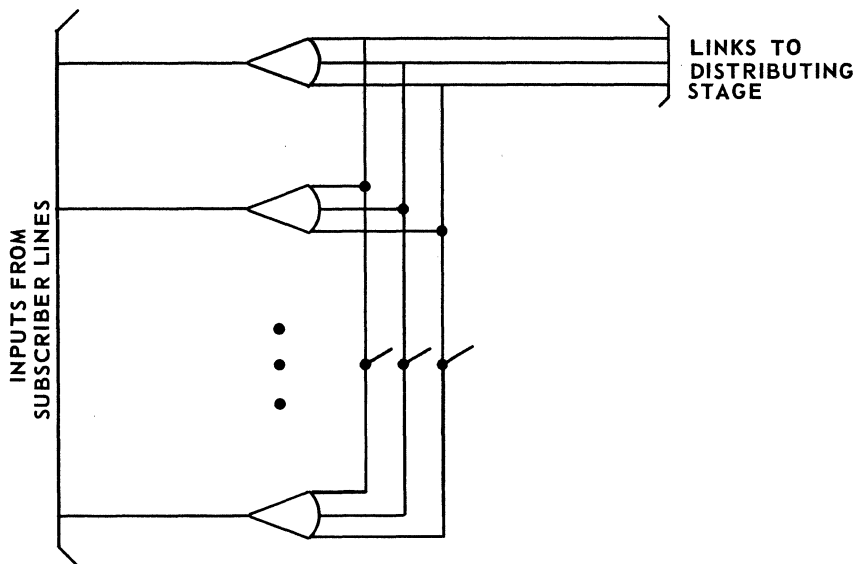
Figure 4-10   Concentration Stage Unit Using
              Multipled Output Line Switches

A master switch is provided for each guide shaft. Supervisory leads from each trunk terminate on a 10-point master switch bank and serve to "mark" busy trunks. The master switch rotates and controls the guide shaft so that it will only come to rest opposite an idle output. It also prevents switches from "plunging in" during the time it is hunting for an idle trunk.

When the line switch plunges in, it disengages itself from the shaft and the input is extended to the trunk, marking the corresponding terminal of the master switch bank to indicate that it is no longer idle. The master switch rotates the shaft and all engaged plungers from left to right until it reaches an idle trunk. When the shaft reaches the right hand position (Trunk No. 1) and finds it busy, a solenoid rotates the shaft, and plungers, back to the left hand position (Trunk No. 10) where the master switch continues its left to right search for an idle trunk. Hence a plunger switch is "preselecting" as opposed to a finder which is "post selecting."

When an input no longer requires attendance, the plunger is released. On some types of switches, known as self-aligning, the plunger is immediately aligned with, and engaged to, the shaft regardless of its position, while in other switches the plunger will "come out" but not engage the shaft until the shaft again swings in front of the trunk and "picks it up."

4.3 GENERAL SWITCHING PRINCIPLES

A. GENERAL

The primary objective of all switching systems is to permit any subscriber to establish a connection with any other subscriber within that system. Also, a switching system must provide the most economical means of switching various paths together.

The paths in the Step-by-Step system are one-way, since the connections are set-up or controlled through the switching elements in one direction. This characteristic suggests that a path may be divided into an originating and terminating stage.

The originating-terminating concept permits all connections from subscriber to subscriber to follow the same general pattern. The plan shown in Figure 4-11 embodies the concept of originating networks being linked to terminating networks by means of three kinds of trunks: outgoing, incoming and intraoffice.

Each call requires a trunk; consequently, the number of trunks which are required is a function of the number of simultaneous calls in an office, since the trunk or trunks used are held for the duration of the call. Obviously this is less than the total number of subscribers. Hence, one requirement placed upon the originating network is that it must concentrate a large number of inputs (subscribers' lines) into a comparatively small number of outputs (trunks) and, conversely, the terminating network must be able to expand the inputs (trunks) into a greater number of outputs (subscriber lines).
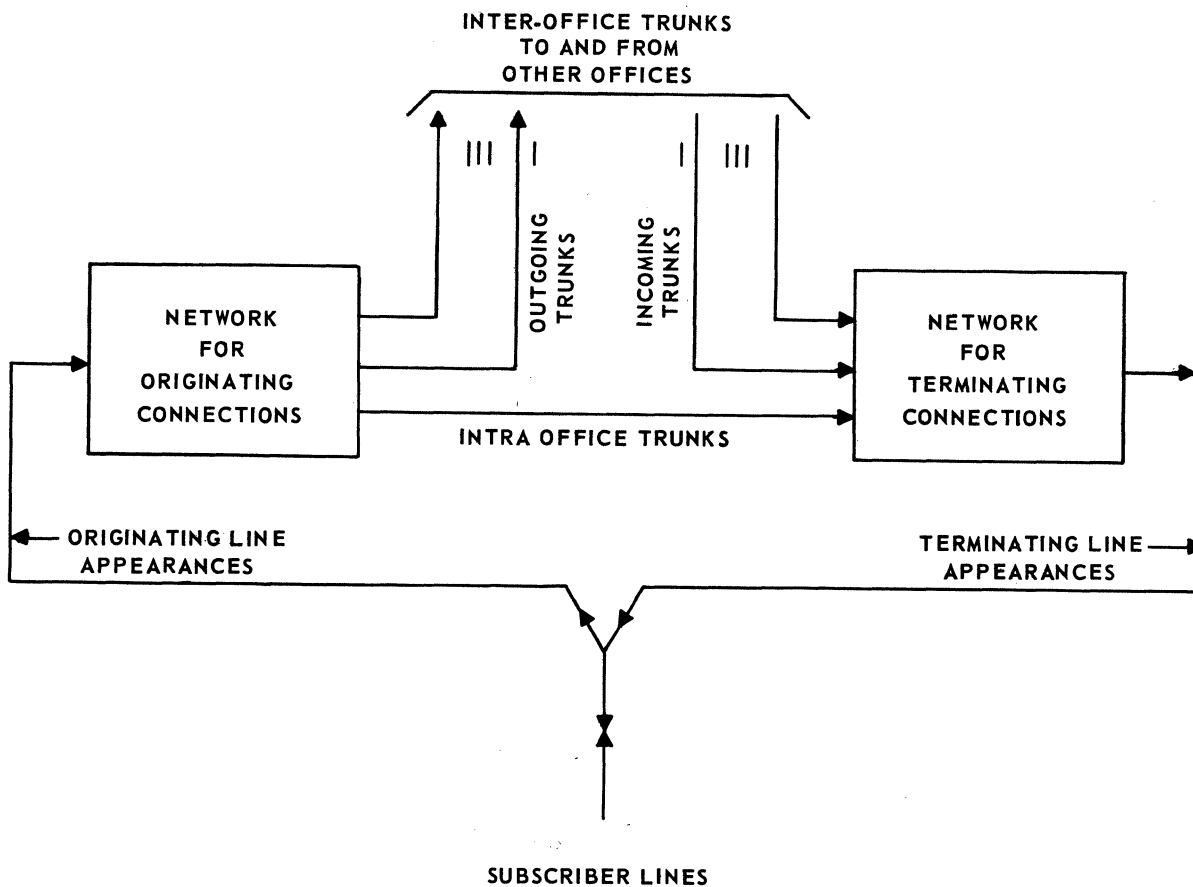
Figure 4-11 Originating and Terminating Connections

Figure 4-11 indicates that the originating network connects to a group of intraoffice trunks as well as several groups of trunks to each of the several "other" offices. A second requirement of the originating network, is that any subscriber's line must have access to every group of inter- or intraoffice trunks, but not necessarily to every trunk in each group in order to reach any other subscriber. However, in the terminating network all trunks in each group must have access to all subscribers.

The requirements placed upon the originating and terminating stages are symbolized in Figure 4-12. It can be seen that the originating network consists of a concentrating stage, where subscribers' lines compete with each other for a connection to the distributing stage. The distributing stage has the same number of inputs and outputs and provides a means of selecting a trunk to the desired terminating office. The terminating stage has a similar distributing stage and an expansion stage.
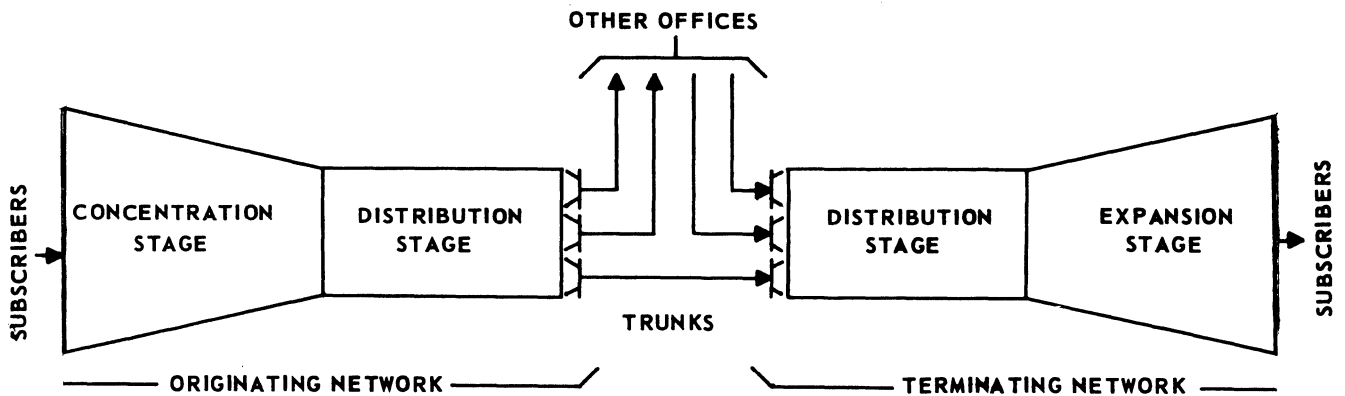
Figure 4-12 Basic Switching Network

The access of a switch is limited by the number of its points; consequently, a fundamental problem in designing a network is to provide access for a particular path that is equal to or greater than the access provided by the basic switch. This is particularly true in the step-by-step system which employs low access switches.

B. CONCENTRATION STAGE

The purpose of the concentrating stage is to provide a means of connecting a large number of subscriber lines to a smaller number of trunks to the distributing stage. Two switches are available for this purpose, the older arrangement utilizing line switches and the new arrangement utilizing line finders. In either case, the concentration stage must recognize when a call is being originated, provide a trunk to the distributing stage and guard (busy out) the calling subscriber's line so that the terminating network cannot connect to it.

(1) Line Finders

The line finder method shown in Figure 4-13 used either a 100- or 200-point line finder switch. When a subscriber originates a call, the switch hunts for the calling line and extends the connection to a permanently associated first selector.

A line finder switch is a concentrating device, or backward-facing switch, operating in the hunt-hunt mode. It is used to concentrate subscriber lines.

100- and 200-point line finders are available. When the switch is called upon to make a connection, it hunts for the terminal to which it must connect. However, in order to do this, control circuits must mark not only the terminal but also a segment of a commutator to indicate the level on which the terminal lies. The switch first steps vertically, examining the commutator to find the proper level, and when it is found, the switch then steps horizontally to find the marked terminal.
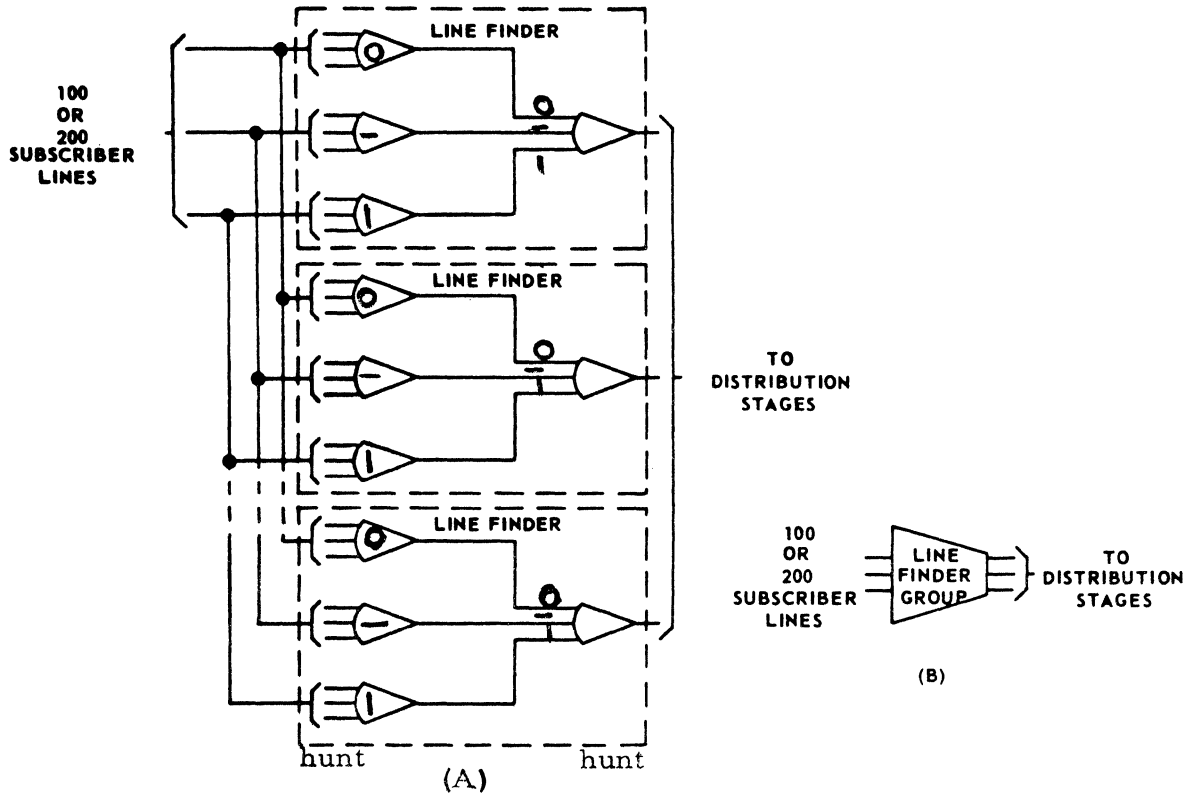
Figure 4-13 Concentration Stage Unit
Using Multipled Line Finders

With the 200-point line finder, each of the switch positions is associated with two lines. As the switch conducts the horizontal hunt for the marked terminal, it simultaneously examines the terminal associated with both lines. When it finds the position, it then determines which of the two lines at that position is marked and then connects to it. To do this, the switch uses two sets of brushes or wipers, one set for the "upper" and the other for the "lower" set of terminals.

To discriminate between certain bank terminals, some switches are furnished with so-called "normal post" contacts. These contacts are actuated when the shaft reaches certain vertical levels, which thus enables the switch to discriminate between vertical levels. A cam mounted near the top of the shaft can be adjusted to operate these contacts at any desired level or levels.

Since the location of a subscriber's line in in a line group has no relation to the listed number, it may be relocated to other groups as desired.

(2) Line Switches

The line switch method utilizes a forward-facing hunting switch, as shown in Figure 4-10, for each line. A forward-facing switch is one in which there are a multiplicity of outputs for a singular input. The switch may be a plunger switch or a rotary switch but in either case the switch preselects an idle trunk and then establishes a connection to the trunk when attending a subscriber's line. The trunks are connected to first selectors in the distributing stage.

Since the line switch method requires one switch per line, it is at a cost disadvantage compared to the line finder method. As a result, plunger switches are no longer being installed except as additions to existing equipment.

(3) Rotary Switches

Rotary line switches, connected as shown in Figure 4-10, are used to a limited extent for groups of subscribers having a particular class of service, such as post-pay coin lines, which are so small that it would not be economical to use 100-point line finders.

4.20

C. DISTRIBUTION STAGE

The network for the originating and terminating distribution stages are essentially similar to each other. The basic distribution network consists of one or more stages of switches known as selectors. The number of selector stages depends upon the number of digits to be dialed and the type of selectors employed.

The selectors (see Figure 4-14) are forward-facing switches operating in the select-hunt mode. Each switch responds to D-C dial pulses at a nominal rate of 10 pps, the number of pulses in the pulse train represents the numerical value of the digit. The brushes are driven upward, one level, for each pulse that it receives. Hence, it will select that level of terminals which corresponds to the digit dialed.
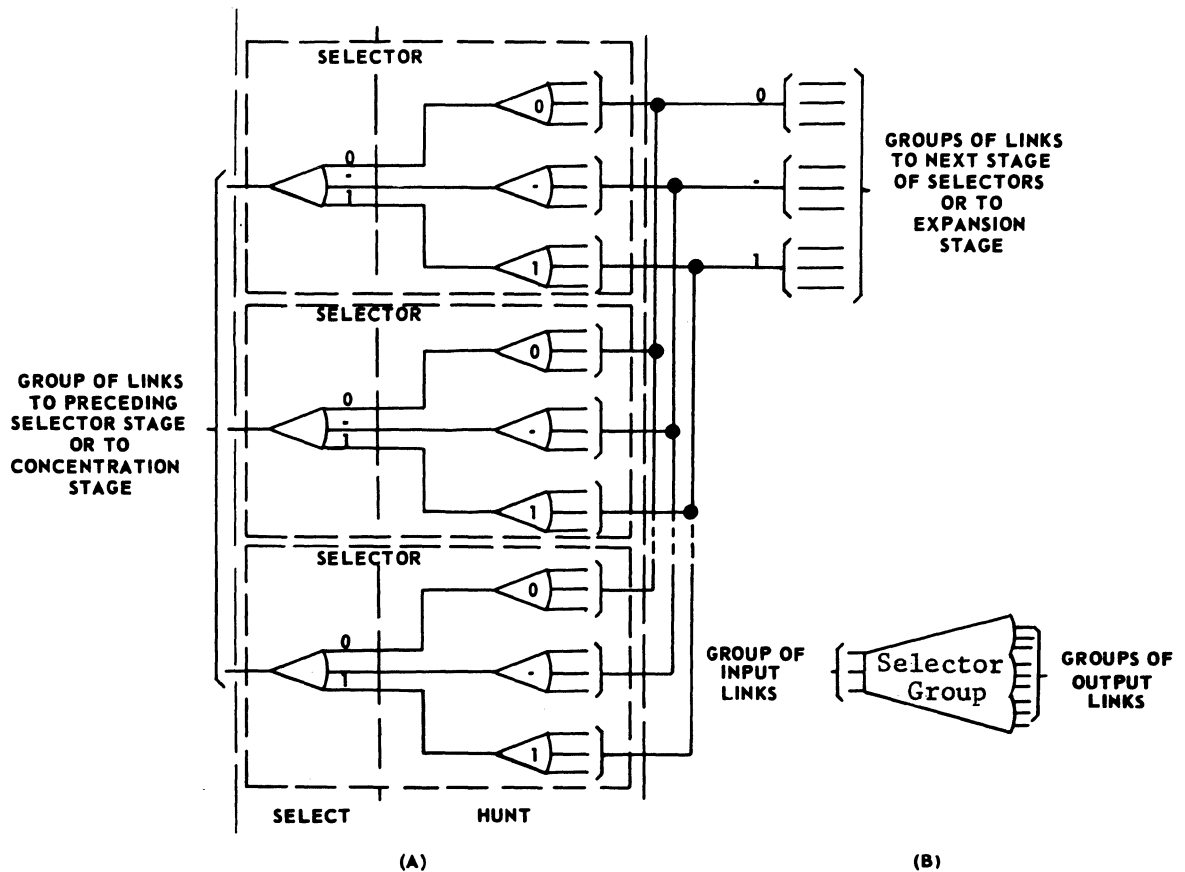
Figure 4-14 A Group of Step-by-Step Selectors in the Distribution Network

Upon selecting a level it will hunt horizontally for an idle terminal, during the interval between digits. After finding an idle terminal, it will cut the connection through to the next switching stage so that the next digit dialed will direct the succeeding switch. If an idle terminal is not found, the selector will step beyond the bank to the "eleventh rotary step" position where path-busy tone will be returned to the subscriber.

With the selector functioning in this manner, each digit dialed requires a selector stage.

The local selector stages are named to indicate the digit to which they correspond; hence, the first and fifth selector stages are controlled by the first and fifth digits, respectively, of the dialed number. Selectors to which incoming trunks connect are termed incoming selectors; i.e., incoming fourth selector.

In order to distribute traffic evenly over the distributing network, the trunks from the line finders are connected to the first selectors in a fixed pattern. The trunk distribution plan is indicated by Figure 4-15.
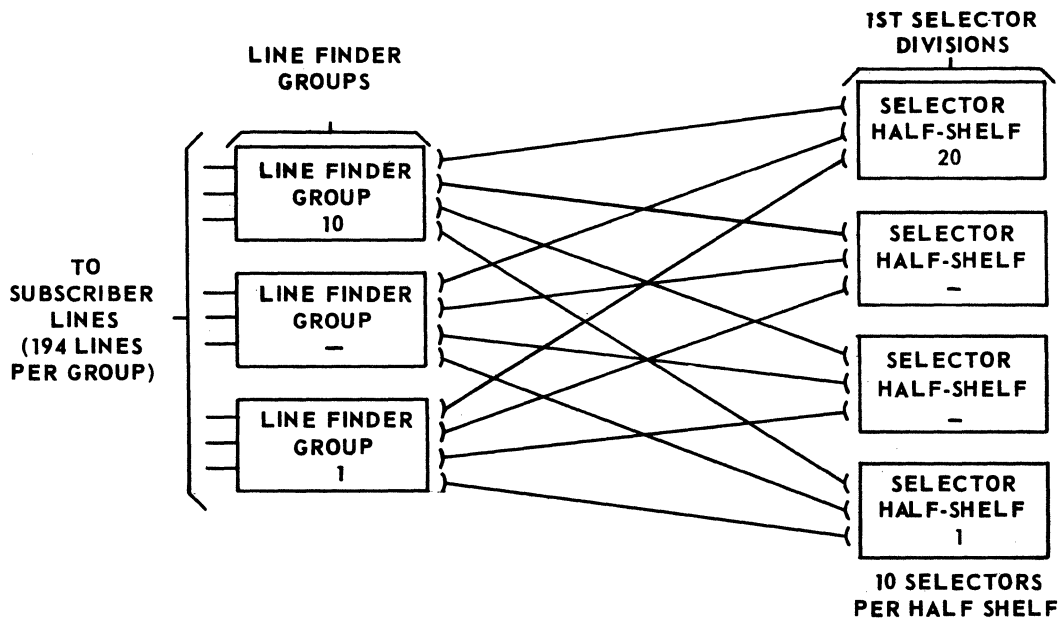
Figure 4-15   Plan for Distribution of Links From
              Line Finders to First Selector Switches

Selector switches are grouped in accordance with traffic and equipment considerations. The number of switches in a group is equal to the number of inputs which, of course, is dictated by the traffic to be handled. The outputs of a group are multipled and connected by trunks to a succeeding distribution stage or to the expansion stage.

D. EXPANSION STAGE

The purpose of the expansion stage is to connect a smaller number of trunks to a larger number of terminating subscribers. This is accomplished by having the last stage of a call completed through a group of switches known as connectors. The connector is a forward-facing switch operating in the select-select mode under direct control of dial pulses of the last two digits. The switch is shown schematically in Figure 4-16. In operation, the switch steps to the level corresponding to the next-to-the-last digit (tens digit) of the calling number and then steps horizontally to the terminal corresponding to the last digit (units digit). Before connecting to this terminal, it tests to see if the called line is busy. If it is, it returns lines busy tone; if not, it connects to the line, applying the proper ringing signal. When the called line answers, it removes ringing and indicates to the preceding trunks and switches, usually for charging purposes, that the call has been completed.

The subscribers connected to the 100 terminals to which the connector switch has access form a group known as a "connector hundreds group." A "connector hundreds group" is a group of 100 consecutive numbers differing only by their tens and units digits.

The number of switches in each group depends upon the expected amount of traffic and must be equal to the number of trunks from the distributing network. Since the location of each subscriber is exactly the same on the banks of each switch in the group, it is obvious that the banks of all switches in the group must be multipled straight through.
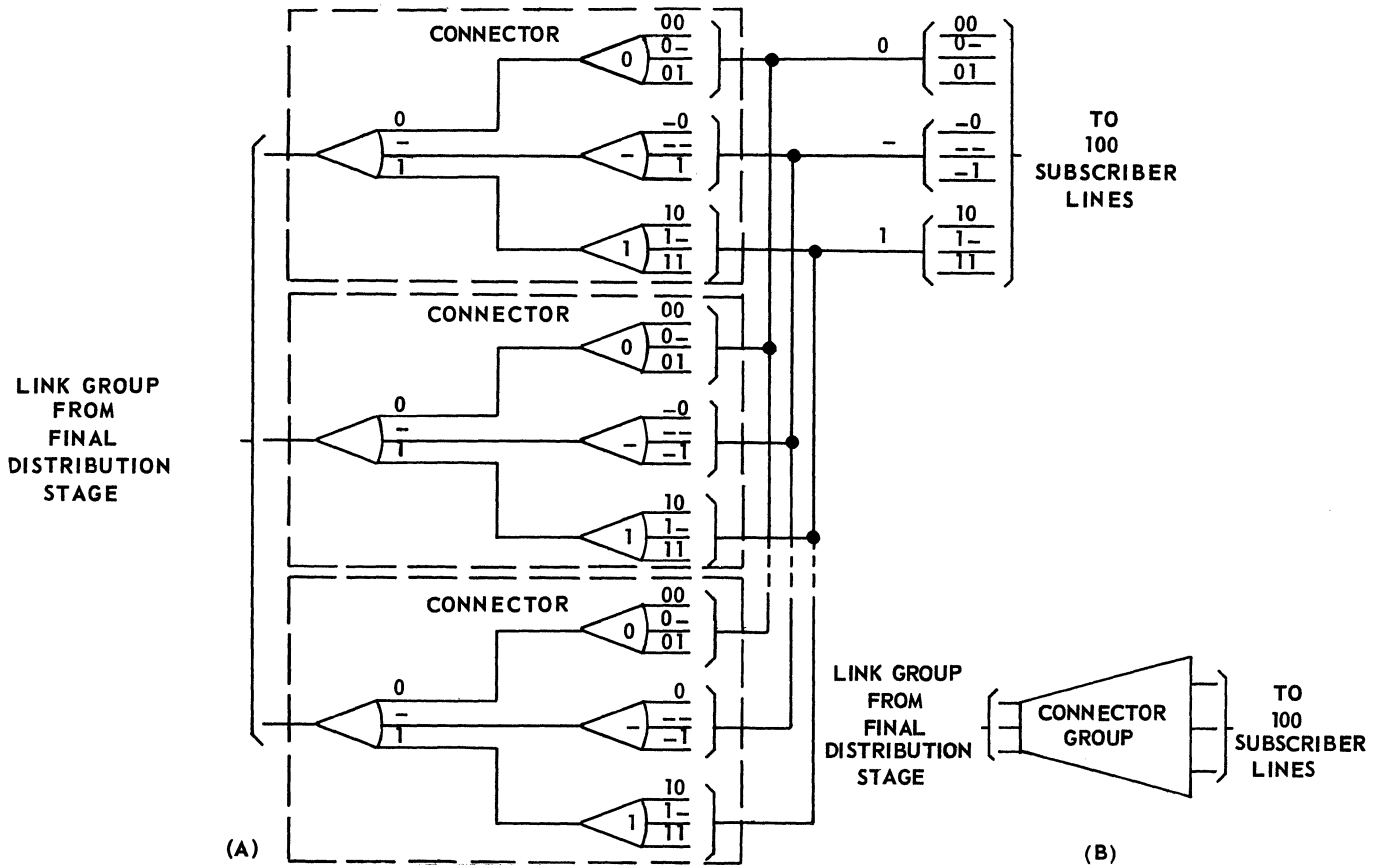
Figure 4-16   Group of Step-by-Step
              Connectors in Expansion Stage

There are several different types of connectors.
They may be categorized as to the type of traffic which they
handle: toll, local, or combined toll and local, or
according to the types of lines to which they connect: two,
four, eight or ten-party; terminals per station or
terminals per line, or according to the type of ringing;
full or semiselective, code ringing, etc.

4.24

Space limitations do not permit discussing the various categories of connector switches except for one important category known as "hunting." A connector operating in the pure select-select mode previously described is called a nonhunting connector. Sometimes a customer will subscribe to several lines but will have only one number listed in the directory. The group of lines is referred to as a PBX group and means are provided so that when the listed number is dialed, a connection is made to any idle line in that group. This is accomplished by a hunting connector.

When the directory number of a PBX group is dialed, a hunting connector selects the dialed terminal. If it is busy, the switch will hunt over successive terminals in the group in a left to right, bottom-up, order.

A rotary hunting connector is arranged to hunt over adjacent terminals on one level only, and may be used for PBX groups of 10 or less lines. Several groups may be located on one level. Level hunting connectors are arranged to hunt successively over terminals on adjacent levels and may be used for PBX groups of up to 100 lines. PBX grouping is accomplished by strapping together a "control" terminal associated with each line. If no idle line is found in the group, line busy tone is returned to the customer.

4.4 THE SWITCHING NETWORK

A. SWITCHING TRAINS

(1) 5-Digit Call

A generalized diagram of a 5-digit office is shown in Figure 4-17. The diagram shows the concentration, distribution, and expansion stages and also indicates the terminations within the network of incoming and outgoing trunks. Actually, the network shown represents three central offices within the same building. These offices have the single digit office codes 5, 6 and 8. Located nearby are two additional offices, 3 and 4.

When a subscriber lifts his receiver to place a call, a line finder having access to this subscriber's line, hunts and connects to the line. The associated first selector is seized and returns dial tone to the subscriber.

The first digit dialed by the subscriber determines which of the five offices the call is for. If the call is for one of the offices in the same building, the first digit drives the first selector to the level corresponding to that office. At the conclusion of the pulse train, the switch hunts over that level for an idle link to a second selector and cuts through the tip, ring and sleeve conductors. This same process is repeated in the second and third selector stages. In each case, the selector must find an idle trunk and cut through to it during the inter-digital time.

After the third selector has found and cut through to an idle trunk, the subscriber is connected to a connector switch. As he dials the fourth and fifth digits of the called number, the subscriber drives the connector to the desired line of the 100 lines it serves. The connection is established as soon as the subscriber finishes dialing. At this point, the connector tests the called line and, if it is idle, connects ringing current to it until the called line answers or the call is abandoned. If the line is busy, the connector returns busy tone to the calling subscriber. It is possible that during the establishment of a connection, a selector switch may have found all available links busy. In such a situation, the selector makes the 11th rotary step and returns an all-paths-busy signal to the subscriber.

If the dialing area contains a large number of lines, the office codes may of necessity be either 2 or 3 digit codes. Each additional digit dialed requires an additional stage of selectors in the switching train.

Each switch unit in the network provides supervisory control over all preceding switches in the train as a connection is being established.

This supervision is relinquished when the next switch in the sequence assumes control. Thus, during conversation, the connector maintains supervision of the entire connection. This connection is held until the calling subscriber hangs up.

(2) 7-Digit Call

(a) Using 7 Switching Stages

Figure 4-18 is a generalized diagram showing the originating portion of an office arranged for 7-digit switching. The diagram shows the concentration and distribution stages involved. The network shown represents 2 central offices within the same building and a portion of the other offices within the local dialing area.

A call progresses through the network in the same manner as a 5-digit call. The switching network contains two more stages of switches, 4th and 5th selectors and the customer must dial a total of 7 digits.

The additional digits are used in the originating network in selecting trunks to the local office or building. Reference to Figure 4-18 indicates that with some calls 3 digits of the office code are used in selecting outgoing trunks and in other calls only two digits of the office code are used, as in the case of codes 23- and 93-. All of the offices using 23 for the first two digits are located in one building. In this case the incoming third selector routes the call to the proper local office.
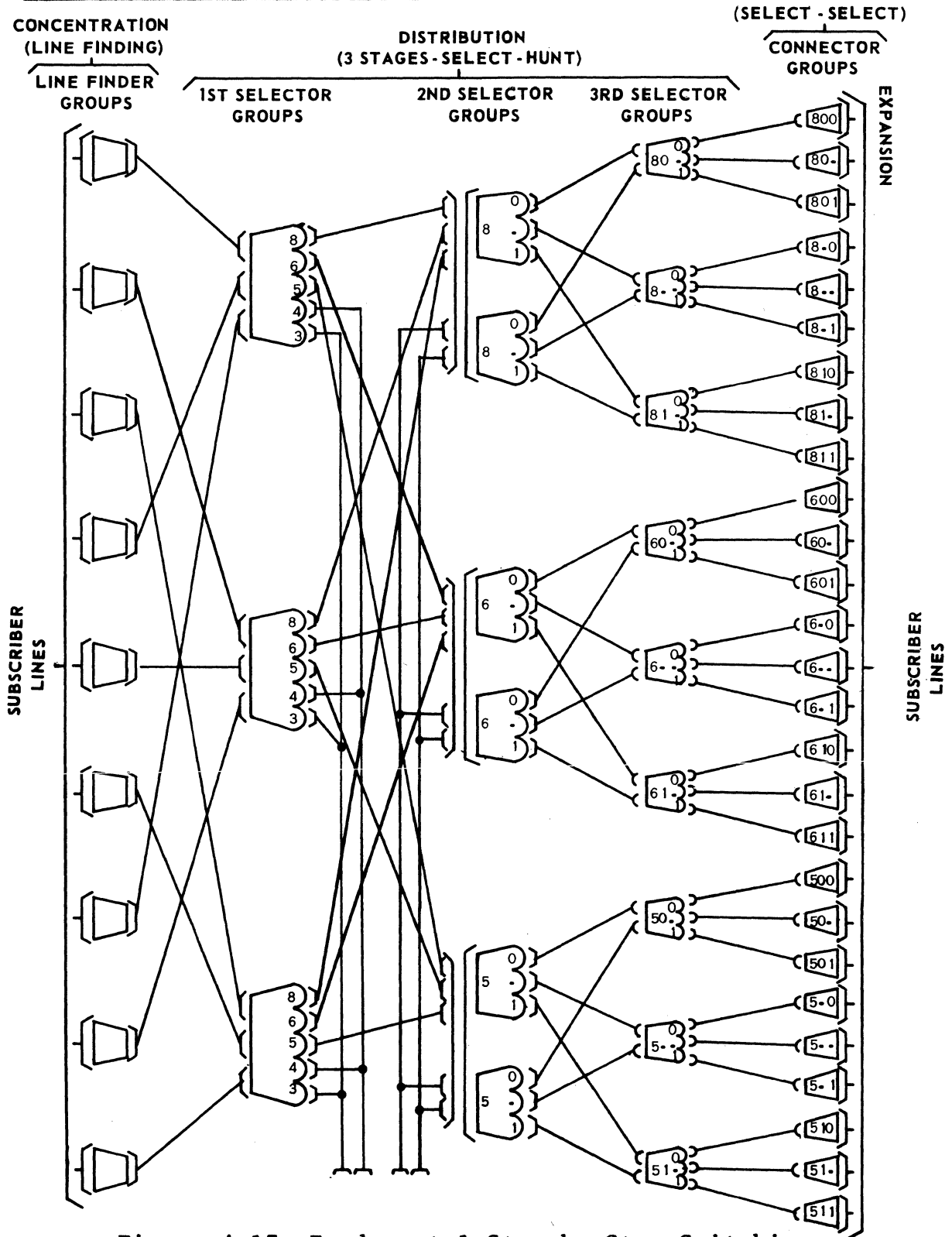
Figure 4-17   Fundamental Step-by-Step Switching
Network for 5-digit Office

(b) Using Less Than 7 Switching Stages

The telephone companies have found it desirable to adopt a uniform numbering plan which provides a 7-digit number for all subscribers regardless of the size of the community; however, for smaller communities requiring only four, five or six digits, the 7-digit numbering plan imposes a heavy penalty by requiring one, two or three selector stages that are not required from a switching standpoint. The use of selectors known as "digit-absorbing" selector avoids this wasteful practice.

As the name implies, a digit-absorbing selector absorbs digits that are not needed for economical switching but which are needed from the standpoint of uniform numbering. These switches are designed so that when a digit is received which drives the switch to a level marked for absorption, the switch drops back to normal. The levels are marked by bending cams associated with normal post springs.

Levels may be marked for "repeated" absorption and a switch will drop back to normal whenever it is driven to that level. On the other hand they may be marked for "once-only" absorption and the switch will return to normal the first time that digit is dialed but will hunt for an idle terminal on that level the second time it is dialed. Switches may also be marked to absorb on one level on the first digit and on a different level on the second digit.

Digit absorbing switches also provide a feature known as "blocking." When a level is marked for blocking, the switch, if it is driven to that level, will return paths-busy or no-such-number tone unless the switch has previously been driven to a level marked for absorption. This feature is used to restrict service and to prevent wrong numbers.
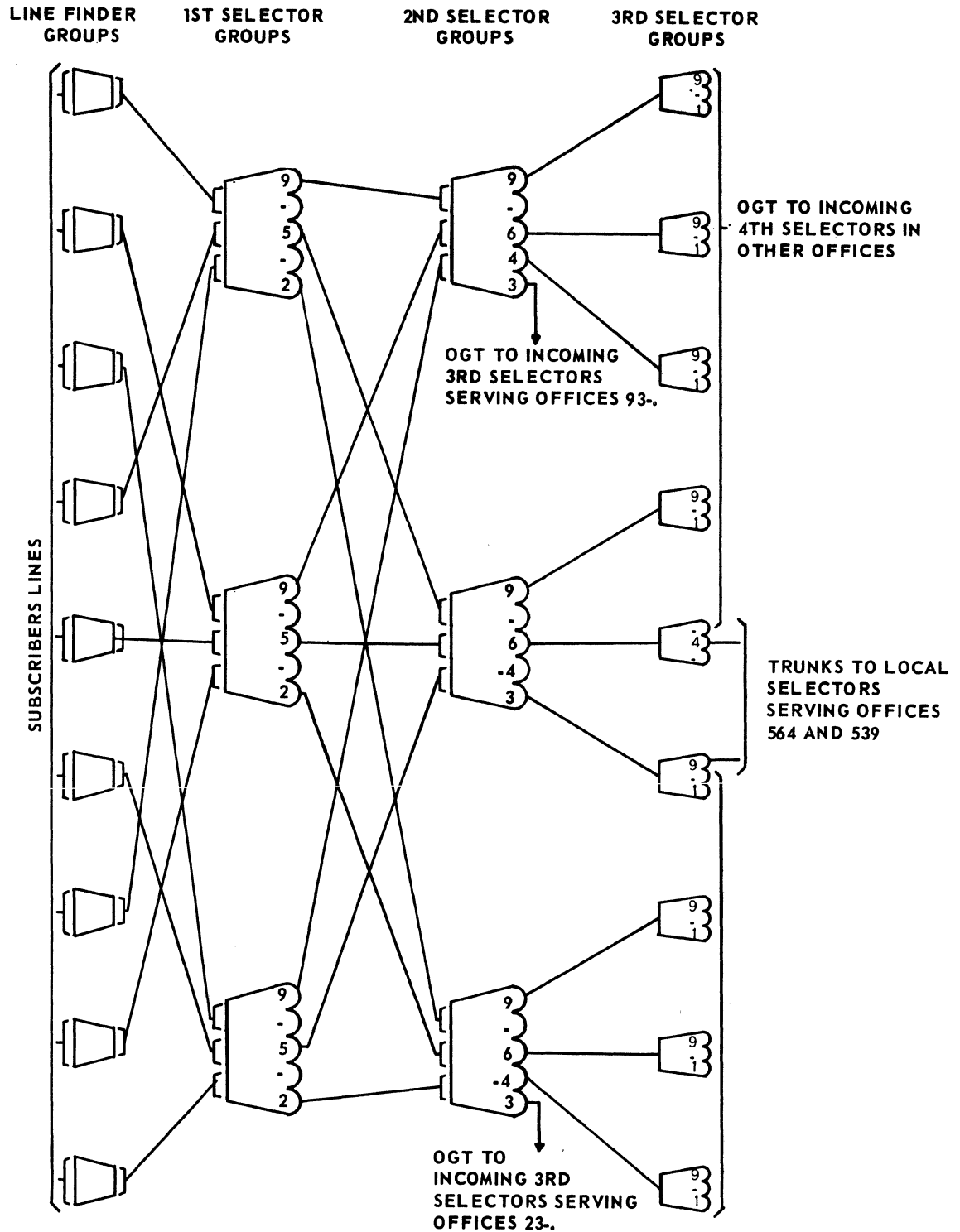
Figure 4-18   Fundamental Step-by-Step Originating
Switching Network for 7-Digit Office

The following is an example of a possible arrangement of a two-digit, digit-absorbing selector. Levels 3 and 5 might be specified to absorb and level 6 to block on the first digit (see Figure 4-18); levels 4 and 5 to absorb and levels 0, 1, and 8 to block in the second digit; and to trunk hunt on all levels on the third digit. Assume present office codes with 5-digit effective trunking to be 354 and 545 and with 6-digit trunking to be 328. When code 354 is dialed, the first digit, 3, is absorbed, the second digit, 5, is absorbed, and the switch trunk hunts on the third digit, 4. Similarly, with code 545, the switch absorbs the first two digits and trunk hunts on the third. If code 328 is dialed, the switch absorbs the first digit, 3, and the trunk hunts on the second digit, 2. The third digit, 8, is handled by the succeeding switch (in another office). A nearby office which cannot be dialed from our sample office might have codes 677 and 587. If a customer tries to dial these codes, he will be blocked on the first or second digit, respectively.

(3) 11 X Service Codes

The 11 X codes are used for reporting trouble, requesting assistance, etc. These calls fall in a broad group known as service code calls, the "X" at the end of the code represents a digit between 2 and 0. This digit is preceded by two "1's" in order to distinguish the "X" digit from digits representing office codes.

Figure 4-19 is a line diagram showing how 11 X codes are handled. It can be seen that the first digit "1" received drives the first selector to level 1 where a trunk is seized to an idle service code selector. The service code selector is a digit absorbing selector arranged for repeated absorption of digit "1". Levels 2 to 0 of this selector can not be used unless digit "1" has been absorbed, unlocking the switch. Thus, on a code such as "117" the first selector trunk hunts on the first "1" received. The

service code selector absorbs the second "1" of
the code and unlocks the service code selector
so it can trunk hunt on the digit "7".

If an accidental jiggling of the switch hook
caused a false "1" to be sent ahead of the
"11 X" code, the second and third "1's" would
have been absorbed in the service code selector.
On the other hand, a false "1" preceding an
office code, will result in a blocked call.
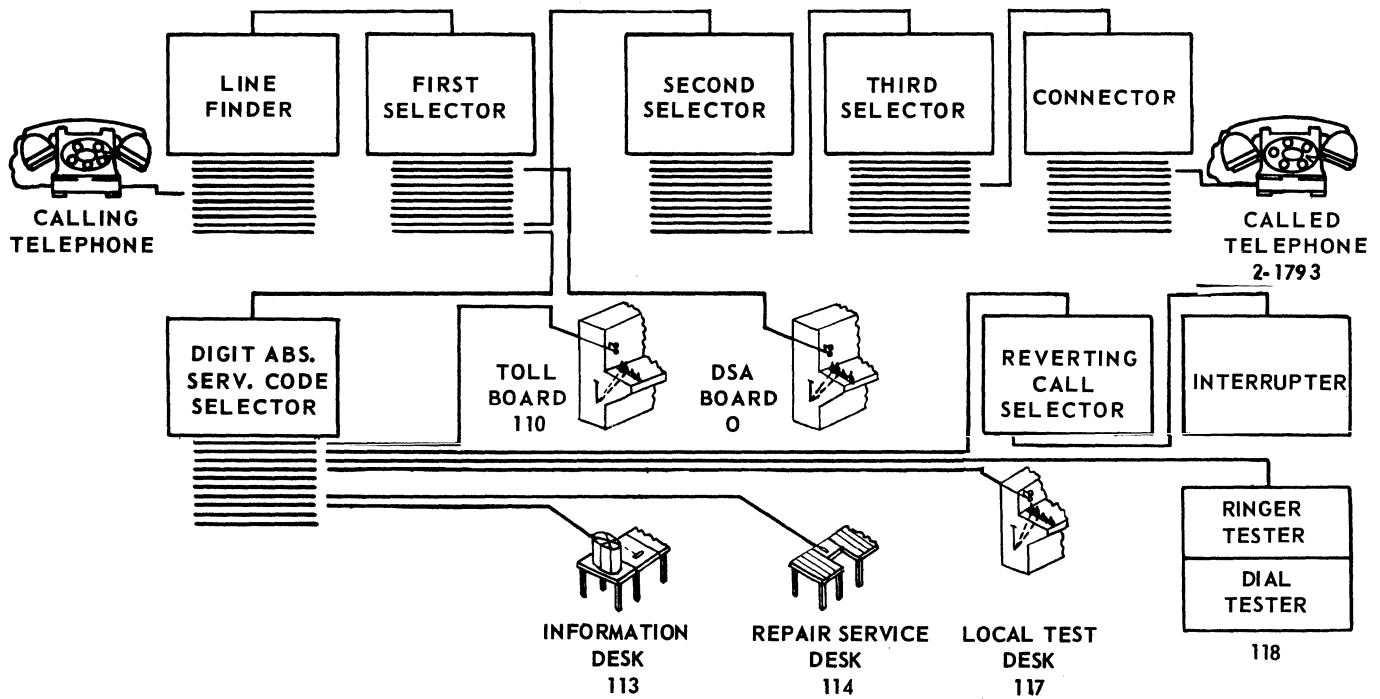
Figure 4-19   Switches, Switchboards, and Desks
Used in a Step-by-Step Dial System

4.32

(4) One Digit Access

In placing calls into the direct distance dialing network it is necessary to present all 10 digits to the toll switching offices. In Step-by-Step offices this can be accomplished by having the customer dial a "11 X" code followed by the 10 digits required to route the call. With this technique the "11 X" code routes the call through the local office to outgoing trunks to toll.

A more desirable method is to precede the ten digits of the called number by the digit "1". A trunk is located between level 1 of the first selector and the service code selector as shown in Figure 4-20. This trunk has a connection to a trunk to toll as well as a connection to the service code selector. During the interdigital time between 1 and the first digit of the area code, a seizure signal is sent to the toll office, signaling it to prepare receiving equipment for the digits to follow. As the second digit is received it is sent to the toll office as well as to the service code selector.

If the call is a direct distance dial call, the second digit received is some digit other than "1". The trunk circuit recognizes this condition and releases the connection to the service code selector. On the other hand, if the call is a service code call, the second digit is "1"; the trunk recognizes this condi-tion and releases the connection to the toll office.

A direct distance dial call is of the structure "1 X----"; while, a service code call is of the structure "11 X". The trunk permits the call to start routing into both networks; then upon determining if the second digit is a "1" or some other digit, it drops the connection to the undesired network.
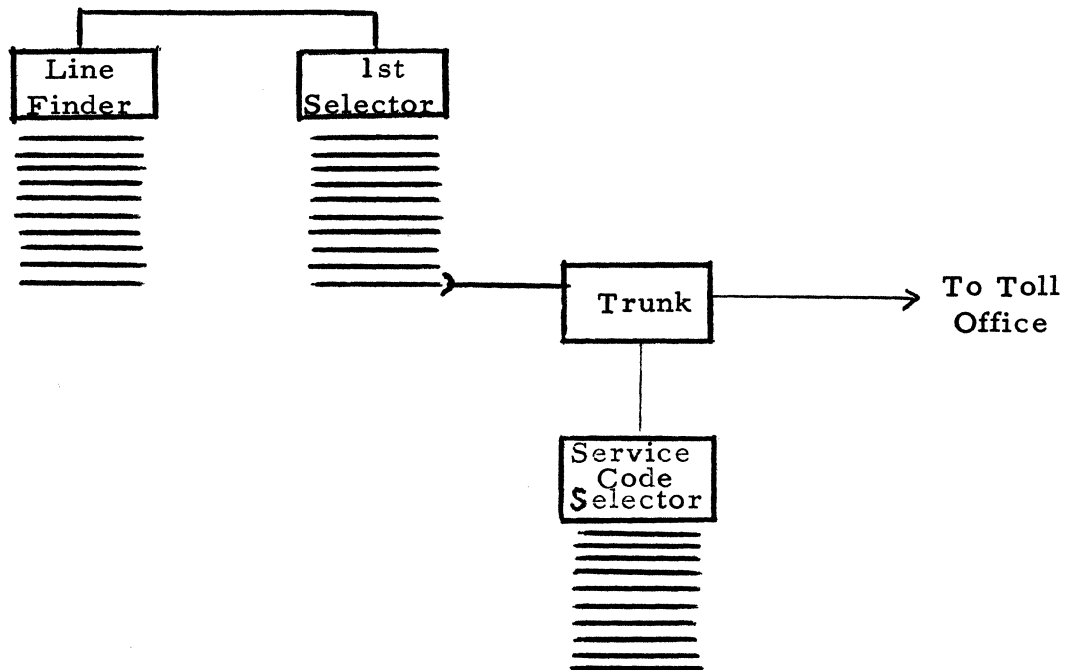
Figure 4-20   Routing For One Digit Access

(5) **Toll**

Step-by-Step toll switches are used to
handle several categories of traffic; which, in
general, can be classified as Toll Completing and
Intertoll. Toll completing traffic can be defined
as the traffic incoming to a local office from
a toll operator or intertoll network. Intertoll
traffic can be defined as traffic between toll
offices.

The Toll Train (Toll Completing traffic)
joins the local network at terminals of the
connector switches through toll or combination
toll and local connectors. The number of toll
selector stages preceding these connectors is
determined by the number of digits that must be
dialed to reach the subscriber's line.
Figure 4-21 is a block diagram of a Toll Train.
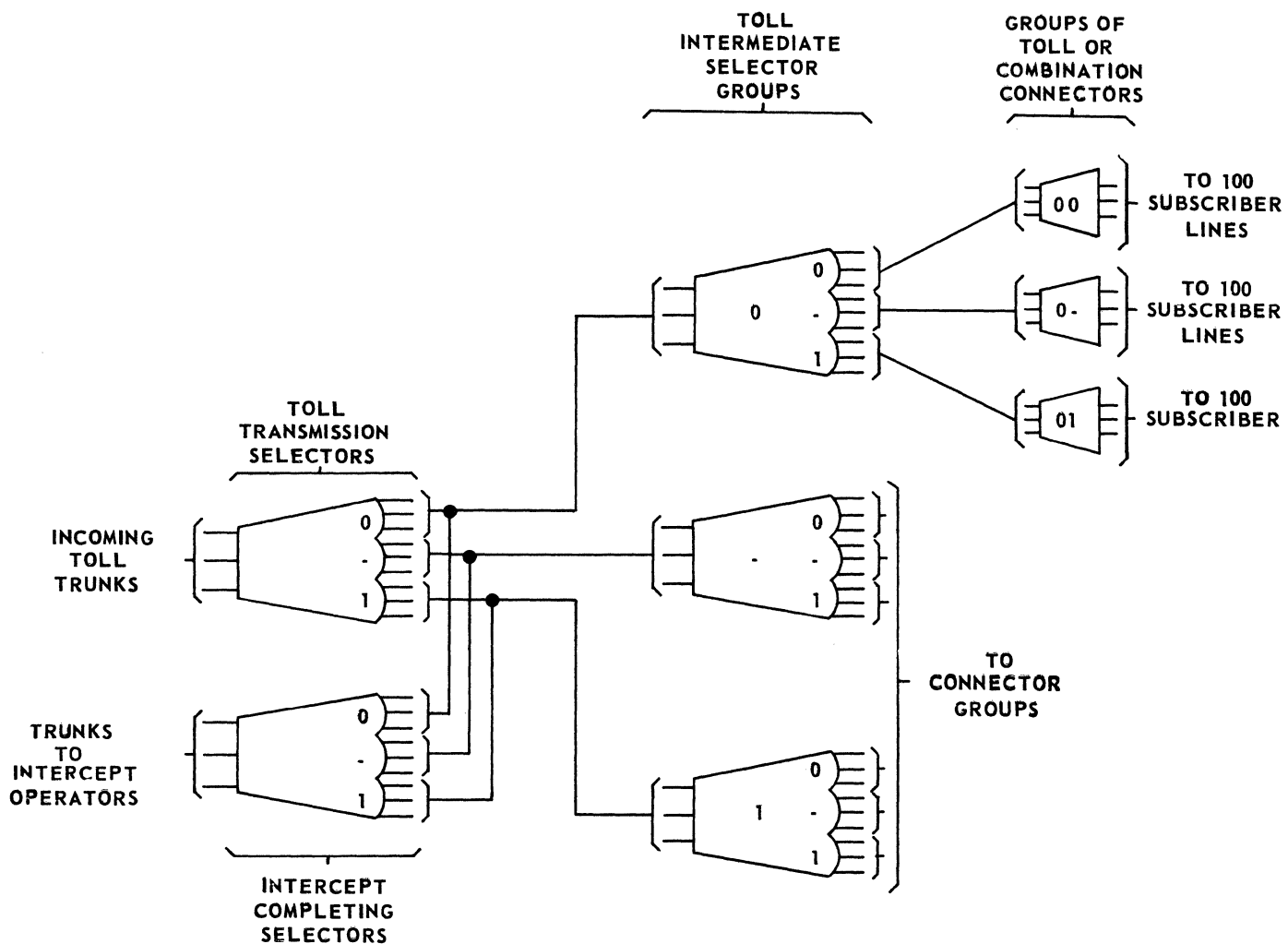
Figure 4-21 Typical Toll Train

The Intertoll Train is used to interconnect toll offices. Calls may be placed into the Intertoll network by operators or by "common control" offices. Likewise, calls can be terminated on toll switchboards or in common control offices. If calls are completed to Step-by-Step customers from the intertoll network, the last stages of the call is handled by Toll Trains. The number of stages of selectors required is determined by the number of outgoing trunk groups that the Intertoll offices have access to. One, two, or three stages may be required as shown in Figure 4-22.

The method of distributing trunks over the toll selector banks is identical to that used for the local selectors. The toll selectors are normally mounted on shelves designed for ten or twenty selectors; all switch banks on a shelf are permanently multipled. The basic selector subgroup, then, consists of ten or twenty switches. The bank levels of these subgroups are interconnected in a graded multiple, the exact arrangement depending upon the number of switch banks in a group and the number of trunks from each group to the succeeding stage.

B. SWITCHING FEATURES

(1) Slip Multiples

The lines are arranged on the switch banks of the line finders as indicated by the diagram of Figure 4-23. The lines which terminate on the tenth level of one line finder switch appear on the first level of the adjacent switch on one side, and on the ninth level of the adjacent switch, on the other side. In a group of twenty, 200-point line finders, for example, each group of twenty lines will terminate on the first level of two switches. The horizontal position of a particular line within the level remains the same on all switches. This method of multipling is known as a "slipped multiple."
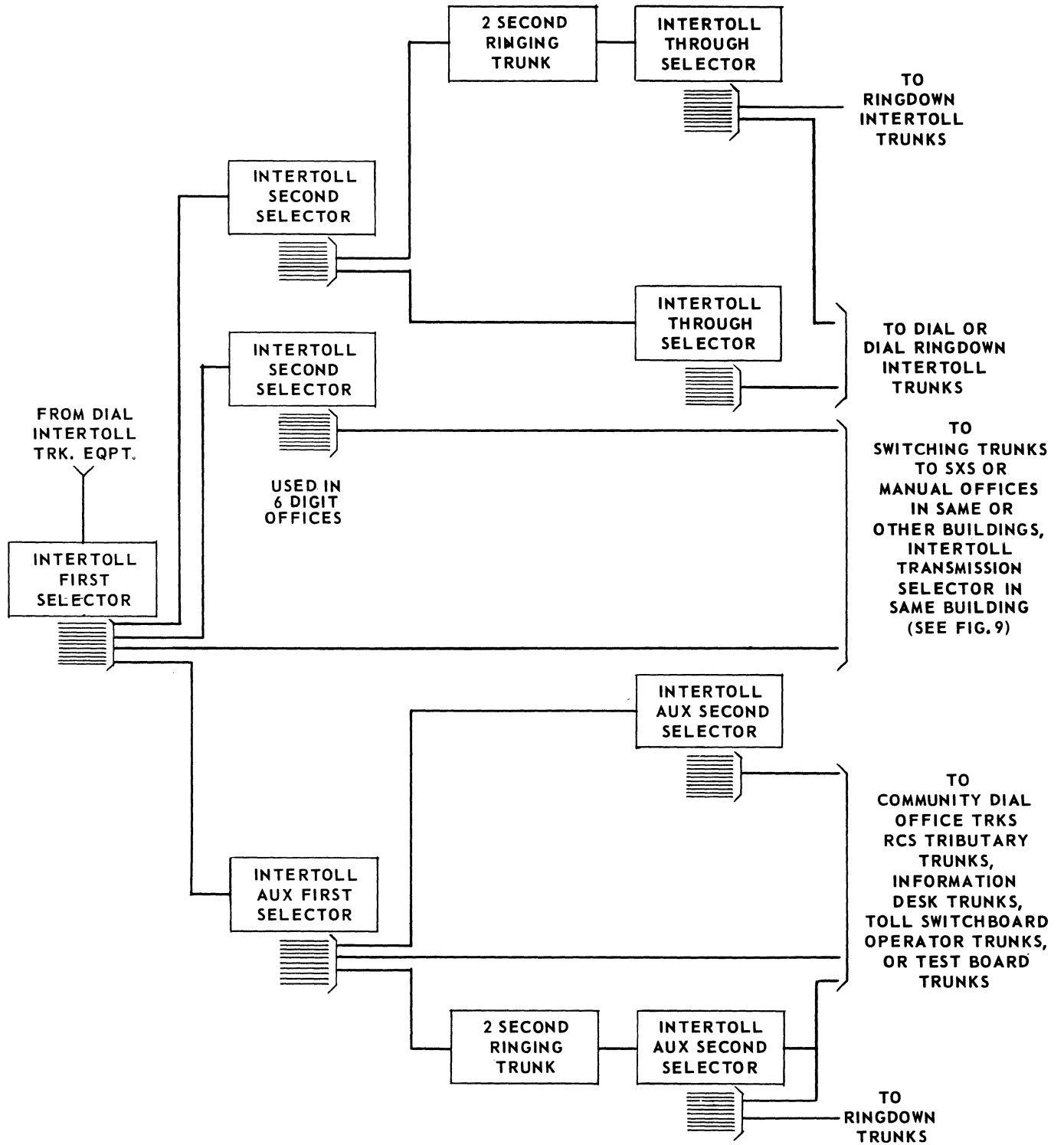
Figure 4-22 Typical Intertoll Train

The line finder group is controlled by an allotting circuit which allots to any call that finder, among those idle, that will find the requesting line on the lowest bank level. Thus, if all finders in the group are idle, a switch having the requesting line on its first level will be allotted to the call.

For charging purposes, subscriber lines served by a step-by-step office are divided into various classes of service such as: <u>flat rate</u>, <u>individual message rate</u>, <u>two-party message rate</u>, <u>coin box</u>, etc. Each class may be further sub-divided into lines given extended dialing area service or restricted dialing area service. With certain exceptions, the lines served by a group of line finders must all be of the same class and have the same dialing area service.

(2) <u>Graded Multiple</u>

Selector banks are permanently multipled together in subgroups of ten banks. From an equipment standpoint, a group of selectors must be an integral multiple of ten selectors. From a traffic standpoint, however, fully equipping these subgroups with switches might not be warranted. Hence, while selector groups are fully equipped with banks, they are not necessarily fully equipped with switches.

A switching group has greatest efficiency when every input has access to every output. Figure 4-24 is an example of this arrangement, where every switch has access to every output and the maximum number of outputs depends on the access of the switch. For step-by-step switches, this limit is ten. When the number of inputs increases to the point where the output group is overloaded, the group can be split as shown in Figure 4-25. But smaller groups are less efficient than large ones and splitting the multiple would require increasing the total number of output trunks.
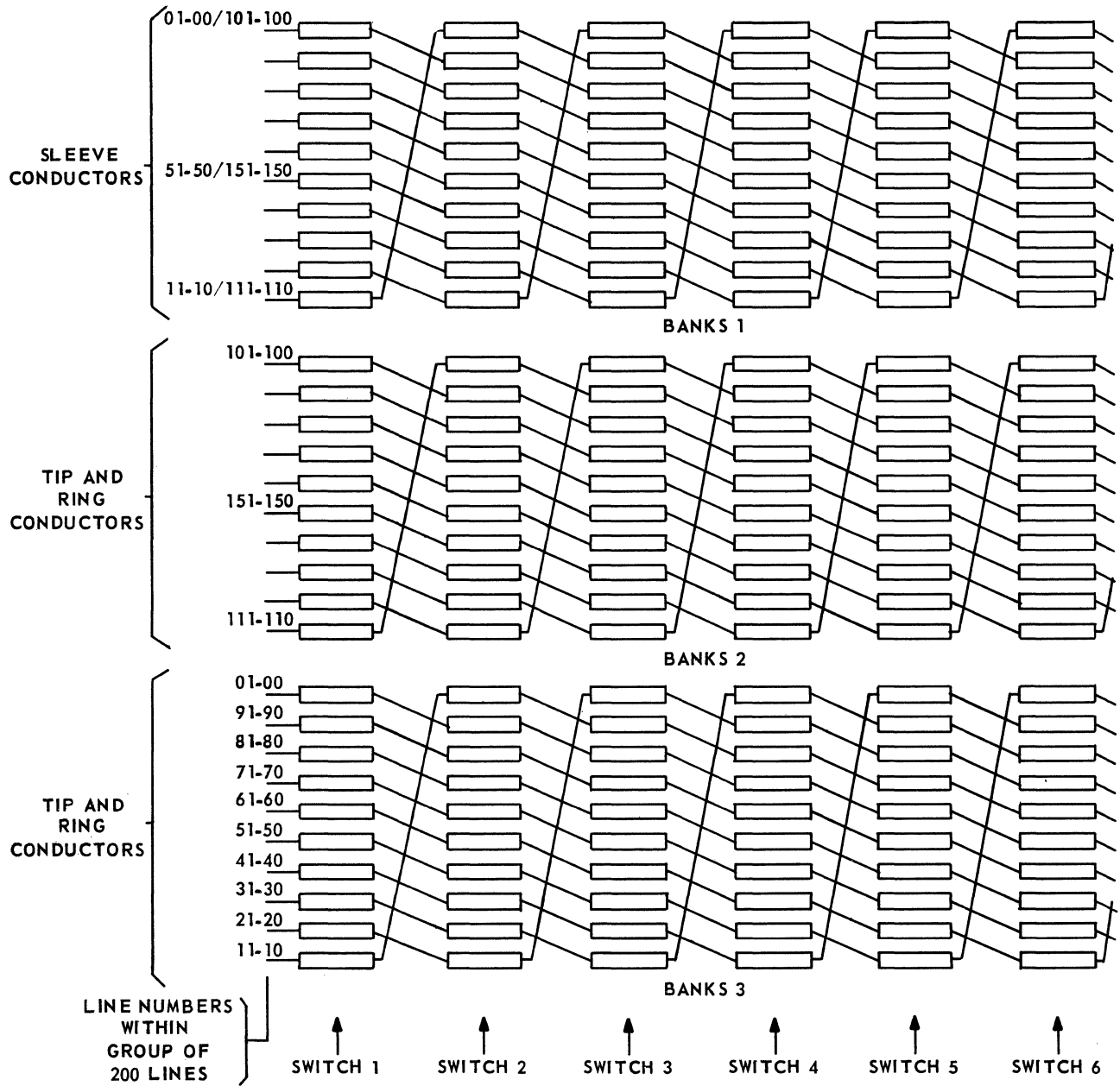
Figure 4-23 Slipped Multiple on Terminal
Banks of Line Finder Switches
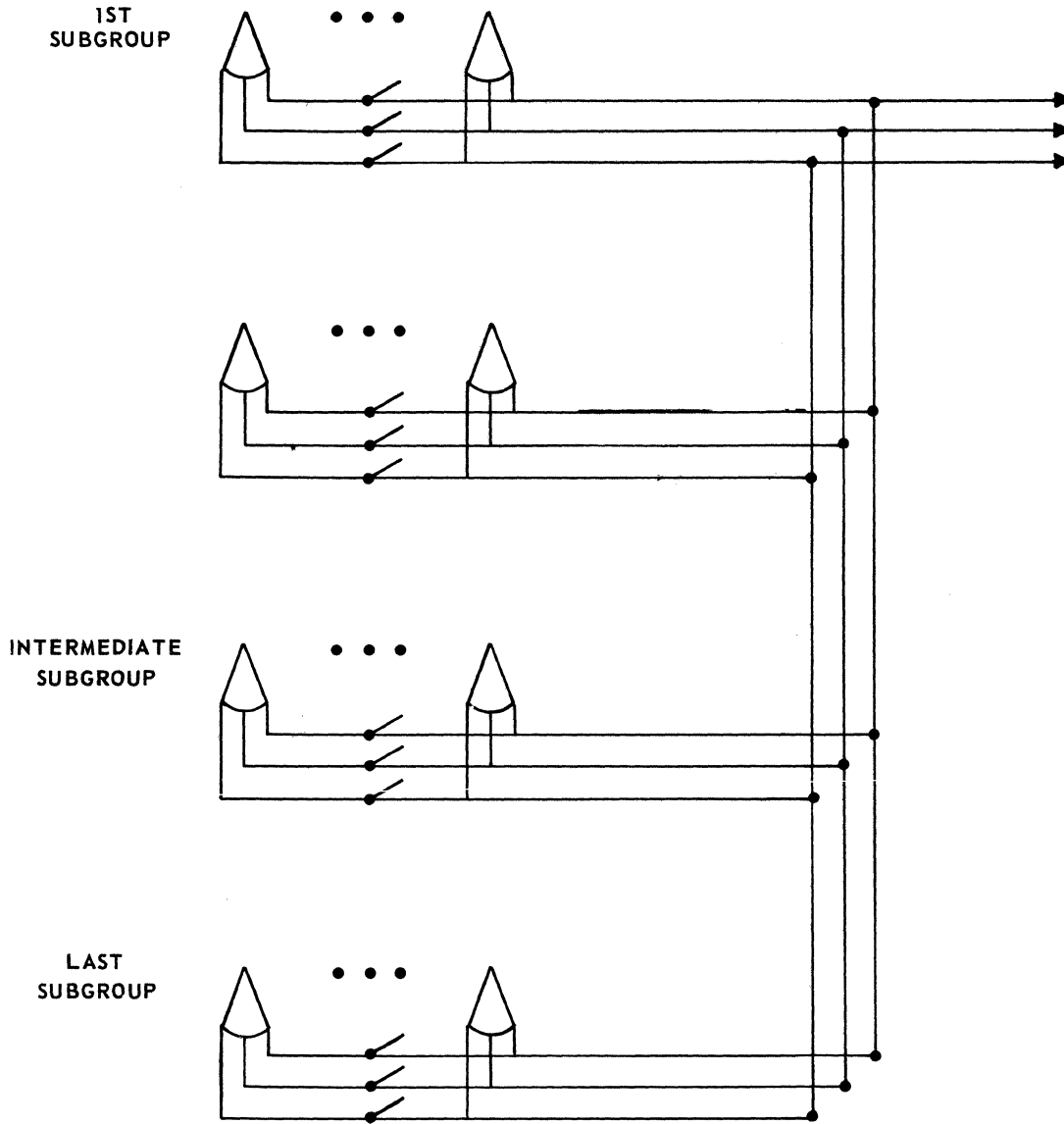
Figure 4-24   Common Multiple to All Subgroups
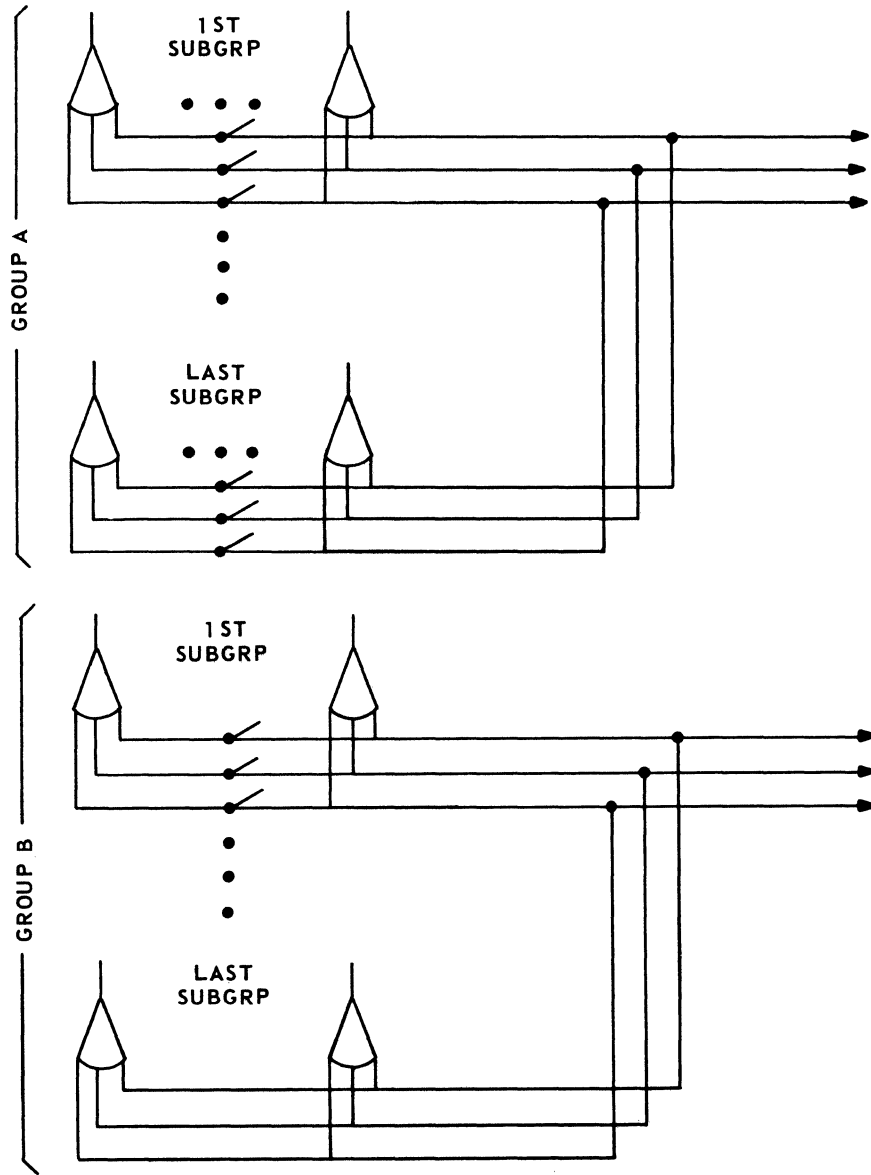
Figure 4-25   Multiple Subgrouped
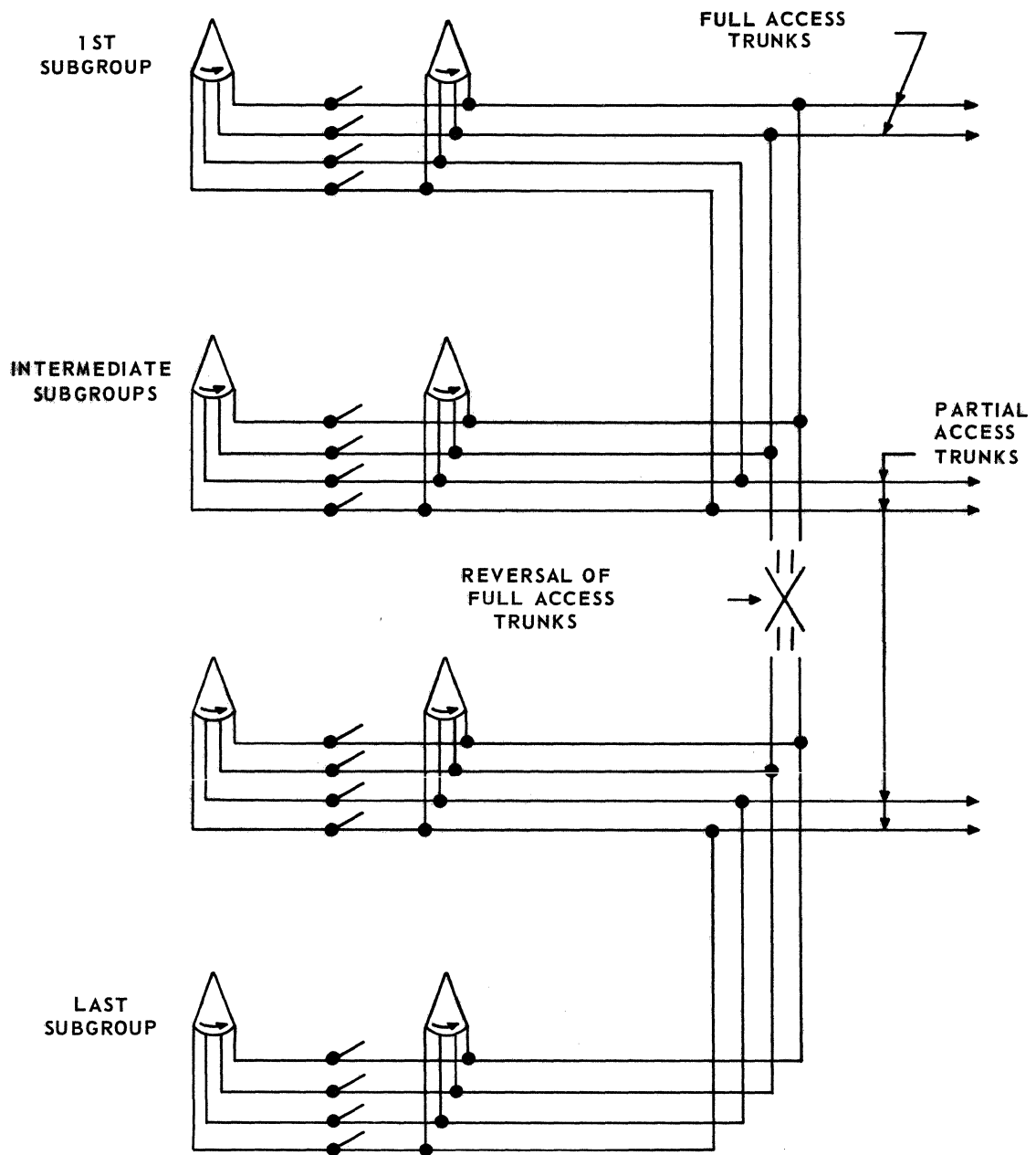
Figure 4-26   Graded Multiple

This situation is improved by employing graded multiples as shown in Figure 4-26. With this arrangement, there is full access to only a fraction of the trunks. The graded multiple may be thought of as a combined full access and split multiple. It is a compromise dictated by limited access switches, not as efficient as a full access multiple, but more efficient than a split multiple.

(3) Rotary Out Trunks

Traffic between local step-by-step offices leaves the originating office on outgoing trunks from the first, second or third selector stages. This traffic is distributed over the various groups and subgroups of the selector bank multiples.

Each of the above subgroups must be engineered for a given quality of service during its peak load condition. The total trunks required from all of the subgroups of trunks to a particular destination is greater than would be required if the traffic could be concentrated in one large group of trunks. The difference in the total number of trunks required by using one large group is of considerable importance from an overall cost standpoint since trunks between offices represent considerable plant investment compared to trunks within an office.

The use of Rotary Out Trunks is one method of reducing the number of interoffice trunks to the theoretical minimum. In essence, the rotary out trunks are a distribution stage between the selector terminals leaving one office and the incoming selectors of the terminating office. Approximately 40% of the outgoing trunks are connected directly to the terminating office. These trunks are in the individual subgroup portion of the graded multiple. The remaining 60% of the outgoing trunks are connected to the rotors of Rotary Selector Switches. The banks of the Rotary Selector Switches are connected to

the previously mentioned individual trunks as well as to enough other outgoing trunks to meet traffic requirements. Figure 4-27 shows this arrangement between two offices; office 2 and 3.

With this technique the rotary selectors have access to individual trunks from a number of subgroups as well as what would normally be called common trunks. The banks of the rotary selectors are multipled; thus, we have a distribution stage that in effect groups a number of small groups into a larger group for greater efficiency.

The connection through the rotary selector must be established during the interdigital timing period but after the previous selector completed its rotary hunt. In order to avoid traffic blockage due to two rotary hunts during one interdigital timing interval, the rotary out trunk is always positioned on an idle outgoing trunk. Whenever a trunk that has been preselected by the rotary selector is seized by some other selector, another idle trunk is preselected. The rotary hunting action of the rotary selectors is stopped during an all-trunks-busy condition to prevent the selectors from continuous hunting action.

4.5 PROGRESSIVE CONTROL TECHNIQUES

A. GENERAL

(1) Direct Progressive Control

The system examined so far has various disadvantages inherent in direct progressive control systems.

First, since signals generated by the calling subscriber's device are received directly by the switching device, improvements involving major changes in control signaling cannot be made to one device without being made to the other. This limitation in signaling flexibility
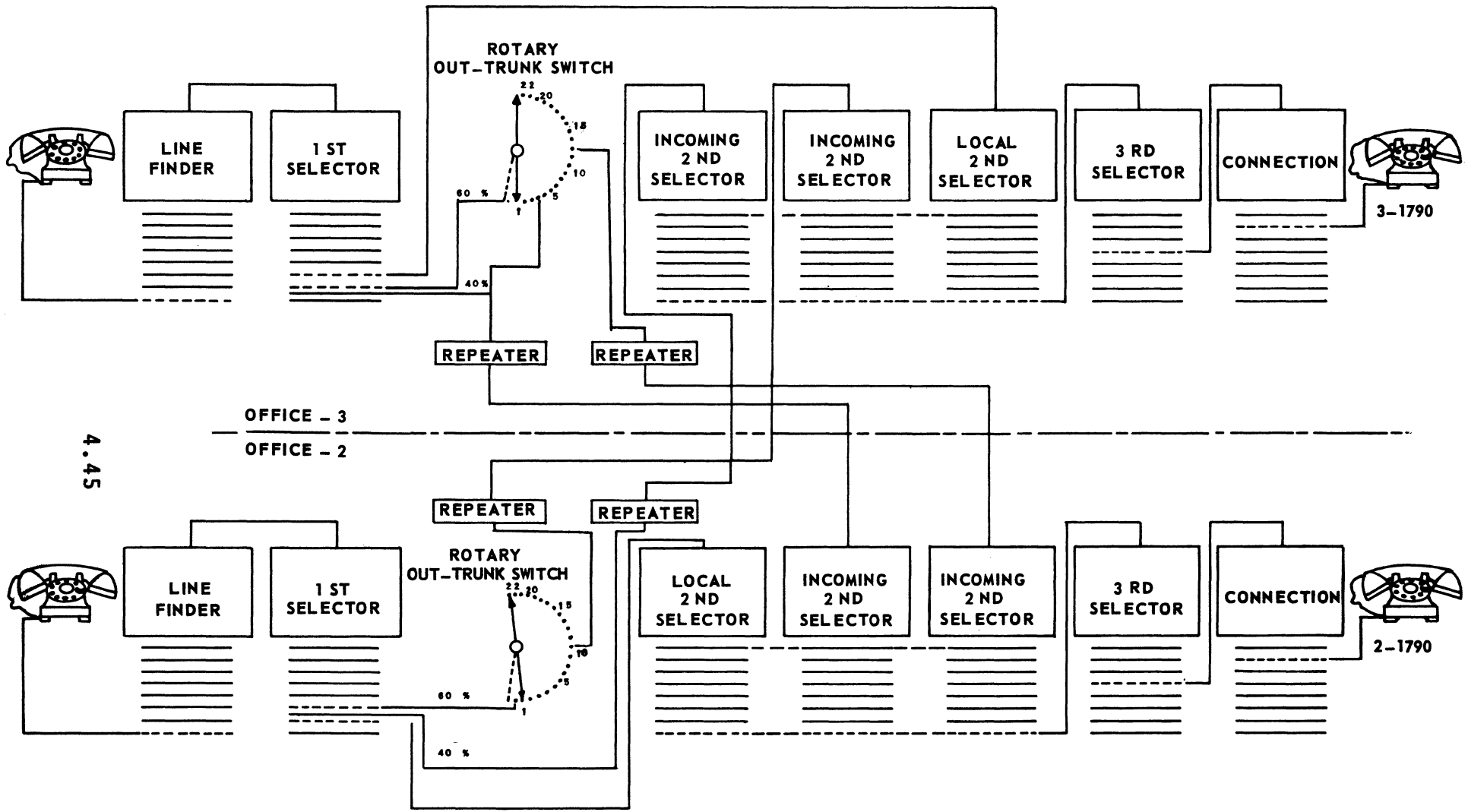
Figure 4-27   Trunking Using Rotary Out Trunks

has been brought sharply into focus by the introduction of touch-tone calling since the tone signals generated by the subscriber are not compatible with existing switches and it is not economically feasible to modify or replace the huge number of switches involved.

Second, the assignment of a numeric code to a subscriber specifically fixes the location of his line in the terminating stage. Similarly, assigning a numeric code to associated offices specifically fixes the location of the trunk groups to those offices in the distribution stage of the network. Extreme care is required to properly assign these codes to provide economical trunking and to insure against serious traffic imbalances or poor trunking arrangements. Also, subscribers are reluctant to have their numbers changed and it is not practical to reassign office codes to control the routing.

Third, since the switches are directly controlled by the subscriber, a signal must be generated by the subscriber for each "node" or switch in the tree-like structure of the switching network. When step-by-step intertoll facilities are used for long distance calls, from one to three switches are required at each intertoll office. When a call requires that several intertoll offices be connected in tandem, several digits must prefix the called subscriber's number in order to select the proper path through the intertoll network. Obviously this does not lend itself to the uniform dialing procedures required for direct distance dialing.

Fourth, the progressive buildup of a path through the network under the direct control of the subscriber, makes it impossible to try an alternate route if, as the path progresses, a blocked point in the network due to an all trunk busy or a trouble condition is encountered. Under this condition the call must be abandoned and another attempt made to complete the connection. This is a serious limitation.

(2) Register Progressive Control

In order to overcome certain of these limitation, various methods have been developed which provide, partial or full register progressive control for step-by-step systems. The step-by-step intertoll CAMA facilities is one such facility. Two other recent developments, common control and "noncompatible" touch-tone calling, also utilize register progressive control in local offices.

B. COMMON CONTROL

"Common Control" has been previously defined in terms of a switching system principle. It may also be defined, from a circuit viewpoint, as a control common to more than one switching device. When used in this context, common control circuits are used in progressive control systems.

Controlled outpulsing permits, translation, code conversion, alternate routing, multifrequency outpulsing and permanent signal routing. In addition, these facilities are compatible with the facilities needed to accept Touch-Tone signals. Hence, common control may be furnished to provide either Touch-Tone calling or controlled outpulsing or both. If only one of these features is originally provided, the other may be added at a later date by providing compatible features initially.

(1) Controlled Outpulsing

A block diagram of common control facilities is shown in Figure 4-28. When a customer lifts his receiver, a line finder begins to hunt for his line. At the same time the register trunk and link connects a register to the register trunk associated with the line finder. The register trunk splits the tip and ring between the line finder and first selector and extends the subscriber's loop to a relay in the register. A pulsing path is also extended from the register to the first selector. Dial tone is then supplied by the register to the subscriber who

may be calling from either a dial or a Touch-Tone telephone. If the call is from a dial pulse subscriber, the register repeats the digits over the pulsing path to the first selector. If the call is from a Touch-Tone service subscriber, no dial pulses are given to the first selector at this time.

When three digits are stored (four, if a 0 or 1 prefix digit is received) the register bids for, and connects to, a translator and decoder through their respective connectors. The trunk class connector also connects to the decoder and passes the calling customer's class of service. Having determined the code dialed and the class of service, the decoder informs the register and outpulsing controller if controlled outpulsing is required, and, if so, how it is to be handled.

It should be remembered that before the decoder has determined whether or not controlled outpulsing is required, three or four digits will have already been repeated to the distributing stage, and a switch train will have been partially established. On those few calls which do require controlled outpulsing, the established switch train is dropped by the register. The decoder then provides the register and outpulsing controller with the following information:

1. The arbitrary digits which must be pre-fixed to the dialed number for routing or code conversion.
2. The number of digits to delete from the called number.
3. Which digits, if any, require MF pulsing.
4. The number of digits it must outpulse before releasing.
5. Whether an alternate route is available (so that the decoder can be recalled if on all trunks busy condition is found).

The translator and decoder now release and the required digits are outpulsed, after which the register trunk cuts through; the originating register and outpulsing controller then release.

Figure 4-28 Common Control Facilities

ROTARY DIAL TELEPHONE

TOUCH-TONE TELEPHONE

SUBSCRIBER'S LINE

LINE FINDERS

COIN OR MR TRUNK

REGISTER TRUNK AND LINK

TRK

LINK

PRI

SEC

OG TRUNKS

FIRST SELECTORS

DISTRIBUTING NETWORK

INTRA-OFFICE TRUNKS

TOUCH-TONE CONVERTER

MF RECEIVER

ORIGINATING REGISTER

TRANSLATOR CONN

TRANSLATOR

OUTPULSING CONTROLLER

DECODER CONNECTOR

FOREIGN AREA TRANSLATOR

TRUNK CLASS CONN

DECODER

LEGEND:

EQUIPMENT ALWAYS REQUIRED

EQUIPMENT REQUIRED FOR CONTROLLED OUTPULSING

EQUIPMENT REQUIRED FOR "COMPATABLE" TOUCH-TONE CALLING

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However, if controlled outpulsing was not required, the action taken by the register, after the translator releases, would depend on the type of pulsing received.

When signals from a Touch-Tone phone are received, the digits are detected by the Touch-Tone converter and stored in the register. The register then generates and outpulses dial pulses to match the digits stored in its memory relays. At completion of outpulsing, the register and link release.

In dial pulsing, after the register repeats the pulses to the first selector, the register releases itself and the link during the inter-digital timing interval.

The register trunk then completes the pulsing path from the line finder to the first selector so the customers dial now controls the remaining switching stages in conventional manner.

(2) TOUCH-TONE Calling Without Controlled Outpulsing

Compatible Touch-Tone calling can be furnished initially and at some later date modified to add controlled outpulsing. In this case the equipment shown in the heavy solid line of Figure 4-28 is not required until the controlled outpulsing features are added.

Only those line groups having subscribers with Touch-Tone calling will require the register control equipment.

(a) Calls from Dial Pulse Subscribers

If dial pulses are received, the register repeats them to the first selector and then releases during the interdigital time between the first and second digit. The remainder of the digits are fed to the network on a direct progressive control basis.

(b) Calls from Touch-Tone Service Subscribers

If signals from a Touch-Tone phone are received, the converter and its associated receiver translate the tone signals into D-C signals and store the digits on memory relays in the register. After the first digit is stored, it begins to pulse the digits to the distributing stage at the standard rate of 10 pps.

When three digits are stored (four, if a 0 or 1 prefix digit is received) the register bids for and connects to a translator which tells it how many digits it must receive. When the required number of digits have been outpulsed, the register trunk cuts through and the originating register releases.

C. NONCOMPATIBLE TOUCH-TONE CALLING

In offices in which it would never be economically feasible to provide controlled outpulsing, a cheaper method of accepting signals from a Touch-Tone phone is available. This method is variously referred to as "noncommon control" or non-compatible" Touch-Tone calling. "Noncompatible" because this method cannot be modified to operate with controlled outpulsing. "Noncommon Control," strictly speaking, is a misnomer since this equipment does control several switching devices. However, the term control, when used in step-by-step, refers to the special case of controlled outpulsing.

This arrangement, shown in Figure 4-29, is similar to that described for "compatible Touch-Tone calling only" except that access is obtained through converter trunks and finder switches instead of a register trunk and link. In addition, the functions of the originating register and translator are built into the converter. This equipment is furnished only for those line groups having some subscribers with Touch-Tone service. When a subscriber lifts his receiver, a line finder seizes the line; the converter trunk recognizes that this is a new call and directs a trunk finder to connect to it. In smaller offices the trunk finder connects directly to a converter; but in offices with a large number of converters, increased efficiency is obtained by using converter finders which hunt for, and connect to, idle converters.
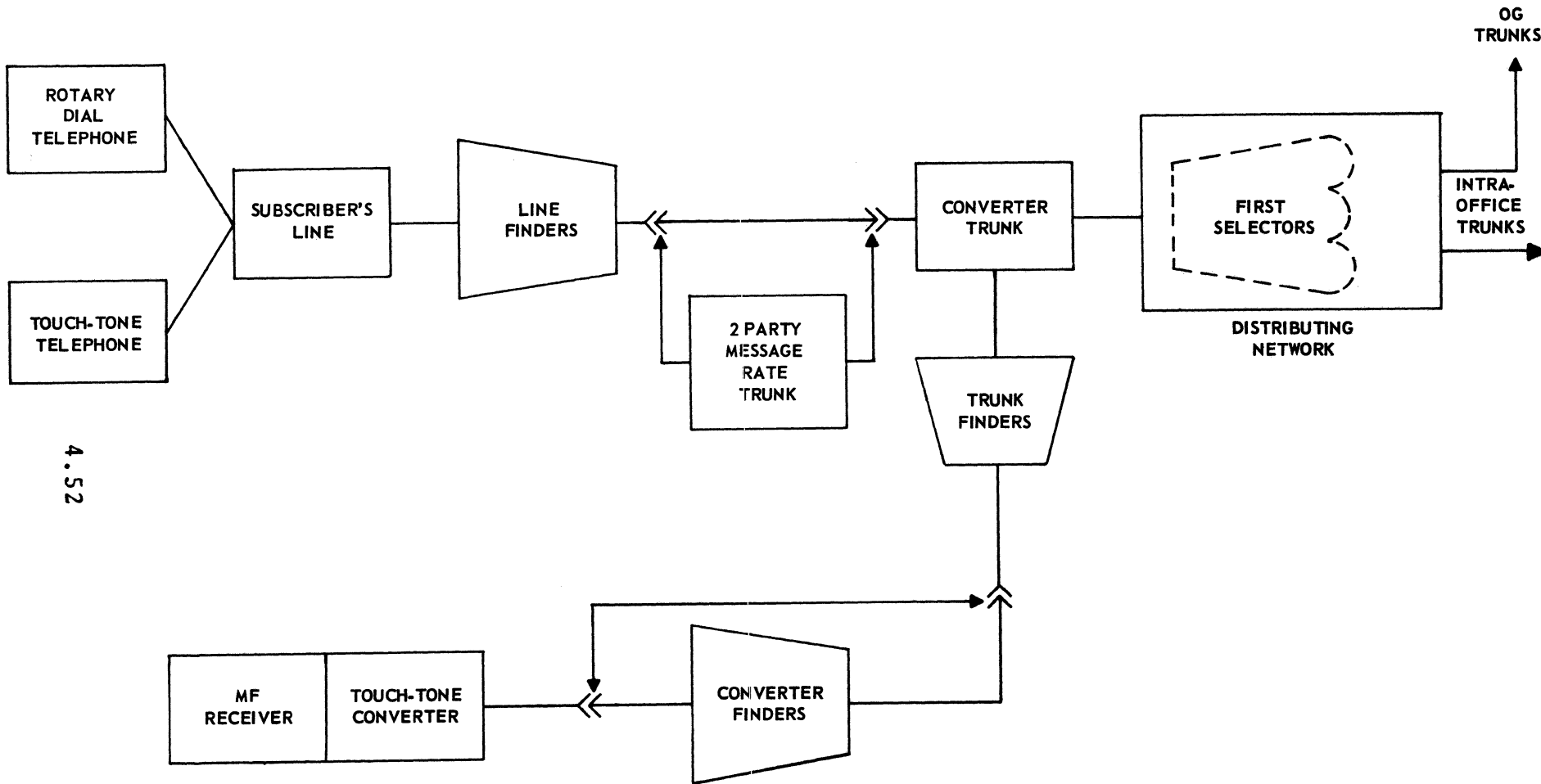
Figure 4-29 "Noncompatible" TOUCH-TONE Calling Facilities

4.52

The converter trunk splits the tip and ring leads between the line finder and first selector and establishes a connection through the trunk finder and converter finder, when provided, to a supervisory relay in the converter. The converter now furnishes dial tone to the customer.

If the call is from a dial telephone, the pulses of the first digit are repeated by the supervisory relay to the first selector, the converter releases during the interval between the first and second digit and the converter trunk connects tip and ring through to the first selector. The remainder of the digits are fed directly to the network on a direct progressive control basis.

When a customer having Touch-Tone calling originates a call, the converter and associated receiver translate the tone signals to D-C signals, stores them on memory relays and outpulses the digits to the distributing network. After the last digit is outpulsed, in a manner similar to that previously described for the originating register, they both release.

The modest amount of translation built into the converter enables it to minimize its holding time by recognizing the number of digits it must outpulse. However, the converter does not control the digits which are pulsed out, except in the case of permanent signals. Under this condition digits are pulsed which route the call to permanent signal holding trunks. Like the originating register the converter times out, returns recorder tone, and releases, if it has not completed a call in a specific allotted time.

CHAPTER 5

PANEL SWITCHING SYSTEM

5.1 INTRODUCTION

The panel system is a local dial switching system that was developed so that dial operation might be applied in large metropolitan areas where the number of central offices to be served created complicated trunking problems. In the panel system, direct control of the switches by the subscribers' dial is abandoned in favor of a register or sender in which the dialed pulses are stored until the equipment is ready to use them. This allows the selecting apparatus more time to hunt over large trunk groups than is normally permitted between the digits dialed by a subscriber. The system is applied only in the larger areas because it does not compete economically with the step-by-step system in exchange areas with a small number of central offices or in communities with only a small number of subscribers lines.

5.2 APPARATUS ELEMENTS

A. PANEL SELECTORS

In order to understand fully the operation of the panel type dial system it is necessary to study the mechanical details of the various pieces of apparatus. The principal piece of apparatus which gives the system its name is the panel type selector, so called, because the terminals over which the selector passes, are arranged in a flat rectangular bank or panel. This is used throughout the system in various forms, differing in size, in detailed arrangements and in electrical connections, but all having the same general mechanical construction. We will begin by considering the general construction and describe later the detailed differences which distinguish the various selectors.

Figure 5-1 is a general view of a selector frame. It will be observed that all apparatus is mounted upon a structural iron framework securely bolted to the floor and to the ceiling. In Figure 5-1 there will be seen several banks of terminals mounted one above the other.

Figure 5-2 shows one of these banks removed from the frame. It consists of flat strips of brass having projecting lugs, separated by strips of insulating material and clamped together by long bolts passing through holes in all of the strips. The lugs are so arranged that they project on both sides of the bank and are repeated thirty times on the front and thirty times on the rear of each strip. A set of three strips constitutes the terminals of one line or trunk and they are designated "tip," "ring" and "sleeve" terminals as in manual practice.

The terminals of the lines or trunks then appear in vertical rows, each row containing 100 lines or trunks in each bank and there are thirty such rows on the front and thirty on the rear, so that, each line or trunk appears sixty times in each bank. Connections to the lines or trunks are made by wire soldered to lugs at one or both ends of the bank. In actual practice, in those selector frames where these terminals represent trunks, only 90 of the 100 possible trunks in each bank are used as trunks, the remaining 10 being required for other purposes.

The selectors consist of hollow brass rods, one mounted opposite each vertical row of three terminals and arranged to slide up and down. Since there are 60 vertical rows, 60 selectors can be accommodated on each frame, 30 on each side. The selector tubes carry sets of spring fingers or "brushes" in front of each bank which may be made to rub on the terminals when the selector is driven up or down. Connections from the brushes are carried through the rods to sliding contacts at the top.

In the middle of the frame at the bottom are long rolls covered with cork composition which are constantly revolved by an electric motor through the medium of gears. The lower roll rotates in such a direction as to drive the selector upward and the upper roll in the opposite direction to drive the selector downward. Each selector tube is attached at its lower end to a flat strip of bronze called a "rack," which normally stands just in front of the revolving rolls but not touching them. In front of each rack is an electro-mechanical device called a "clutch." A separate clutch, selector rod and drive unit are shown in Figure 5-3. When an electric current is passed through one of the magnets of the clutch, a roller attached to its armature presses the rack against one of the revolving cork covered rolls which, by friction, moves the selector up or
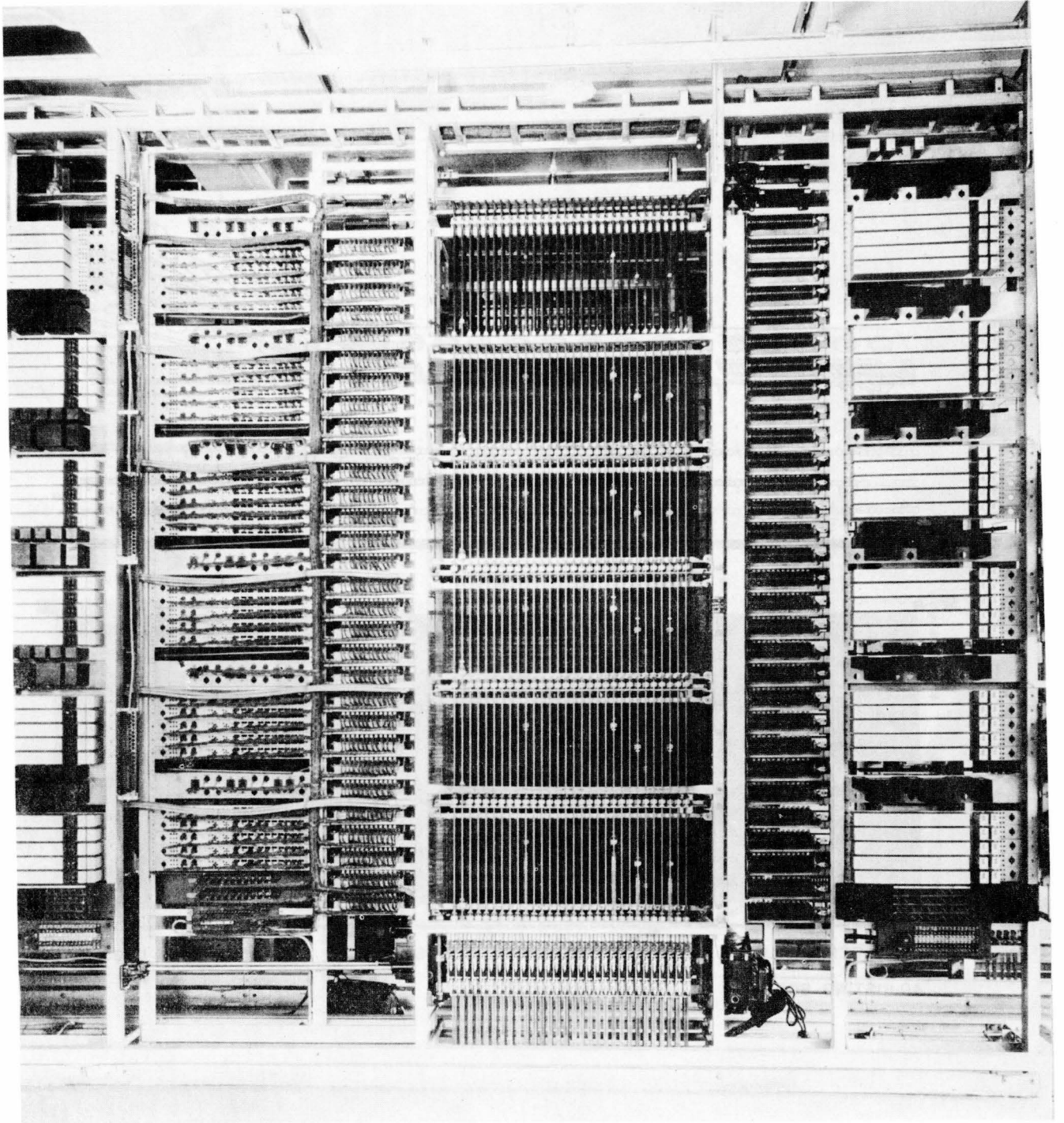
Figure 5-1 Typical Panel Dial Selector Frame
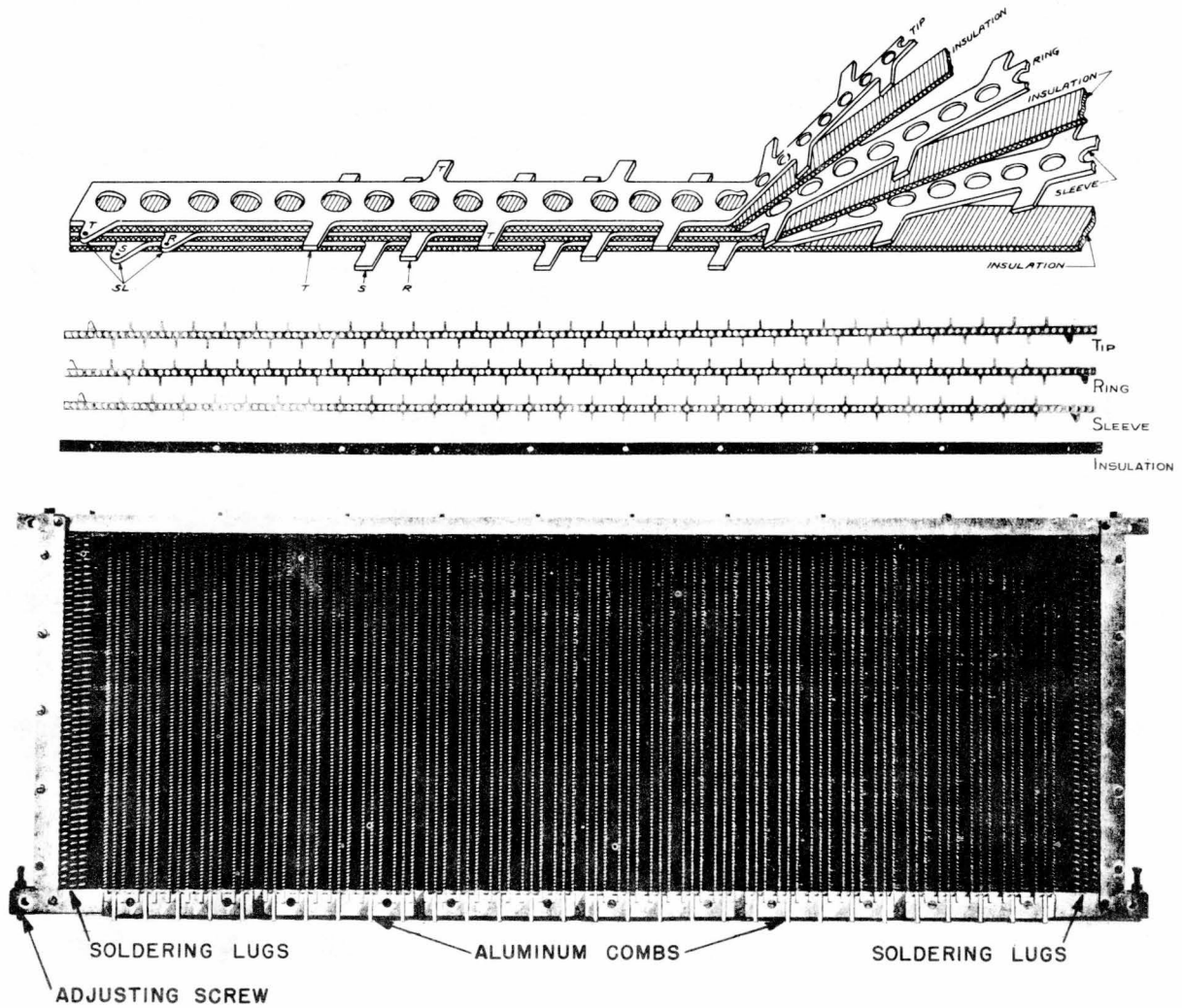
Figure 5-2 Panel Multiple Bank

COMMUTATOR

COMMUTATOR
BRUSH

TF 4
BR. 4

BR. 3

BR. 2

BR. 1

TRIP ROD

TRIP
FINGER O

SELECTOR ROD

BRUSH O

MAGNETS

TRIP

DOWN
DRIVE

UP
DRIVE
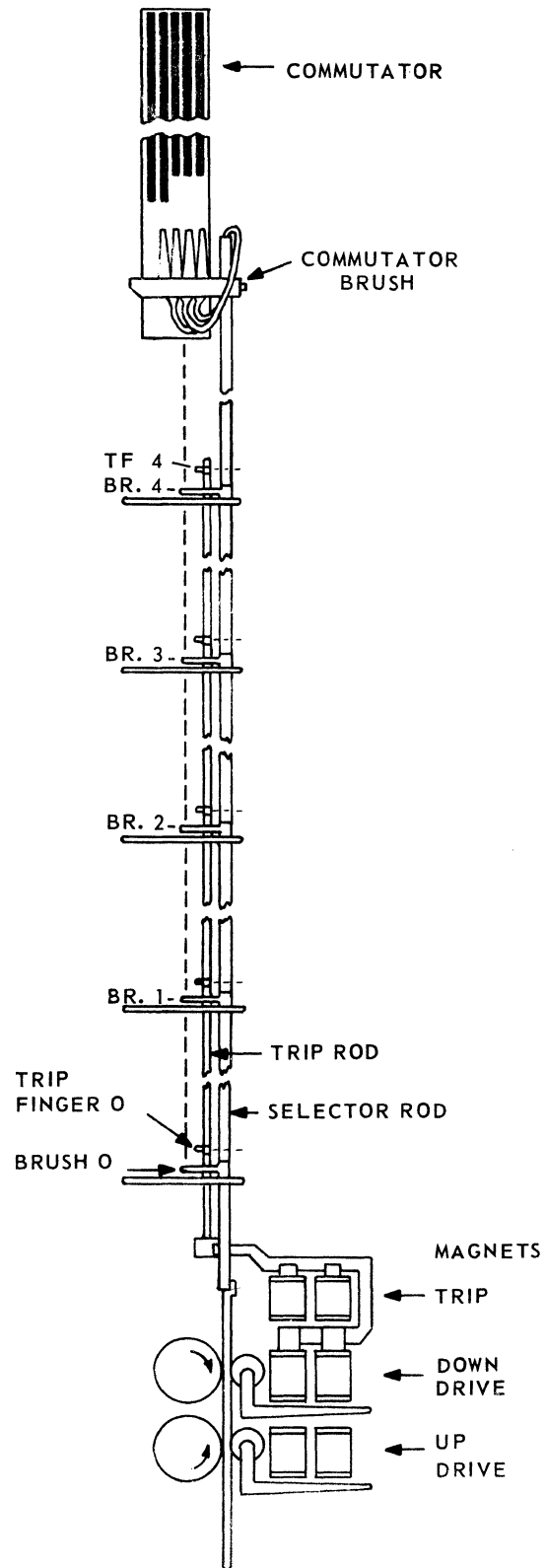
Figure 5-3 Selector Rod, Drive Mechanism, and Clutch Assembly

down. A spring pawl just above the upper roller of the clutch drops into notches punched in the rack, which can be seen in Figure 5-4, and prevents the selector from falling when it has been raised. An arm on the armature of the down drive manget of the clutch withdraws the pawl when the selector is driven downward. The rack, brushes, and upper part of the clutch are clearly shown in Figure 5-4.

Corresponding terminals of the five brushes on each selector tube are connected together by wires which pass inside the tube and come out at the top where they are connected to another brush of different construction mounted at the extreme top of the tube. This brush slides on a "commutator" which consists of brass bars molded in insulating material and serving to conduct current which enters the commutator through the moving selector brushes. The commutator and the commutator brush also control electrically the movement of the selector, as will be described later. The commutator and commutator brush are shown in Figure 5-5.

The selector brushes which are shown in detail in Figure 5-6 do not normally touch the terminals, their fingers being held apart by two little hard rubber rollers which are forced between them. When the selector rises, no contact is made with any of the terminals unless one of the brushes is closed or "tripped" by withdrawing the rubber rollers which hold the brush open. One method of tripping a desired brush is described in the following. Between each selector tube and its terminals and encircled by the fingers of the brushes, is a small vertical brass rod arranged to be partially rotated by a magnet at the top of the clutch (see Figure 5-4). This rod carries five spring-mounted latches and is called the "trip rod." Either in the normal position or when full rotated, the latches of the trip rod do not interfere with the movement of the selector, but if the selector is raised to a certain point and the trip rod then rotated, one of the latches will catch on a projection of the associated brush and be held there while the other latches continue to rotate with the trip rod. This projection is attached to the hard rubber rollers which hold the brush open and any further upward movement of the selector will now cause the hard rubber rollers to be withdrawn and the brush to close and make contact with the terminals of the bank. When the selector descends again, a long trigger

attached to the hard rubber rollers strikes the framework
and restores the brush to its normally open position just
as it reaches the lowest point of its travel.

The brushes on the selector tube and the latches on
the trip rod are placed equal distances apart but the
latches are not the same distance apart as the brushes.
There is, therefore, a certain position of the selector
in which the first latch on the trip rod will, if the rod
is turned, catch the projection on the first brush but in
this position none of the other latches will catch the
projections on the other brushes, being too high.
Similarly, there is a certain position in which only the
second brush will be caught, the latch for the first brush
being too low and the latches for the other brushes being
too high. This is shown diagrammatically in Figure 5-7.
Thus by moving the selector up to a certain point before
turning the trip rod, any one brush on that selector can
be tripped at once. By this plan any terminal in any of
the five banks can be reached by the selector although the
total travel of the selector is only the height of one
bank.

On the line finder frame a different method of
brush tripping is used. Here any one of the thirty
selectors on either side of the frame may rise in
response to a start signal from the subscribers line,
however, once selection has started, only one elevator
can updrive. In this case the trip rods are mounted
horizontally at the bottom of each of the 10 banks. The
trip fingers are so located that when a trip magnet
operates, the fingers swing over the trip levers of all
the idle finder brushes in the bank in which the
subscribers line appears. Any normal elevator if then
made to rise, will have the plunger of that brush pulled
out, allowing the brush to make contact with the bank
terminals as the line finder rises. The other brushes on
the rod, not being tripped, do not touch the bank terminals.

B. SEQUENCE SWITCH

The circuits which control the movements of panel
type selectors are necessarily complicated and their
operation requires the making and breaking of a large
number of connections. Some of these connections are
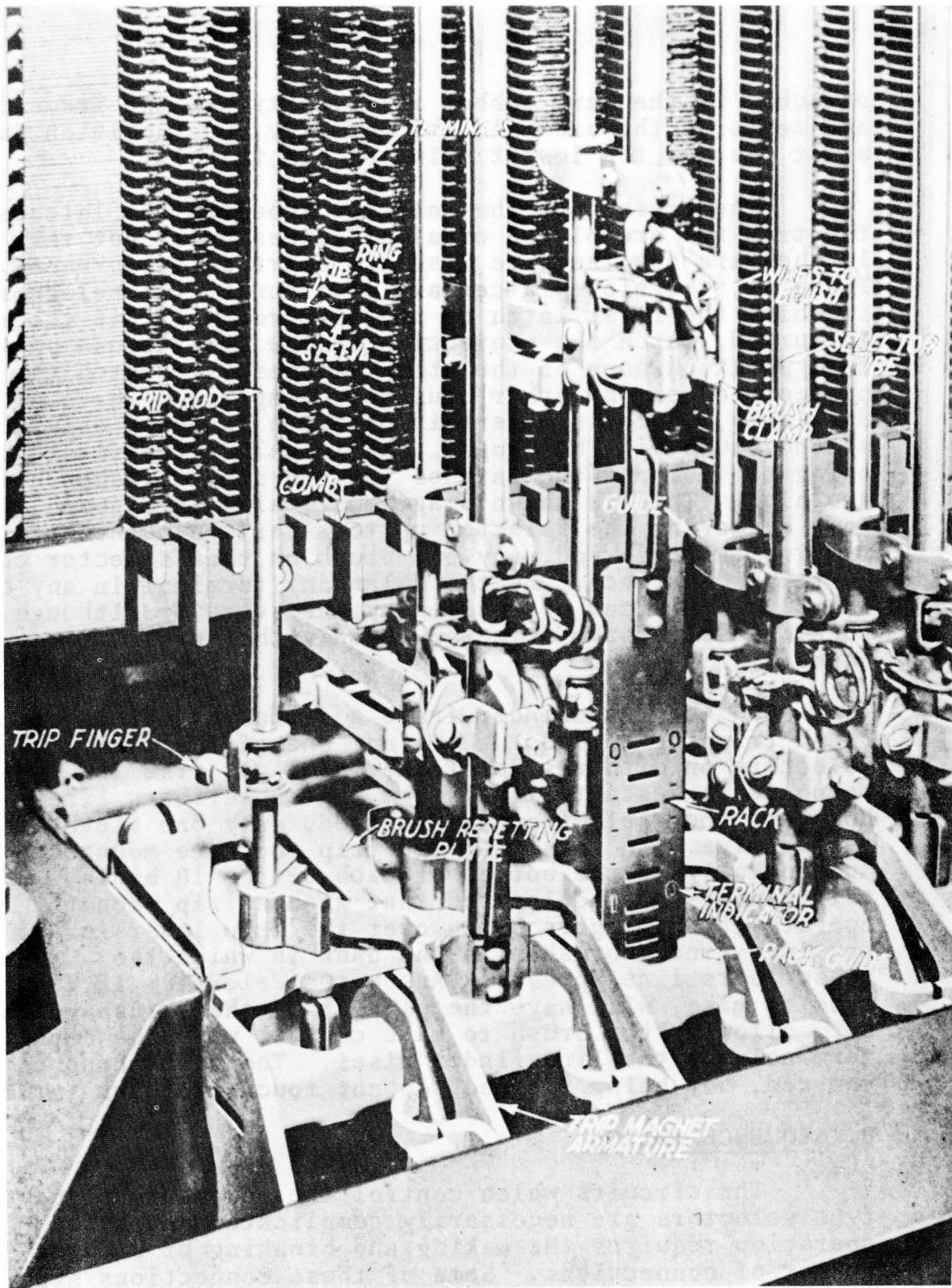established or broken by means of relays. To reduce the
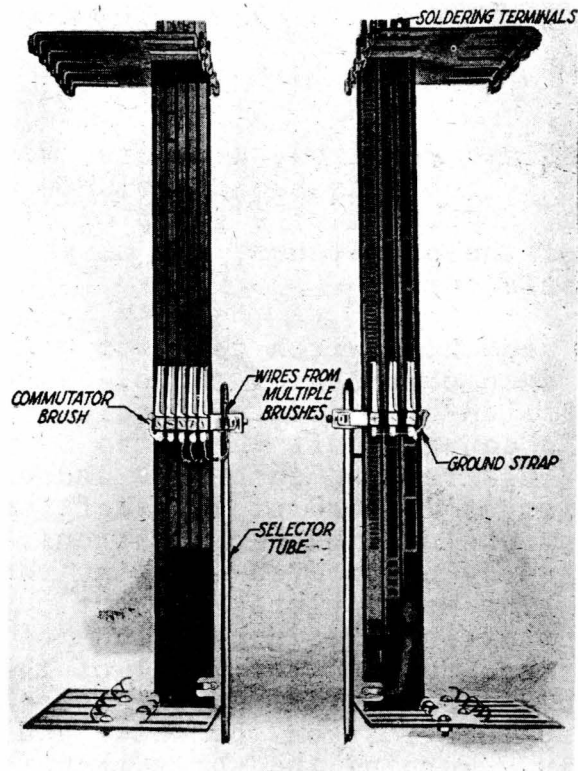
Figure 5-4 Panel Type Selecting Mechanism

Figure 5-5 Panel Commutator Mechanism
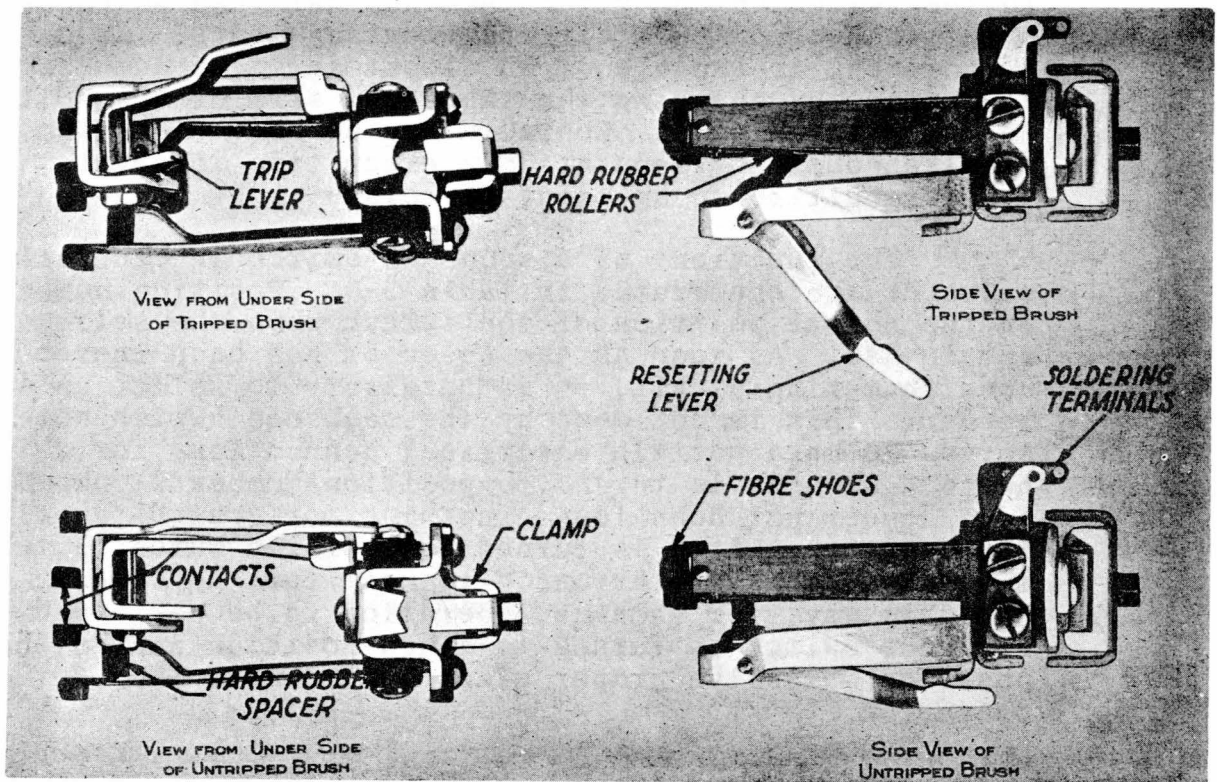
Figure 5-6 Panel Brush Mechanism

number of relays required, a special form of switch called a "sequence switch" has been developed which, in general, performs the functions of a group of relays. Figure 5-8 shows one of these switches, one of which is associated with each selector.

The sequence switch consists of a number of discs or "cams," each composed of two plates of metal riveted one on each side of a disc of insulating material and all mounted on a square shaft which can be revolved. Four contact springs rest on each disc and a fluted cam with a spring roller at the end of the shaft serves to hold the shaft in any one of eighteen positions. These positions are indicated by a numbered wheel at the opposite end of the shaft. The metal plates are cut out with irregular notches so that in certain positions of the shaft certain contact springs rest on the metal of the plates and others on the insulating material; while in other positions, different springs rest on the metal and the insulation, respectively. Turning the shaft therefore, serves to make and break the connections between contact springs in various combinations. As one of these switches will accommodate as many as 24 cams, each of which has four contact springs, there may be 96 separate wires connected to the switch which by turning the shaft can be connected or disconnected in 18 different arrangements. Each arrangement is capable of an almost infinite number of variations by changing the shape and size of the notches in the metal plates. Contacts may be made or broken simultaneously or separated by exact time intervals, which is difficult to do by means of relays.

The functions of a sequence switch in controlling a selector are enumerated in Table 5-1. Position number 1 is the normal position of the switch when the selector is not in use. As soon as the selector has been chosen to be used in making a call, it is necessary to select an idle sender. This is not done by the sequence switch but it serves to make certain electrical connections for this purpose when it is turned to position Number 2. Until the idle sender has been found, nothing more can be done; so the sequence switch is turned to position Number 3, where the connections are arranged to wait for the sender. In the same way, for each new operation to be performed, the sequence switch is turned to a new position and in that position makes the proper electrical connections for that operation.
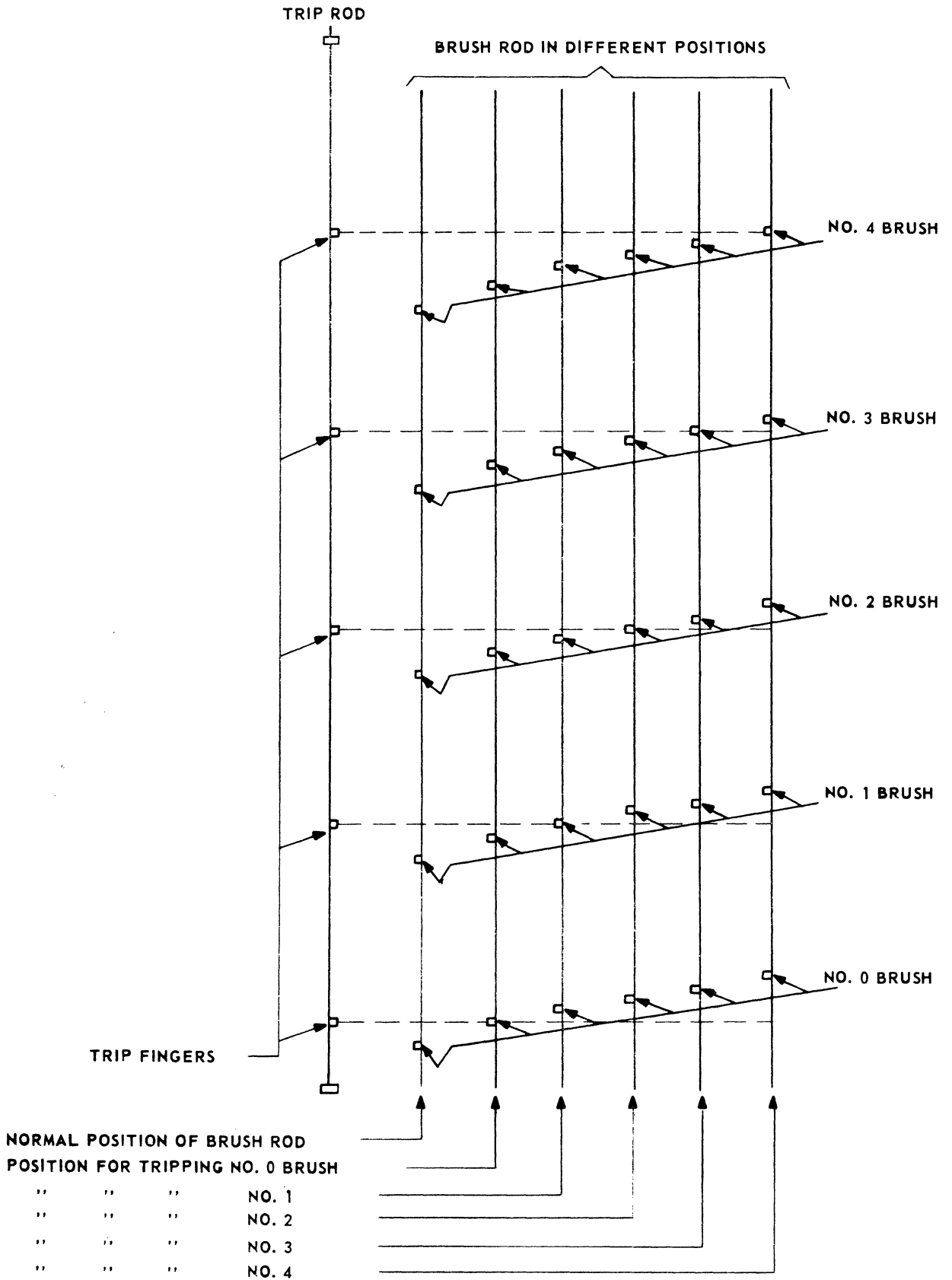
Figure 5-7 Brush Selection
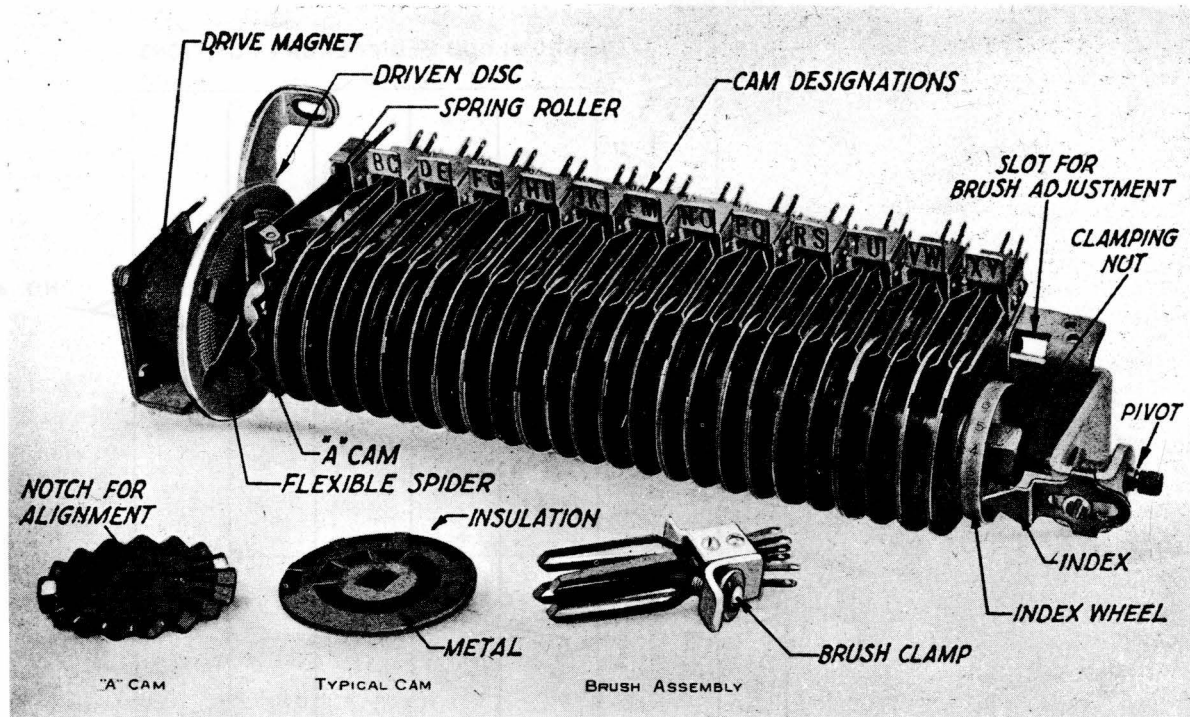
Figure 5-8 Sequence Switch

The sequence switch is turned by a friction drive mechanism at the end of its shaft. Next to the fluted cam is an iron disc mounted on a flexible bronze spider. With the sequence switch mounted on the framework, this disc stands close to but not touching a horizontal iron disc on a vertical brass shaft which is constantly revolved by the same motor which drives the cork covered rollers for the selector drive. Close to the first disc is an electromagnet. When current is applied to this magnet, the flexible mounted disc is drawn against the revolving disc and the sequence switch shaft is driven around by friction. The current on the magnet is maintained by a contact spring on the fluted cam which does not allow the switch to stop until it falls into an insulated notch in the fluted cam. It is only necessary, therefore, to put current on the magnet momentarily and the switch will revolve to the next position at which there is a notch in the fluted cam. If there is no notch in a position, the switch will not stop in that position. Each time the switch stops it is necessary to apply current momentarily to the magnet to make it turn to the next position.

TABLE 5-1

DISTRICT SEQUENCE SWITCH

Position	Corresponding Circuit Condition
1	Normal.
2	Selecting an idle sender.
3	Waiting for sender.
4	Selecting brush.
5	Waiting for sender.
6	Selecting group.
7	Waiting for relays.
8	Hunting idle trunk.
9	Waiting for sender.
10	Selection of brushes, groups, etc. beyond the district selector.
11	Waiting for sender.
12	Talking (nonloaded trunk).
13	Talking (medium-loaded trunk).
14	Waiting for operator ·to answer.
15	Talking to operator.
16	All trunks busy.
17	Operating message register.
18	Returning apparatus to normal.

5.3 EQUIPMENT ELEMENTS

The switching network, of the Panel System, consists of line finders, district and office frames, and incoming and final multiple banks.

A. LINE FINDER FRAME

The line finder frame provides a means of associating subscribers' lines with central office equipment used in establishing connections. The frame consists of ten multiple banks each of which has a capacity of forty lines. This is known as a 400-point frame. An earlier frame made provision for 300 points but is no longer used. Subscribers' lines are terminated on the multiple banks and have access to selectors. Traffic density through the frame is determined by the calling pattern of the subscribers on the frame. It is desirable, then, to provide a flexible pattern of selectors to the

400 lines. This is accomplished by providing an arrangement of splitting the banks and allowing the 400 lines to have access to twenty, twenty-eight, forty, or sixty selectors.

With many lines being served by few selectors there is a need for some preference arrangement on the line finder frame. To accomplish this, the multiple bank is split in the center and a reversal is inserted between the two halves of the bank. The split forms two subgroups, A and B, and half of the selectors serve each subgroup. The reversal in the bank changes the preference of the subscribers' line in each subgroup. He may be last preference in subgroup A, but he would have first preference in subgroup B. Figure 5-9 shows a line finder bank split into subgroups A and B served by sixty selectors. Figure 5-10 shows other possible arrangements of the line finder group.

ARRANGEMENT OF MULTIPLE BANK USED FOR TERMINATING 400 LINES PER FRAME
400 LINES MULTIPLED BEFORE A MAXIMUM OF 60 LINE FINDERS
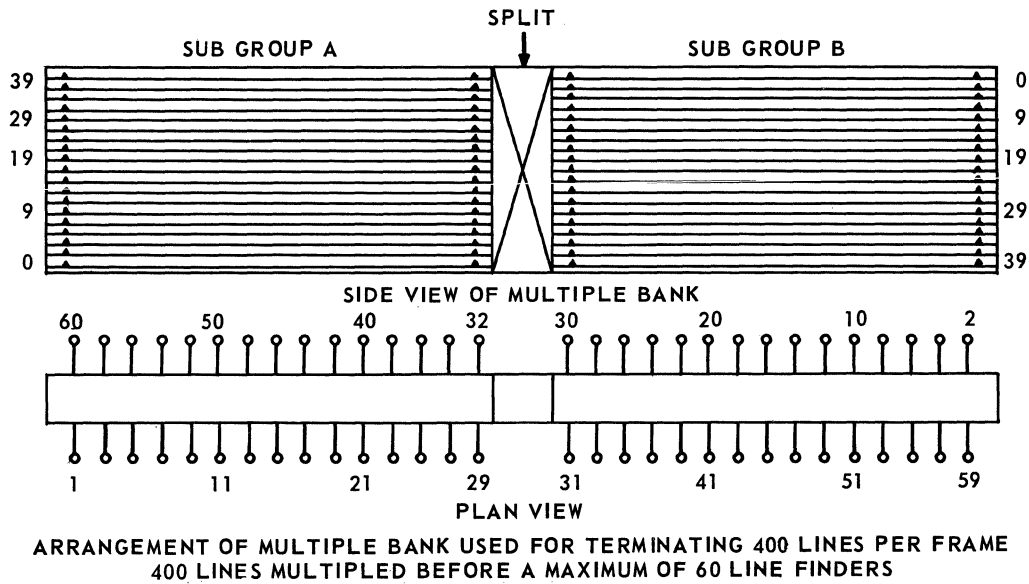
Figure 5-9 Line Finder Group

ARRANGEMENT OF MULTIPLE BANK USED FOR TERMINATING 800 LINES PER FRAME
400 LINES MULTIPLED BEFORE A MAXIMUN OF 28 LINE FINDERS

ARRANGEMENT OF MULTIPLE BANK USED FOR TERMINATING 1200 LINES ON TWO FRAMES
400 LINES MULTIPLED BEFORE A MAXIMUM OF 40 LINE FINDERS
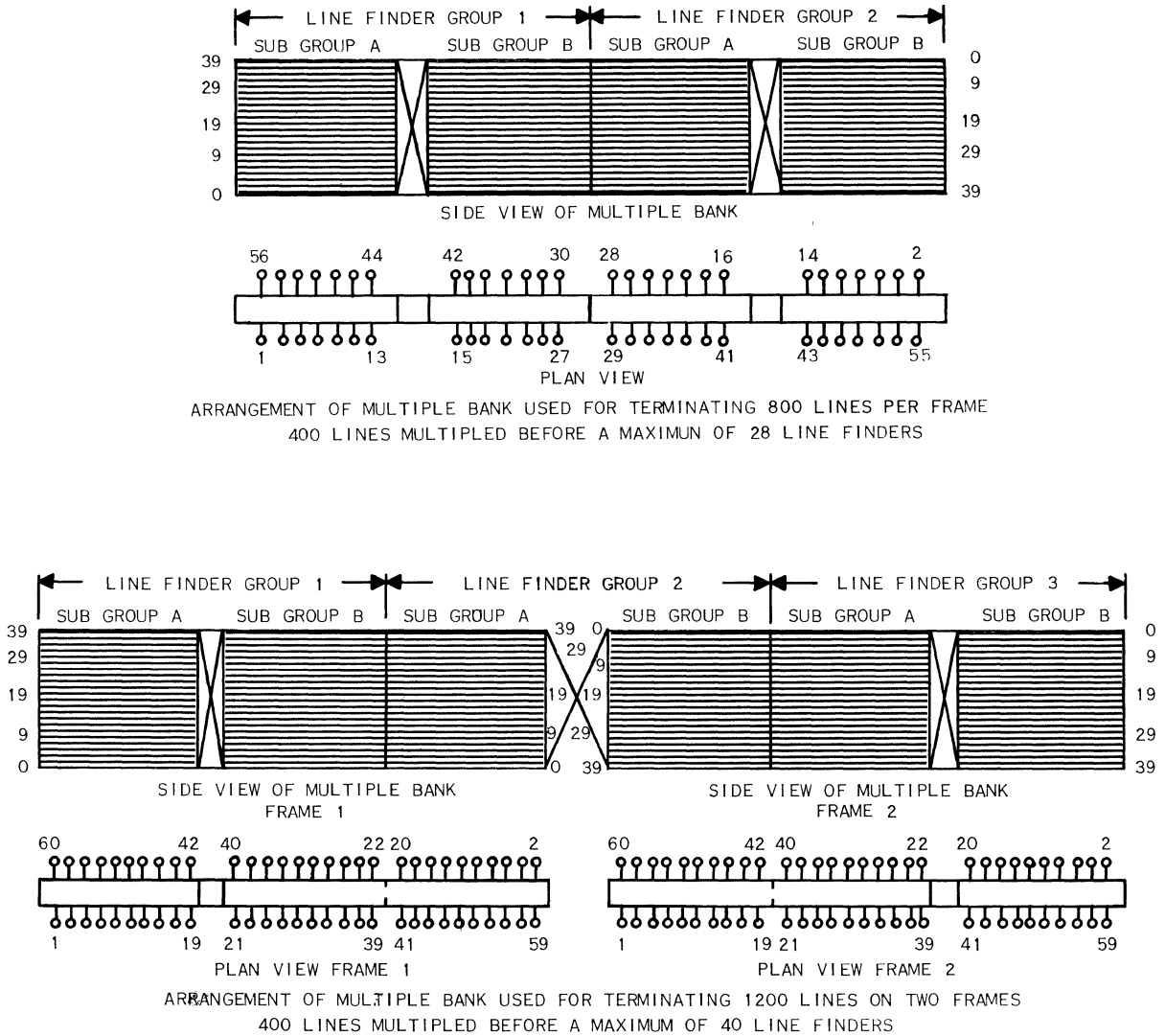
Figure 5-10 Arrangements of Line Finder Multiple Banks

B. DISTRICT FRAME

The **district frame** provides the proper routing for the originating call. At this frame appear trunks to other offices, to operator or desk positions, or to office frames containing trunks to other offices.

5.15

The district frame consists of five multiple banks of 100 terminals per bank and has a capacity for 60 selectors together with the associated mechanism. Each bank is made up of ten sets of terminals consisting of eight sets of 11 terminals each and two sets of six terminals each. The last terminal in each set is wired as an overflow terminal, leaving 90 terminals in each bank available for assignment as trunks or paths. In case more than ten trunks are required for a trunk group the overflow terminal is so wired that it will test busy instead of giving an overflow. In this way, it is possible to establish trunk groups of more than 10 trunks and to arrange for a selector to hunt over the entire group for an idle trunk. Figure 5-11 illustrates a district frame trunk assignment in an office without office frames.

TO OPERATOR AT
SPECIAL "A" BOARD
TO INFORMATION DESK

TO FRANKLIN C.O.

BANK 4

TO METROPOLITAN
TANDEM TOLL OFFICE

10 TRUNKS

BANK 3

TO SPRING C.O.

TO WORTH C.O.

OVERFLOW TERMS.
BUSY
OVERFLOW TERMS.
OPERATIVE

LOCAL TRUNKS
TO INCOMING SELECTORS
IN THIS OFFICE

BANK 2

PERM. SIG. HOLDING LINES
TO WIRE CHIEF

5 TRUNKS
5 TRUNKS

TO CORTLANDT C.O.

BANK 1

TO OFFICE SELECTORS
FOR OFFICES IN GROUP 2

TO LONG DISTANCE OPERATOR

TO CANAL C.O.

BANK 0

TO OFFICE SELECTORS
FOR OFFICES IN GROUP 1

Figure 5-11 Terminal Banks of District Frame

C. OFFICE FRAME

Office frames are installed to provide additional outgoing trunk capacity when the requirements exceed the capacity of the district frame. The capacity of the district and office frames as well as the provision of trunk and overflow terminals within the banks, is similar. Office frames are separated into a number of groups known as office multiples. Each office multiple contains outgoing trunk capacity to a particular group of offices and consists of one or more office frames. The number of office multiples provided is dependent on the number of offices to be served and the number of trunks required to those offices. In large exchanges it may be necessary to provide several office multiples with a number of office frames in each multiples. Figure 5-12 shows the trunking between district and office frames.
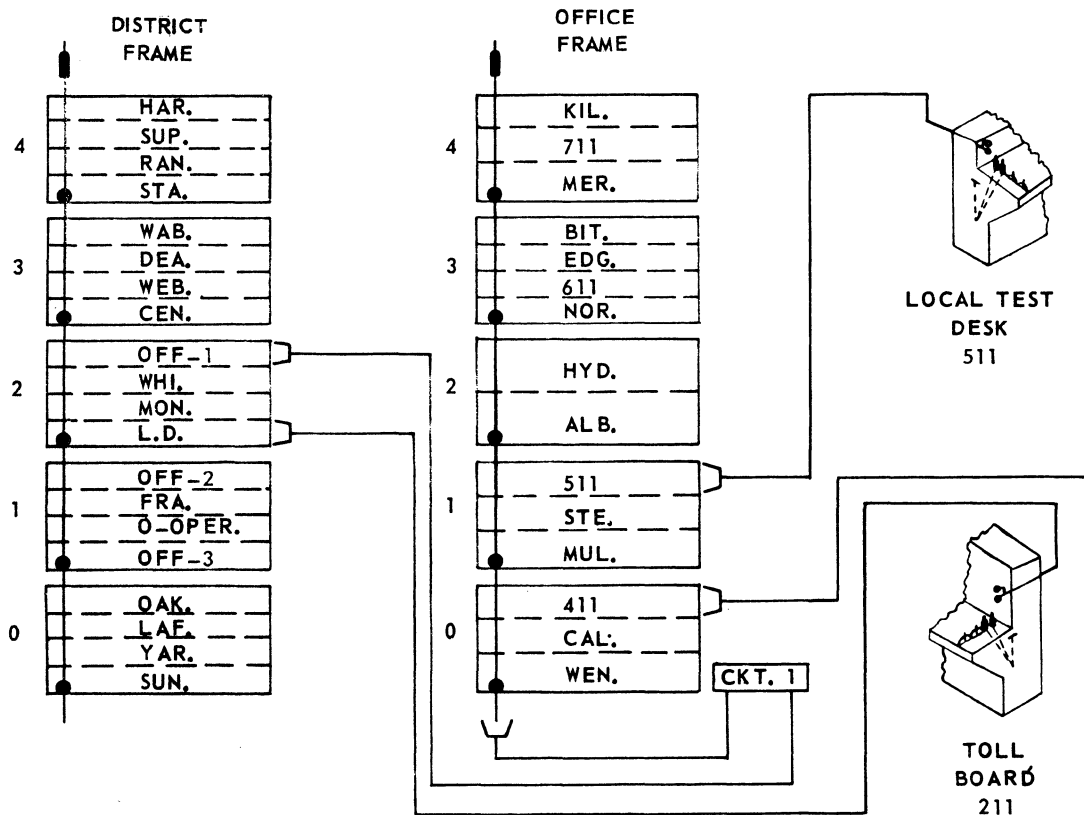
Figure 5-12 Trunking Between District and Office Frames

D. INCOMING FRAME

The purpose of the incoming frame is to make connection between a path or trunk incoming from a dial or manual office to equipment serving a particular 500 numbers. It also supplies the proper ringing current to ring the called station when the line has been selected on the final frame. This frame is similar to the district frame in that it contains five banks of 100 terminals per bank and capacity for 60 selectors. It differs, however, in that each bank is made up of four groups of terminals consisting of 24 trunk terminals and one overflow terminal. Thus, 500 terminals are arranged to provide 20 groups or choices, each of which has access to equipment serving 500 numbers, or a maximum capacity of 10,000 numbers or terminals for a full sized unit. Figure 5-13 shows the trunking between incoming and final frames. Due to circuit requirements, separate groups of incoming selectors are provided for handling calls from dial, manual and toll offices.

Figure 5-13 Trunking Between Incoming and Final Frames

E. FINAL FRAME

The final frame is the last step in the connection
of a call to a dial telephone. Its function is to make
a connection between the path from the incoming frame and
the terminal of the called station. This frame is similar
to the district and incoming frames in that it contains
five banks of 100 terminals per bank and capacity for
60 selectors. However, instead of the multiple banks of
trunk terminals, this frame has multiple banks of
subscribers' terminals. On district, office and incoming
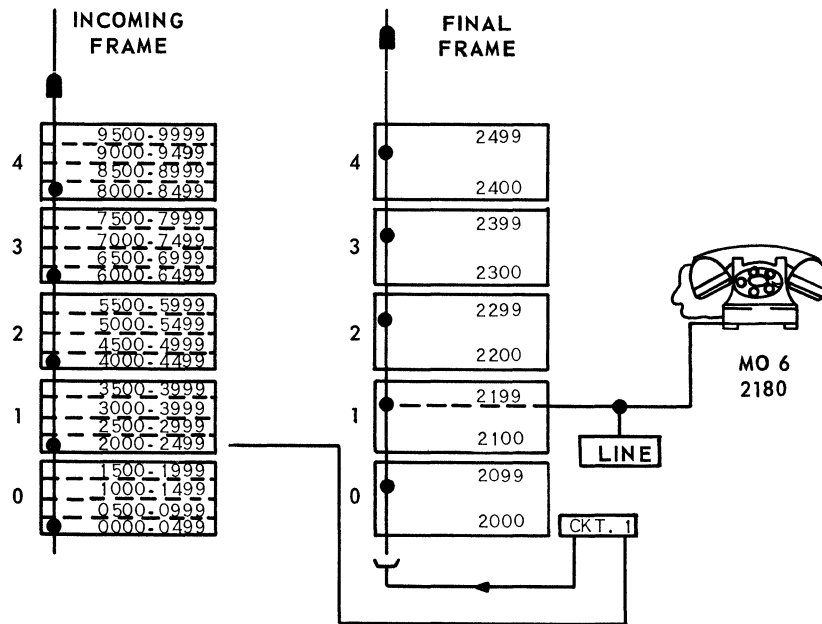frames the selector picks an idle terminal in a
particular group while on the final frame, the selector
picks a particular terminal corresponding to a subscriber's
number; that is, it is of the particular-terminal selecting
type rather than of the hunting type. In the case of a
P.B.X. or multi-line group the wiring is so arranged that
the final selector selects the first idle trunk in the
P.B.X. group.

Normally, one final frame with capacity for
60 final selectors is sufficient to handle calls for a
particular group of 500 numbers. However, more than one
frame can be provided if conditions require more than
60 selectors. For example, if more than 60 and less than
90 final selectors are required, one final frame bridged
with one-half of another constitutes a final choice.
Similarly, two final frames can be bridged together,
giving a maximum of 120 final selectors for a choice.
Also, if less than 60 selectors are required, two-thirds
or one-half of a frame can be utilized to make up a final
choice.

F. SENDER CONNECTORS

(a) Sender Selector

In older offices, a branch of the line
finder-district selector circuit terminates on
the brushes of a rotary type switch known as a
"sender selector." This switch is provided
with a semi-circular multiple bank, upon the
multiple contacts of which terminate trunks
leading to a maximum group of 22 senders. The
purpose of this switch is to select an idle
sender and associate it with a line finder-
district selector unit (that is, with the

calling line) when a call is initiated. The group of senders is multipled through the banks of as many sender selectors as will constitute a load for the sender group. The sender selector is of the "stay-put" type, that is, it does not return to normal after it has completed its functions. When it is used on a second call it starts to test for an idle sender at the point where a sender was connected on the previous call. Figure 5-12 shows the relative position of the sender selector in the train of selection.

(b) Panel Link Frame

A later development in the panel system utilizes a link in place of a sender selector as a means for associating a sender with a line finder-district selector unit. The link permits the use of larger groups of senders with consequent reduction in the total number of senders required. The earlier type or rotary link gives access to a group of 44 senders while the latest type of panel link gives access to a group of 100 senders. The general operation of both types is similar, the rotary type utilizing rotary switches and the panel type utilizing selectors and multiple banks.

The link is a double-ended type of selector and is mounted on a link frame which has capacity for 30 links. One end of the link has access to a sender selector bank with capacity for 100 sets of terminals and the other end has access to a district finder bank with capacity for 20 or 40 sets of line finder-district selector circuits. Both of these banks are mounted on the link frame. The smaller size district finder bank is used for line finder groups of 28 or 40 units while the larger bank is used for groups of 60 or 80 line finders.

G. SENDER

The sender is the unit of equipment which controls the establishment of a connection through the required selectors and trunks. Each sender comprises relays and other apparatus mounted in metal cabinets and 11 rotary switches and 6 sequence switches mounted outside the cabinet. Sender operation is electro-mechanical.

As previously mentioned, in the panel system, direct control of the switches by the subscriber's dial is abandoned. It is the function of the sender - 1) to record and hold the number dialed, 2) convert it into terms of selector, brush and group selections and 3) control the selectors in accordance with them. The sender, therefore, is the major control element of the panel system.

When a sender has been connected to a subscriber's line through the link frame, dial tone is returned to the subscriber which signals him to start circuit impulses which operate the line relay and, through its contacts, a chain of sensitive relays. While these relays are able to follow the rapid pulses, they do not have enough contacts to store them. At the end of each train of pulses which comprise a digit, the information dialed is transferred to a train of register relays and the counting relays return to normal to follow the next train of pulses. As many as eight trains of register relays are provided to accommodate a 3-digit office code, a 4-digit number and a party letter, and each train is called in successively to record and store the successive digits.

When the first three digits representing the office code have been dialed, recorded and stored, the sender calls in a decoder. The decoder looks at the first three digits and determines the location of the called office trunks on the district frame. This information is passed back to the sender over six relay control leads. While this operation was in process, the sender was accepting the remaining digits from the dialing station.

H. DECODER CONNECTOR FRAME

The decoder completes its operations in about 0.3 seconds so that one decoder may serve many calls if it is connected into a circuit only during the time it is

required. This is accomplished by the decoder connector. Dependent upon the number of senders and decoders, arrangements are provided so that all senders have access to all decoders on a preference basis. This prevents loading up one decoder. The connections are completed through relay chains and are released upon completion of the decoder function.

I. DECODER

As previously discussed, the sender is connected to the decoder and submits to it the three-digit office code. The office code is registered and checked in the decoder and then, through a translating relay chain, a particular route relay is operated, one of 800 possible choices. The route relay in operating, grounds six leads which terminate on the cross-connecting frame and which are designated by the letters "CL," "DB," "DG," "OB," "OG," and "CR." These indications are transferred back to the sender where they are locked into the sender register. The sender then sends a disconnect signal which results in restoring the decoder and disconnecting it.

J. EQUIPMENT FOR DIRECT DISTANCE DIALING

(a) The Auxiliary Sender

The auxiliary sender is a wire-spring relay equipment unit, four of which mount in a single frame. It is used in a decoder panel office to provide the Direct Distance Dialing feature for the subscribers. The auxiliary sender registers the last two digits on a 10-digit DDD call, thus supplementing the eight-digit capacity of the subscriber sender in the Panel office. When the outgoing trunk is selected, the auxiliary sender tests to make sure a remote incoming sender is attached. It then signals the subscriber sender to pass the eight digits stored in it on a PCI basis to the auxiliary sender. The auxiliary sender outpulses to the distant office on a multifrequency basis. With the completion of outpulsing, it notifies the subscriber sender so that both senders may release. Figure 5-14 shows a block diagram of auxiliary senders applied to a Panel Office.
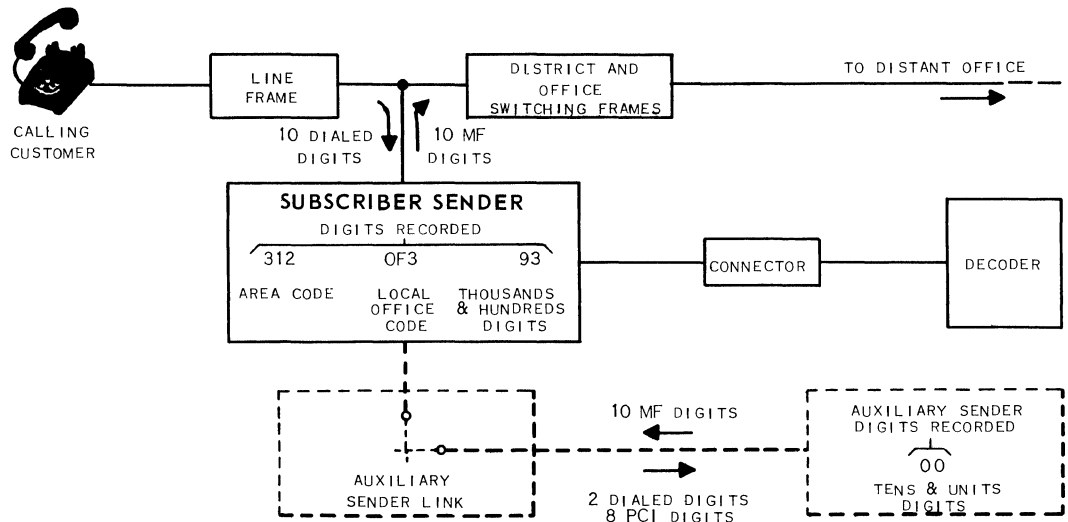
Figure 5-14 Block diagram of auxiliary sender applied to a panel central office.

(b) The Auxiliary Sender Link

      The auxiliary sender link provides the connecting path between any one of a maximum of 100 subscriber senders and their associated auxiliary senders. This frame may be partially equipped in individual units, each with capacity for ten subscriber senders and, when fully equipped, consists of ten auxiliary sender link units. An auxiliary sender link unit consists of a 200-point, 6-wire crossbar switch with associated relays. The senders appear on the verticals of the unit, two verticals per sender. The auxiliary senders appear on the horizontals and may be multipled over as many link units on as many link frames, as the auxiliary sender traffic will permit.

      To provide a certain degree of service protection, the senders in the same sender group should be spread over two or more

auxiliary sender link frames. Duplicate
control equipment is normally provided so that
trouble in one frame will not affect service
to senders appearing on the other link frame(s).
It is also possible to split the senders on a
particular auxiliary sender link frame between
two groups of auxiliary senders by providing
control circuits for each group.

5.4 COMPLETION OF A FULL MECHANICAL CALL

Figure 5-15 is a block schematic diagram of all the
elements of the panel system required to complete a call
on a full mechanical basis.

The removal of the receiver from the hook operates
the line circuit which in turn operates the line finder
trip circuit, causing a horizontal trip rod on each side
of the frame, opposite the bank in which this line appears,
to operate. Two trip rods are required because the line
finders available to any subscriber are on both sides of
the frame and the trip rod must engage with the proper
brush of any line finder that the link circuit may have
previously selected to handle the call.

As soon as the trip rod has operated, the trip
circuit operates the start circuit, which operated the
up-drive of the line finder clutch through the wiring of
the links associated with this group of 400 subscribers'
lines and the line finder-district wiring. The selector
rod rises, tripping the brush opposite the bank in which
the subscriber's line appears.

As soon as the selector rod brush has been tripped,
the start circuit is released for other serice. In any
particular group of line finders only one finder can
start up-drive at a time.

After the line finder has been started it continues
upward until the tripped brush makes contact with the
terminals of the calling line which causes its upward
travel to stop. When the line finder started upward, a
sender selector on the link frame also started upward to
hunt for an idle sender, if not already resting on one.

The sender immediately sends dial tone through the sender selector and district finder of the link circuit, through the line finder-district wiring and line finder to the calling subscriber. The subscriber on hearing dial tone proceeds to dial the office code and number which is registered in the sender.

As the subscriber dials, the pulses are received by pulse control relays and as soon as each train or series is completed, the pulses control relays which cause the register relays to register the number of pulses counted by the pulse control relays. As each set of relays make their registration, they close a path to make the next registration take place in succeeding register relays.

As soon as the office code letters have been registered and the decoder connector which serves this sender is idle, the decoder connector is caused to select an idle decoder. After the connector has found an idle decoder, it connects the code letters relays through to the decoder for the purpose of informing it of which office is being called.

When the decoder has been notified which office has been called, it registers in the sender a record of the position of the terminals of trunks to that office. This record appears on the district brush, district group, office brush, and office group (marked DB, DG, OB, and OG), groups of relays via the decoder connector. As soon as the decoder outpulses DB to OG it causes itself to be released.

During the time the decoder is used and the time taken for the selections described later to be made, the subscriber continues to operate his dial until the desired number has been completely dialed. As each code letter or digit is dialed the pulses are counted and locked into the next and proper register relays. After the decoder has been disconnected from the sender enough information has been received to start selecting a trunk to the desired office, so the selection control causes the district to start brush selection, governed by the sender's selection circuit through the setting of the DB relays.

There are three steps taken by the district selector in selecting an idle trunk; i.e., first, the selection of the brush on whose bank the trunks to the called office
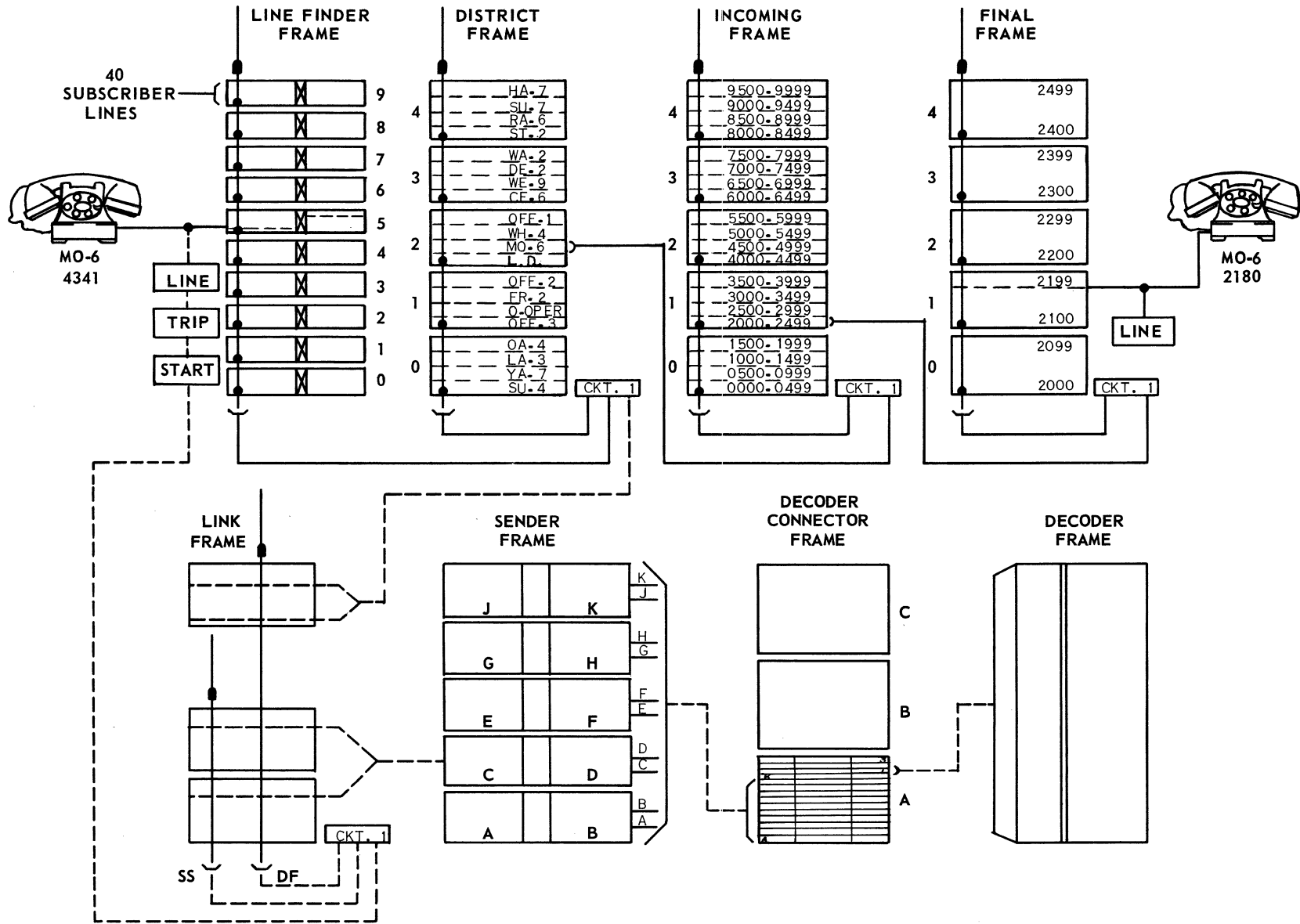
Figure 5-15 Plan of Direct Mechanical Selection

appear (called district brush selection); second, the
passing over all trunks to other offices that may appear
lower on the bank (called group selection); and third, the
picking of the first idle trunk (called trunk hunting).

The sender having found from the decoder which
brush to trip causes the district elevator to up-drive to
a position where a trip finger on the trip rod will engage
with the trip lever of the brush to be tripped when the
trip rod operates. In order that the sender can exactly
control the height of rise by the elevator, the progress
for brush selection is indicated to the sender by means
of "A" commutator segments at the top of the selector.
Figure 5-16 shows the "A" segments of the commutator used
on the district selector.

As the elevator is moved up under control of the
sender, the "A" commutator spring, moving with it, passes
over "A" commutator segments. The "A" spring when sliding
over each segment causes a pulse to be sent to the sender,
whose selection control circuit counts or registers the
pulses. As soon as the sender receives as many pulses as
are recorded to be needed for the DB selection (DB relay
group set by decoder) it stops the up-drive of the
district elevator. The clutch pawl engages with the rack
and upon operation of the trip magnet the proper trip
finger engages with a brush trip lever. At this time the
brushes have not yet come opposite any bank terminals but
have risen only far enough for brush selection. After
brush selection the elevator continues for other selections.

Group selection is also governed by the
registration in the sender from the decoder through the
use of commutator segments and the selection control
circuit. The metal commutator strip "B" (Figure 5-17) is
used for group selection and is mounted with commuator "A"
and other commutator strips in the surface of the
insulating base of the commutator. It has a number of
segments 0, 1, 2, etc., corresponding to the group or layer
division of each multiple bank. The length of the
commutator strip "B" corresponds to the height of the
100 terminals in a multiple bank, and the distance between
the first sets of terminals of adjacent multiple layers
or groups. This is illustrated in Figure 5-17, where the
commutator is placed opposite a bank of multiple terminals
so as to show the relation between the first terminal of

each layer or group and their respective commutator segments. Commutator brush "B" is arranged to make contact with these segments as the elevator moves upward for group selection. Each time the spring makes contact with a segment it sends a pulse to the selection control circuit of the sender, where it is counted or registered, and when the number of pulses equal the number recorded as necessary for district group selection in the sender by the decoder, the up-drive is stopped. This leaves the tripped brush in contact with the first trunk in the group to the desired office. As soon as the brush reaches the level of the first trunk in the desired group it comes under the control of the trunk hunting circuit and continues to rise until it reaches the first idle trunk in the group.

Some offices have their trunks appear in the groups on the banks of an office frame, in which case a trunk to an office circuit is selected by the district office. After the office selector circuit has been picked, the sender directs the office selector into contact with a trunk to the desired office in exactly the same manner as a district selector is directed into contact with a trunk. The sender for office selections uses the registration received from the decoder by the OB and OG groups of relays.

The incoming selector circuit which the district (or office) selector has chosen may be on a frame at the same office in which the call originated or any other dial system office.

For terminating connections, the subscriber's lines are multipled on the banks of final frames in groups of five hundred. This makes it necessary that a final selector be used that has access to the group of 500 lines where the called line appears. The incoming selector chooses the selector on the proper final frame.

As there are twenty final choices of usually one frame each in a complete central office unit of 10,000 lines, the terminals on the incoming banks are divided into twenty layers or groups, four groups to each bank. There are 100 terminals in each bank; therefore, in each group on an incoming bank there are twenty-five terminals, twenty-four of which are terminals of trunks to final selectors, the other being an overflow set of terminals. In order that connection can be made to terminals in any one of the five banks, brush selection must be made.
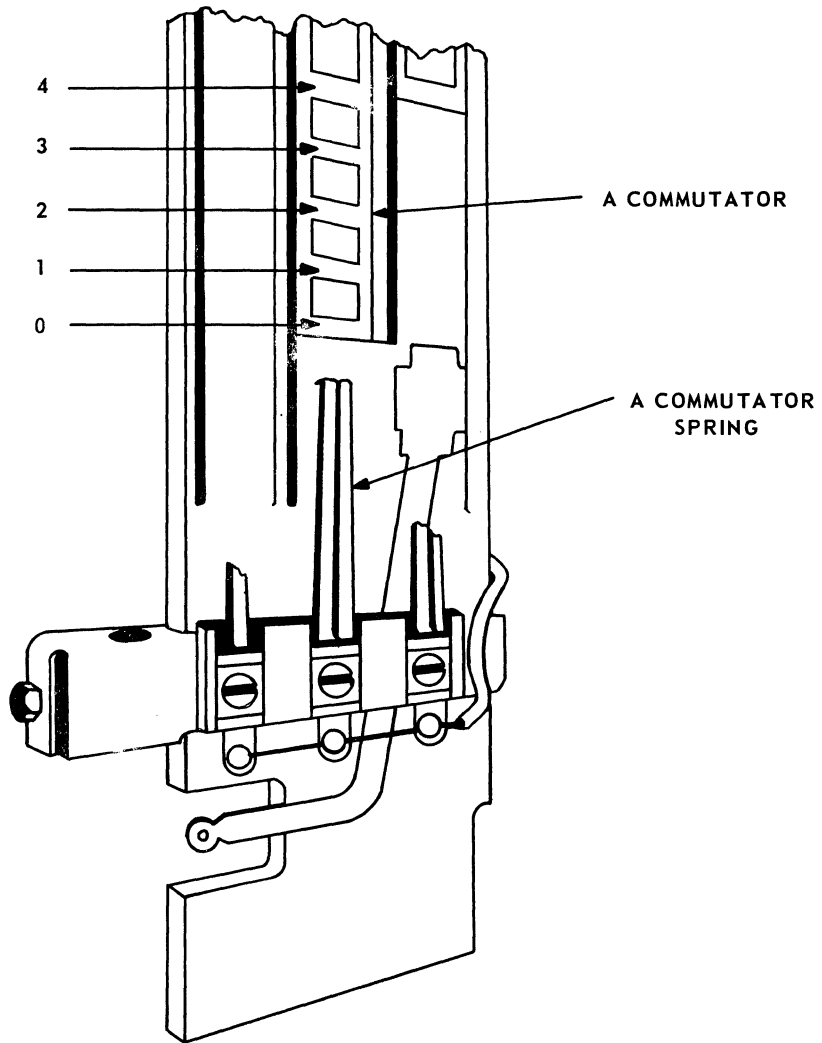
Figure 5-16 "A" Commutator Segments

The sender, as soon as an idle trunk to an incoming frame is found, registers the number of the brush and group to be used on the incoming frame on its IB and IG groups of relays as determined by the setting of the TH and H pulse registering relays. The selection control circuit can then direct the incoming elevator up for brush selection, counting pulses from the "A" segments just as it did for district brush selection and office brush selection.

After the incoming elevator has risen far enough and stopped in position for the proper trip finger to engage with the brush trip lever, it must rise again for group selection to trip the brush and connect to the first set of terminals in the group to which the trunks to the proper final frame are connected. The selection control circuit starts the elevator upward and counts pulses, until the number received from the "B" commutator segments agrees with the registration on the IG group of relays. The method of group selection, as well as brush selection, is identical with brush and group selections of the district and office selectors, only the number and spacing of "B" commutator segments being different.

When the incoming elevator stops on the first terminals of a group, it immediately starts up again if the trunk sleeve terminal is connected to ground; which indicates that the trunk is busy. When an open condition is found on a sleeve terminal, the incoming elevator is stopped and remains in contact with that set of terminals. This leaves a connection established through which final selections now take place.

As the called subscriber's line may be in any one of the five banks, the final frame must make brush selection through use of "A" commutator segments just the same as the district office, or incoming selector does, except that the sender gets its information from the registration in the "H" group of register relays.

When brush selection has been completed the sender directs the final brush up for group or tens selection, the selected group depending on the registration in the "T" group of register relays. Tens selection is made in the same way that group selection is made on district, office or incoming selectors. The "B" commutator segments are numbered from 0 to 9 and are so positioned that they correspond to every tenth subscriber's line terminal
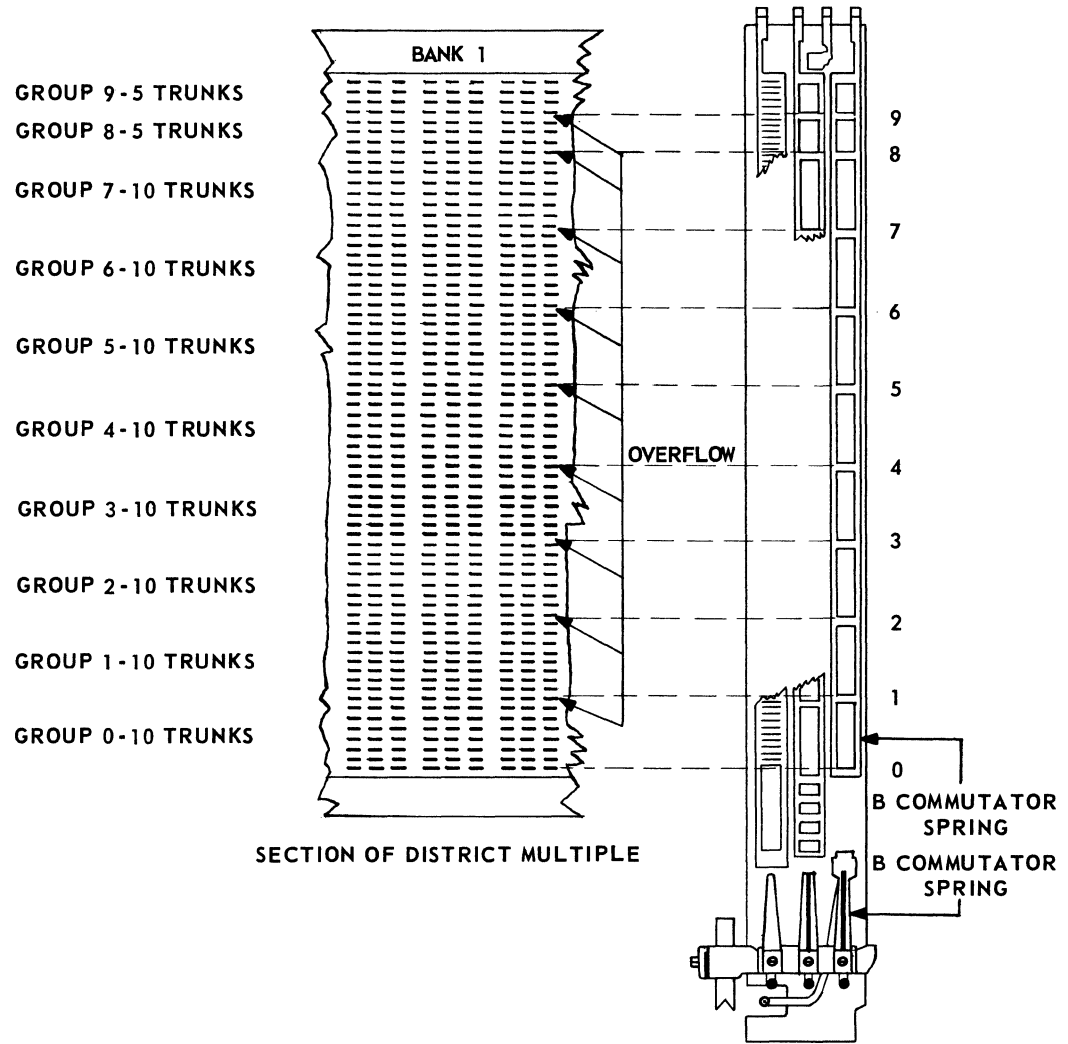
Figure 5-17 District Brush Selection

on the banks. By this arrangement when the sender has counted the proper number of pulses from the "B" commutator it stops the final elevator, leaving the tripped brush on a line whose number ends in 00, 10, 20, 30, 40, 50, 60, 70, 80 or 90. The wires to the brush are open circuited in the final wiring at this time so that such lines are undisturbed while units selection drives the elevator up again from 1 to 9 terminals if necessary for connection to the called line as determined by the units digit of the dialed number.

Units selection is under control of the sender, which counts pulses from the "U" commutator segments and when the number of pulses properly match the number registered on the "U" register relays it stops the up-drive, leaving the final selector on the called line.

When selections have been completed, the link discharges the sender and selects an idle line finder-district circuit to be used later when that link's turn to be used arrives again.

The talking path is closed between the line finder and the district selector under control of the sender just before it is discharged, completing the connection between the calling and called subscribers. Intermittent ringing current is then applied automatically by the incoming selector to the called subscriber's line until he removes the receiver.

When the conversation is finished, replacing the receivers on the hooks causes all selectors through which talking occurs to return to normal, where they await reselection for another call.