# 6

# Step-by-Step

> "*One small step for man; one giant leap for mankind.*" — Neil Armstrong, when he stepped off the LEM *Eagle* onto the surface of the moon

The Step-by-Step system is the oldest architecture of the automatic exchanges and was an extremely successful commercial system. But, because of Step's economy in small offices (Section 2.4.5), it is still found in several countries and it is only fairly recently that Step has come close to extinction inside the United States. While Step's ancient architecture inherently lacks the power of common control, Step offices have been modernized for Touch Tone and even computerized to provide some new services and modern signaling. Since Step was summarized in Section 2.5.1, the reader who is in a hurry could skip this chapter entirely. But I urge you to skim it, at least, because Step has historical value, an interesting ''cellular'' architecture (as defined in Section 2.4.1), and a novel originating-to-terminating sidedness. Even more relevant, two concepts from Step could be applied to our most modern systems.

- The process by which a call is progressively set up in the fabric, one stage for each dialed digit, carries over to modern self-routing packet-switched networks, described in Section 7.5.
- Procedures that distribute wear uniformly, like Step's *slipped multipling* wiring pattern, are useful models for modern distributed wireless LANs, where the architectural objective is to distribute power consumption uniformly [1, 2].

The overall architecture is discussed in Section 6.1 and the Strowger switch is described in Section 6.2. Three different configurations of a Strowger switch provide the implementations for three kinds of stages in the Step-by-Step fabric. These stages are the line finder, selector, and connector and they are described in Sections 6.3, 6.4, and 6.6, respectively. Digit absorbing in selectors is discussed in Section 6.5. An example of a small Step-by-Step office is given in Section 6.7 and a discussion of Step's pros and cons is found in Section 6.8. Section 6.8 begins the discussion of what I call the ''partition,'' a discussion which continues through the closing sections of Chapters 8, 11, 14, and 18.

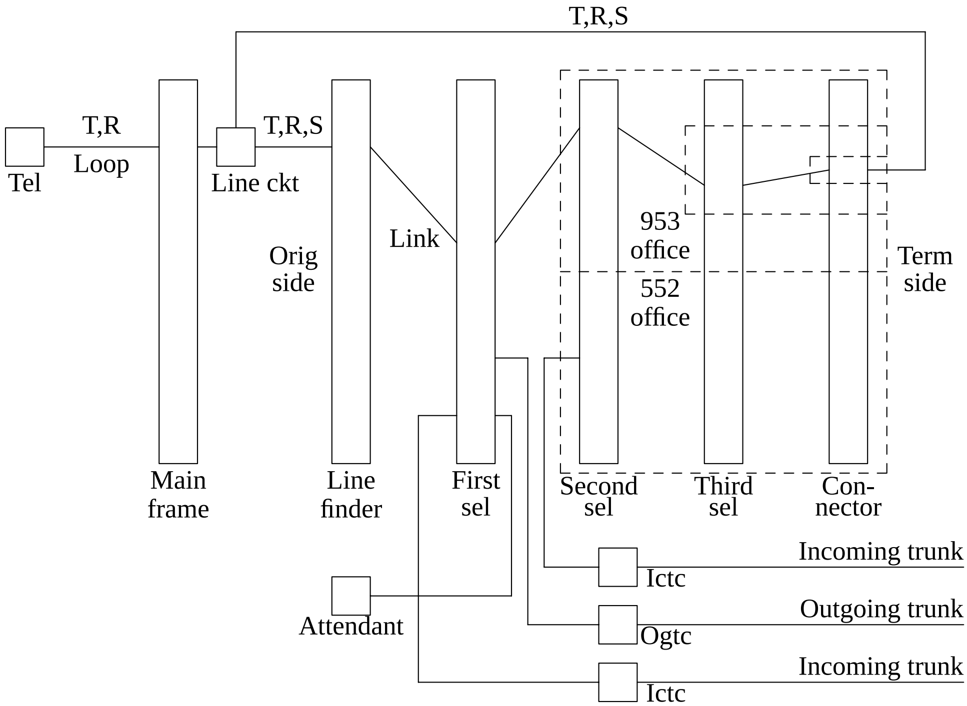


**Figure 6.1.** Step building with two offices.

## 6.1 ACHITECTURE

Step's architecture is described in this section, with details provided in later sections. A block diagram is shown in Figure 6.1 and subsections in this section describe a connection of a telephone to the system, the fabric, operation during call setup, and trunking into and out of a Step-by-Step office. Figure 6.1 illustrates the architecture of a Step-by-Step building containing two offices. Step-by-Step has a two-sided fabric, where the two sides are the *originating side* and the *terminating side.* The direction of placing a call is from left to right across Figure 6.1.

### 6.1.1 Telephone Connection

A telephone that can both originate and terminate calls must be connected to both sides of the fabric. Once a call connection is established through the fabric, with the calling party on the originating side and the called party on the terminating side, speech goes both ways over the talking path.

The tip and ring wires connect a subscriber's telephone with a line circuit (Section 3.5) in the office via the loop plant and a cross-connection at the main frame (Section 3.4). One line circuit is dedicated to each line served by the office. A third wire, the sleeve, joins the tip and ring at the line circuit, and these three wires connect to the originating and terminating sides of the fabric (Figure 3.4).

The tip, ring, and sleeve of each subscriber's originating appearance are wired from its line circuit to the input side of the *line finder* stage, as shown on the left of Figure 6.1. The location on the fabric of this originating appearance is independent of the subscriber's directory number. The tip, ring, and sleeve of each subscriber's terminating appearance are wired from its line circuit to the output side of the *connector* stage, as shown on the right of Figure 6.1. The location on the fabric of this terminating appearance corresponds directly to the subscriber's directory number.

### 6.1.2 Fabric

The first stage is called the line finder stage, shown on the left in Figure 6.1. At this stage, the subscribers' originating appearances are concentrated down (Section 5.2.5) to a smaller number of *first selector links,* wired between the output side of this stage and the input side of the *first selector* stage. Each active call uses a first selector link, for the duration of the call. Thus, the number of subscribers that are active simultaneously, on calls they originated, cannot exceed the number of first selector links in the office.

The intermediate stages of the fabric are called *selector* stages. The usual three are shown in the center of Figure 6.1. The line finder stage, first selector links, and first selector stage are common to a Step-by-Step building. The output side of the first selector stage is wired, by second selector links, to the input side of the second selector stage. The subfabric that includes the second and third selector stages and the connector stage is segmented into the offices in the building. Two offices are indicated in Figure 6.1, a 552- office and a 953- office.

The output side of the second selector stage is wired, by third selector links, to the input side of the third selector stage. The subfabric that includes the third selector stage and connector stage is segmented into thousands-groups within the offices in the building. One such segment is indicated within the 953- office in Figure 6.1. The rightmost stage of the fabric is called the connector stage. The output side of the third selector stage is wired, by connector links, to the input side of the connector stage. The connector stage is segmented into hundreds-groups within the offices in the building. One such segment is indicated within the 953- office in Figure 6.1.

### 6.1.3 Call Setup

Immediately after going off-hook, the calling party is connected, through the line finder stage to a first selector link, to the first selector stage of the fabric. This first selector stage returns dial tone back over this switch path to the subscriber, who then dials over this same path into this first selector stage. Immediately after the first selector stage receives the first dialed digit, dial tone is disabled.

The first selector stage extends the switch path to one of its outputs, depending on the digit or digits dialed by the subscriber. If the subscriber dials 0, the switch path extends to an output that is wired to an attendant, shown as the lowest output off the first selector stage in Figure 6.1. The procedure after the subscriber dials 1 is discussed in the next subsection. If the subscriber dials 2 – 9, the first selector stage waits for two more digits (usually), accepting the entire office code of the called party's directory number. If this office code represents a switching office in this building, the first selector stage extends the switch path to one of its outputs, wired by a second selector link to the second selector stage in this building. The switch path extends to that particular segment of this second selector stage that corresponds to the office code dialed by the subscriber. This is indicated on Figure 6.1 by the highest indicated output of the first selector stage, wired to the 953- segment of the second selector stage. At this point in the call setup, the switch path has reached the called party's office.

The next digit dialed by the subscriber proceeds over this switch path, on through the first selector stage, into this second selector stage. The switch path then extends to an output of the second selector stage, wired by a third selector link, to that segment of the third selector stage corresponding to the office code and to the thousands digit that was just dialed by the subscriber. The next digit dialed by the subscriber proceeds over this switch path, on through the first and second selector stages, into this third selector stage. The switch path then extends to an output of the third selector stage, wired by a connector link, to that segment of the connector stage corresponding to the office code and thousands digit and to the hundreds digit that was just dialed by the subscriber. The next two digits dialed by the subscriber proceed over this switch path, on through the first, second, and third selector stages, into this connector stage. The switch path then extends to that output of the connector stage corresponding to the called party's directory number, the called party's terminating appearance on the fabric.

There may be many variations on this theme. In a small exchange, with less than 1000 subscribers, directory numbers would only require six digits and the fabric would not have the equivalent of the second selector stage, for switching on the thousands digit. In a PBX (a Step-by-Step PBX, called the 701, was a popular system), subscribers do not dial an office code for an intraoffice call and the fabric would not have the equivalent of the first selector stage for switching on the office code. But the first stage of selectors would trunk out to the local switching center on a 9 (Section 10.4.2).

### 6.1.4 Trunking

Recall from Section 1.5 that the *sidedness* of a switching building is specified as the line side and the trunk side. However, the sidedness of the fabric in a Step-by-Step building is specified as the originating side and the terminating side. This distinction is carefully illustrated in Figure 6.1. Consider an outgoing call to another office, first by direct trunking and then by toll switching.

Return to that step in the call setup where the first selector stage awaits the subscriber's first dialed digits. Let the subscriber dial the three-digit office code, into the first selector stage, of a switching office that is located in another building, but one that has direct trunks to this building. The first selector stage extends the switch path to an output that is wired to the originating trunk circuit of an outgoing trunk that connects to that remote office. This call is represented in Figure 6.1 by the middle output off the first selector stage, connected to the middle trunk on the trunk side of the building. In the office at the other end of this trunk, the trunk interfaces to a terminating trunk circuit that is wired to the appropriate segment of the second selector stage. The subscriber's next digits are repeated over this trunk and advance the switch path through this distant office.

If there are no direct trunks to the other office, the call must be toll-switched and the subscriber's first dialed digit must be a 1. Then, the switch path extends through the first selector stage to an originating trunk circuit that interfaces to an interoffice trunk to the toll office that serves the calling party's building. This trunk is also represented in Figure 6.1 by the middle output off the first selector stage. The subscriber's next digits are repeated over this trunk and delivered directly to this toll office.

Similarly, there are two kinds of incoming call from another office, by direct trunking or by toll switching. Incoming trunks from an office with direct trunking are represented by the upper trunk on the trunk side of Figure 6.1. A terminating trunk circuit is typically connected to the second selector stage because the calling party would have dialed the first three digits into his home office to reach this trunk, and only the last four digits would come over the trunk. A terminating trunk circuit, for an incoming trunk from a toll office, is connected to the first selector stage, represented by the lowest incoming trunk in Figure 6.1. Since the called party's entire directory number is expected, the first selector is needed to switch on the office code.

Unlike lines, incoming trunks are not concentrated through a stage of line finders. One reason is that they are assumed to be busy anyway. A two-way local interoffice trunk has its originating circuit connected to the output of the first selector and its terminating circuit connected to the input of the second selector. A two-way intratoll trunk has its originating circuit also connected to the output of the first selector, but its terminating circuit is connected to the input of the first selector.

At the position in the fabric where the *switch train* reaches a toll trunk, the identity of the calling party is unknown. If the calling party places a toll call, which must be billed, the equipment in the toll office that computes charges must, somehow, identify the calling party. This information can be obtained by operator intercept at the toll office or by automatic number identification (ANI) equipment in the Step-by-Step office. In the latter case, it is outpulsed over the same trunk to the toll office. ANI and the billing process are described in Section 9.2.3.

## 6.2 STROWGER SWITCH

The generic Strowger switch is described. General operation is explained and three distinct operating modes are discussed. These three modes are shown to correspond to the application of the switch as a line finder, selector, or connector.

### 6.2.1 Description

The cover of a Strowger switch is the size and shape of a rural mailbox, but mounted vertically. A long rod, which protrudes vertically out of the bottom of the switch's cover, carries three to six wipers. When the switch is positioned on a frame, the wipers are in proximity to a semi-cylindrical bank of contacts that are part of the frame. Removing the cover reveals a complicated structure of electromechanical actuators, electromechanical relays, wires, switch contacts, and this vertical rod.

The upper half of the switch's internal structure holds six relays labeled A – F. With only minor physical changes, the same Strowger switch can be used as a line finder, selector, or connector. The function of these relays depends on whether the switch acts as a line finder, selector, or connector. For example, when the switch acts as a selector or connector, relays A – D perform the supervision and dial repeating functions described in Section 3.5.7.

The bottom half of the switch's internal structure holds three actuators that control the vertical and rotary position of the rod. Each operation of the *vertical actuator* moves the rod upward by one additional vertical notch on a ratchet attached to the rod. Ten vertical actuations, as might be caused by 10 dial pulses, move the rod upward about 1.25 inches. Each operation of the *rotary actuator* moves the rod clockwise by one additional longitudinal notch on a different ratchet attached to the rod. Ten rotary actuations, as might be caused by 10 dial pulses, move the rod from a 10 o'clock position to a 2 o'clock position. A third actuator disengages the other two actuators from their respective ratchets. When this *release actuator* operates, the spring at the top of the rod, rotates the rod counter-clockwise back to its 10 o'clock position. Simultaneously, gravity drops the entire rod down to the *rest* position, below the first vertical position on the ratchet. Switch operation has a characteristic ''clackety-clack'' sound, and switch release, when this release actuator operates, has a characteristic loud ''clunk.'' A building containing thousands of Strowger switches is physically large and extremely noisy.

Any Strowger switch has several contact stacks that are optional, depending on its specific application. For example, one contact stack, controlled by a bushing mounted at the top of the rod, operates when the rod is brought to the rest position by the release actuator and releases when the vertical actuator begins to move the rod upward. These contacts indicate the idle/busy status of the switch.

Two (or three, if the switch is a line finder) bushings, about 1.5 inches apart, are mounted on the bottom of the rod where it protrudes outside the cover. A pair of electrical wipers is mounted on each bushing. Two flexible wires, for a tip and a ring, connect to the wipers on the lower bushing. These wipers brush against contacts, which are mounted on posts that are arranged in a semi-cylindrical bank, with 10 vertical rows and 10 radial positions, similar to the structure and operation of the rotary traveling switch in Figure 2.3(a). Each post has a contact on the top and the bottom, for separate electrical conduction with the two wipers. A third flexible wire, for a sleeve, connects to a wiper on the upper bushing. These wipers brush against contacts in a separate semi-cylindrical bank, physically above the bank that provides contacts for the tip and ring. These tip, ring, and sleeve wipers travel together, vertically and radially, as the rod is moved by the actuators. The two banks of contacts that these wipers brush against are physically part of the frame on which the Strowger switches are mounted.

### 6.2.2 Equipment Frames

Inside a switching office, each switch's rod and bushings are exposed below the switch's cover, but the actuators and A – F relays are covered. When covered, a Strowger switch has the size and appearance of a rural mailbox, except it is mounted vertically, and the cover is typically pale gray. A Strowger switch is mounted on the front side of an equipment frame. Each switch's contact banks are part of this frame and all the inter-switch wiring appears on the back of the frame. Switches are mounted side-by-side on a frame and, depending on its height, a frame may have several levels of switches.

These frames stand on the central office floor, physically adjacent in rows, with aisles between the rows for personnel access. All the interframe wiring is carried in troughs above the frames. The line finder stage, selector stages, and the connector stage of Figure 6.1 are made from similar frames, each made using similar switches. The floor plan of a typical building of Step-by-Step switching offices is similar to the diagram in Figure 6.1. With row after row of high frames, the feeling of being inside such an office is like being inside a tall library room filled with large gray books. The noise level, however, bears no such resemblance to that in a library.

A Step-by-Step building, containing one Step office that serves 4000 lines, needs about 1000 Strowger switches. Mounting the switches 6 inches apart on a three-level frame requires 167 linear feet of frames. Allowing 6 feet between rows of frames, this office requires over 1000 square feet, just for the fabric. A 4000-line main frame, frames for 4000 line circuits and several hundred trunk circuits, tone and ring generators, and power equipment all would require at least that much area again.

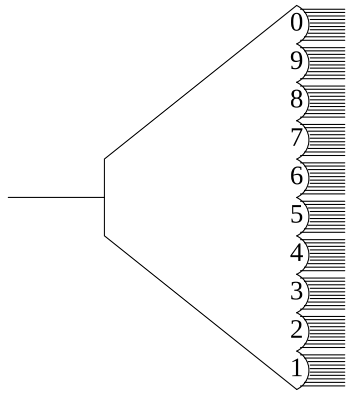


**Figure 6.2.** Schematic symbol for a Strowger switch.

### 6.2.3 Operation and Modes

The vertical and rotary actuators and their ratchet mechanisms are made to move the rod to one of 100 positions, arranged as 10 vertical by 10 rotary positions. Mounted on this rod, the *ganged* wipers, one each for the tip, ring, and sleeve, are directed to one of 100 contact positions, triply ganged in two semi-cylindrical banks. A Strowger switch brings one three-wire common to one of 100 triple-contacts, electrically a triple-throw, 100-pole switch. Figure 6.2 shows a schematic symbol for a Strowger switch. The single line at the left represents a three-wire ‘‘common.’’ The 10 bumps on the right represent the 10 vertical levels, and the 10 outputs on each bump represent each level’s 10 rotary positions. Each of the 100 outputs on the schematic represents three wires.

Once directed to a position, the ratchet mechanisms hold it for the duration of a call. Removal of the electrical ground from the sleeve connection through the fabric is the signal to the release actuator in each switch used for a given call. This action, called ‘‘dropping the switch train,’’ disconnects the call by breaking the electrical connection of the tip, ring, and sleeve through the fabric and normalizes all the switches used for the connection of the call. These normalized switches are made available for another call. An intraoffice call through a typical Step office uses five Strowger switches, one in each stage of the fabric in Figure 6.1. With calling party supervision, when the calling party hangs up, these five switches release almost simultaneously with a loud ‘‘clunk.’’

Both the vertical and rotary actuators are operated in one of two modes, called select and hunt. In *select mode,* the respective actuator is directed by dial pulses from a telephone. Since each dial pulse is an open circuit followed by a closed circuit, the receiving actuator is operated and released by each pulse. Each pulse directs the respective pawl one position along the respective ratchet. If the calling party dials a 7 into a switch whose vertical/rotary actuator is in select mode, then this actuator moves the rod by seven vertical/rotary positions.

In *hunt mode,* the respective actuator is directed by the electrical state of the contacts that are touched by the wipers moved by this actuator. The wipers sweep over all contacts in the vertical/rotary direction until one with a specified electrical condition is found, typically an ungrounded sleeve contact. Using hunt mode, for example, an *N*th selector searches over all its outputs to find a link to an idle ($N$ + 1)th selector. Since actuator current must be pulsed for each position that the rod is moved, an actuator in hunt mode requires additional mechanisms that an actuator in select mode does not need. One mechanism operates contacts that temporarily break the current to this actuator's coil and another indicates the final position of the rod's motion.

The operating mode of a Strowger switch is described by the pair [V,R], where the switch's vertical actuator operates in mode V and its rotary actuator operates in mode R. Only three of the four possible pairs of *switch modes* are used: [hunt, hunt], [select, hunt], and [select, select], corresponding respectively to the switch being used as a line finder, selector, or connector.

## 6.3 LINE FINDERS

The originating side of the fabric in a Step-by-Step office is called the line finder stage. The line finder stage is a collection of line finder groups and each group is a collection of individual line finder switches. An individual line finder is a Strowger switch, configured to operate in [hunt, hunt] mode. The purpose of the line finder stage is to provide concentration. Without it, an office would require a dedicated first selector for each subscriber's line. Since lines are usually idle, such dedicated equipment would be wasteful.

A line finder group is described and its operation is discussed, with two over-simplifications. The simplifying assumptions are lifted and class of service is described.

### 6.3.1 Line Finder Group

Figure 6.3 shows more detail than Figure 6.1 of a small part of the originating side of a Step-by-Step fabric. Two line circuits are shown at left. The line finder stage, shown at right, is partitioned into line finder groups. Only one line finder group is shown, and it is shown to have only two line finders. The line finders face in the opposite direction from the selectors and connectors in the Step office. The common of each line finder is the tip, ring, and sleeve of a link to the common of a dedicated first selector. Line finders and first selectors are wired as a pair, connected common-to-common. While a line finder has 10 vertical positions, only four are depicted on the schematic in Figure 6.3 of each line finder. While a line finder connects to 100 lines (shown below to be 200), the connection to only two is depicted. Besides containing a set of line finder switches, a line finder group also has 10 start circuits, with only one shown in Figure 6.3, and one allotter circuit, as shown. The set of subscriber lines served by a line finder group is also considered to be part of the group.

As a pedagogical tool, temporarily assume that a line finder provides access to the originating appearance of 100 lines. It will be shown that a line finder serves 200 lines. Let all the lines in the building be arbitrarily partitioned into groups containing 100 (200) lines. Each group of lines is part of a different group of line finders. The tip, ring, and sleeve of each subscriber line are connected to one three-wire pole on each line finder in the line finder group that serves this group of lines. The start wires from all the line circuits in a group are connected to the lone allotter circuit in the line finder group. This allotter circuit has a separate control wire to each line finder.

Let the 100 (200) lines in each group be arbitrarily partitioned into start groups, each containing 10 (20) lines. A start circuit serves each different start group. The two lines in Figure 6.3 are not only in the same line finder group, they are also in the same start

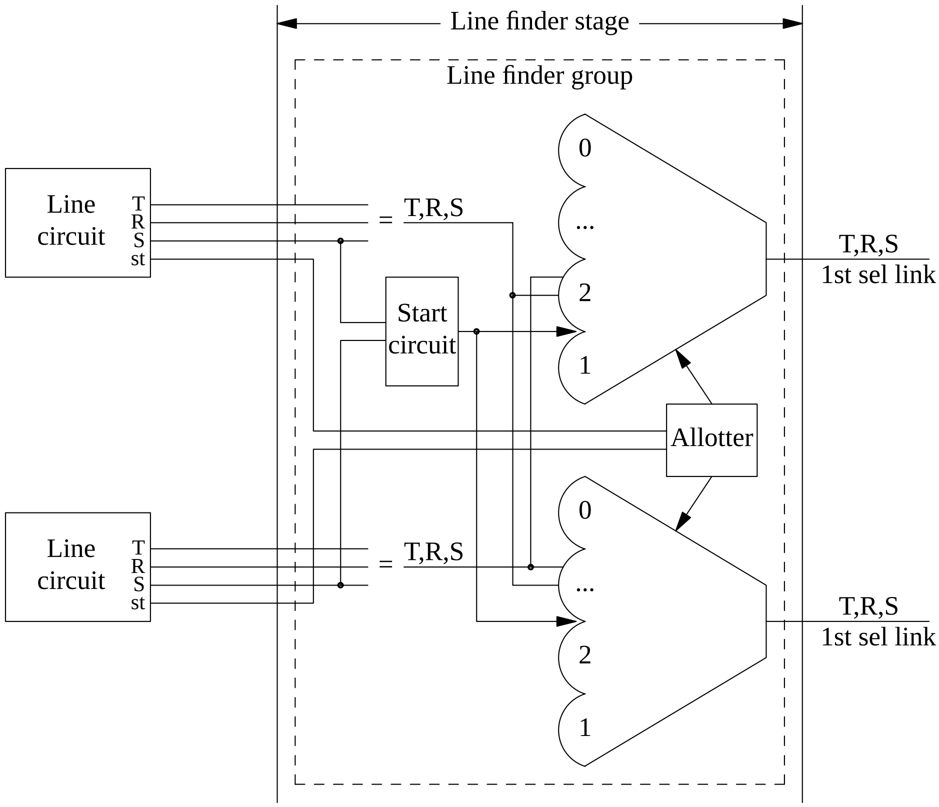


**Figure 6.3.** A line finder group.

group. When the lines in a start group are connected to the poles on a line finder, they are always connected to a common row of poles, and in the same order. Each start group's common row is a different numbered row on every line finder. The two lines in Figure 6.3 are served by the indicated start circuit and they are connected to row 2 on the upper line finder and row "..." on the lower one. The upper line is connected before the lower one in the rotary direction in both rows.

When a Strowger switch is configured as a line finder, a *vertical commutator* is mounted on the rod and it brushes along a bank of 10 vertically mounted contacts, one contact corresponding to each row of poles. The output from each start circuit is wired to that vertical contact on each line finder that corresponds to the row of poles to which this start circuit's input lines are connected. In Figure 6.3, the start circuit's output is wired to the vertical contact corresponding to row 2 on the upper line finder and to the vertical contact corresponding to row "..." on the lower one.

### 6.3.2 Simplified Operation

Referring back to Section 3.5.2, when a telephone goes off-hook, the line relay in its line circuit operates, placing battery on the sleeve wire and ground on the start wire. All other sleeve wires in this group of lines are grounded if the line is busy and served, or open if the line is idle. Battery occurs only on the sleeve wire of a line that has just gone off-hook but hasn't been "found" yet. The start circuit, serving the start group of which this line is a member, responds to the battery on one of its input sleeve wires. It places ground on that vertical contact on each line finder that corresponds to the row of poles to which its start group's input lines are connected.

The allotter circuit, serving the group of which this line is a member, responds to the ground on one of its input start wires. It selects an idle line finder in the group and signals it, over the control wire, to begin operation. In hunt mode, the vertical actuator on this selected idle line finder raises the rod until the vertical commutator brushes the vertical contact that was grounded by the start circuit. The tip, ring, and sleeve wires of the line that just went off-hook are connected to one of 10 poles in this row. After reaching the grounded vertical contact, the vertical actuator stops and the rotary actuator begins. Also in hunt mode, this rotary actuator rotates the rod until the sleeve wiper brushes some sleeve contact that has battery on it.

Several events occur at the instant this off-hook line is found. The rotary actuator stops, with its tip, ring, and sleeve wipers electrically brushing the tip, ring, and sleeve contacts of the desired line in the semi-cylindrical bank of poles. A relay connects ground to the sleeve wire, operating the cut-off relay in the line circuit and indicating that the line is busy to the terminating side of the fabric. The tip, ring, and sleeve are connected by a link to that first selector that is directly wired to this line finder. Supervision passes to this first selector's A relay and another relay operates to connect dial tone across tip and ring.

### 6.3.3 Access to 200

A real line finder serves 200 lines, not 100 as described so far. Since each line has a tip, ring, and sleeve, some form of triple-contact pole is required in the switch bank. To serve 100 lines, a Strowger switch requires three wipers and 300 electrical contacts. Section 6.2 described three wipers mounted on two bushings, with two wipers mounted on the lower bushing and one mounted on the upper. In rotary motion, the double wipers straddle the corresponding physical posts, brushing against electrical contacts mounted on the top and bottom of a post. So, the 300 corresponding contacts are configured as a lower bank of 100 posts with double contacts and an upper bank of 100 posts with single contacts. To expand a Strowger switch to serve 200 lines, it requires six wipers on three bushings and 600 electrical contacts. The 600 contacts are configured as three banks of 100 posts, each with double contacts.

A line finder's contacts are configured as three 10-by-10 semi-cylindrical banks of dual contacts. This arrangement provides six electrical connections, enough for the tip, ring, and sleeve of two telephone lines, for each of its 100 mechanical positions. The wipers on the upper bushing brush the tip and ring of one line, the wipers on the lower bushing brush the tip and ring of the other line, and the wipers on the middle bushing brush the sleeves of both lines. With 20 lines on a row, instead of 10, each start circuit serves 20 lines. A line finder finds the line requesting service by first locating the vertical position that had its vertical contact grounded by this start circuit, and then locating the rotary position at which some sleeve contact has the battery condition. Whether the upper or lower sleeve at this position has battery determines whether the tip and ring brushed by the wipers on the upper or lower bushing are connected, with this sleeve, to the switch's common wires.

The reason for serving 200 lines, instead of 100, is to expand the *access* of lines to line finders in this stage of concentration (Section 5.2.5 and Section 7.2). It was seen in Section 5.3 that larger access provides greater efficiency. For example, let the typical line be busy an average of 1.8 minutes out of every hour on calls this line originates. Calls that terminate on this line do not tie up a line finder. Then, each subscriber produces 0.03 Erlangs of traffic intensity at the line finder stage in the Step office. If there were 100 subscribers in a line finder group, the group must handle 3 Erlangs total. By Figure 5.4, eight line finders would serve this group of 100 lines with a $P_b$ = 0.012 and 37.5% occupancy. Instead, with 200 subscribers in a line finder group, the group must handle 6 Erlangs total. By Figure 5.5, 13 line finders would serve this group of 200 lines with a $P_b$ = 0.009 and 46% occupancy. By this example, placing 200 lines in a line finder group instead of 100, saves three line finders for every 200 subscribers for roughly the same $P_b$, a savings of 60 Strowger switches in a 4000-line Step office. While an individual line finder provides 200:1 concentration, the group described above provides for 200:13 ≈ 15:1 concentration.

### 6.3.4 Allotting

Since one line finder, and its link to a first selector, is required for each originated call, the number of line finders in a line finder group is determined by the intensity of originating traffic from the group served. The 200 lines are concentrated ‘‘down’’ to this number, typically 10 – 15.

When a subscriber lifts his handset to originate a call, the line circuit for this line places a ground signal on the start wire. The allotter responds to this ground signal and selects a line finder in the line finder group to find the line that has just requested service. The allotter is a circuit of relay contacts, wired in a scheme called a preference chain (Exercise 6.3). The allotter examines all the line finders in its group that are idle and selects the one in which this line is wired on the lowest row. This selection criterion reduces the time spent in vertical hunt and distributes wear over all the line finders in a group.

Even with the access at 200 lines, the quality of service provided by a line finder group is sensitive to variations in traffic intensity. Consider subscribers, like brokers, who originate more than the average number of telephone calls or who connect via modems to computers and have calls with a long holding time. When such a subscriber is added to a line finder group, or when existing group members suddenly change their calling patterns, it can be noticeable to the other subscribers in the group. If all the line finders in a group are busy, a subscriber may go off-hook and not get a dial tone.

For example, consider a group served by 13 line finders, based on 0.03 Erlangs per subscriber. Let five of these subscribers be off-hook for hours on modem-connected calls. The remaining 195 subscribers are served by the eight remaining line finders. At 0.03 Erlangs each, the net traffic intensity is $0.03 \times 195 = 5.85$ Erlangs and, from Figure 5.5, $P_b$ = 0.25, highly unacceptable. The telco must either add more line finders to this group or move some originating appearances to another group. Moving line appearances on the originating side of a Step fabric is not a problem, except for the labor cost involved and possible problems with preserving class of service (next section).

### 6.3.5 Class of Service

Some lines have certain conditions, limitations, or privileges that require special handling. Examples are coin telephones, PBX trunks, restricted calling, subscription to Touch Tone, wide area telephone service (WATS), speed calling, and other services, or even indication that the bill is unpaid. Indication for special handling is called class of service. One way to identify such conditions in a Step-by-Step office is for all lines with the same originating class of service to be wired to a common line finder group. One line finder group might serve all the coin telephones in an office, another group might serve all the PBX trunks, and Touch Tone subscribers might also be segregated into separate line finder groups from dial-pulse subscribers.

Another way to identify such conditions is to associate an *n*-bit binary code to each line. A coding method, sometimes used in Step-by-Step offices, is for each line finder to have a fourth bushing and wiper pair on its rod, corresponding to a fourth bank of posts with two contacts per post. The contacts are binary-coded with open or ground. If the two lines corresponding to each [horizontal, rotary] position have the same class of service, then both corresponding contacts in the fourth bank are used for both lines together to encode four distinct class of service conditions. If the two lines corresponding to each [horizontal, rotary] position have different class of service, then only one corresponding contact in the fourth bank is used for each line to encode two distinct class of service conditions.

## 6.4 SELECTORS

In the Step-by-Step fabric, the *selector subfabric* is a collection of selector stages, where the *N*th selector stage is a collection of *selector groups* and each group is a collection of selector switches. An individual selector is a Strowger switch operated in [select, hunt] mode. The purpose of the selector subfabric is to route the *switch train* as the calling party dials the directory number of the called party.

The selector subfabric is described and its operation is discussed, but with two over-simplifications. The operation of a selector stage, group, and switch are described. Digit disposition, network blocking, and interstage wiring are discussed.

### 6.4.1 Selector Subfabric

Assume that the selector and connector stages from Figure 6.1 are redrawn in Figure 6.4 in greater detail. While Figure 6.1 correctly shows three selector stages and one connector stage, Figure 6.4 incorrectly shows seven selector stages because two pedagogical simplifications are made. The *N*th stage is assumed to be responsible for the *N*th digit of directory number dialed by the calling party. Each selector stage receives and absorbs one dialed digit in the number and extends the switch path to the next stage in the fabric. The handling of the first three digits by the first selector stage is described in Section 6.5, and the handling of the last two digits by the connector stage is described in Section 6.6.

Under these two simplifications, if a seven-digit directory number is assumed, seven selector stages are needed in this hypothetical selector subfabric. The first three selector stages would be common to a building, because the office code of the called party's directory number is not known until the switch path reaches this point in the fabric. The last four selector stages would be segmented into the separate offices within a building.

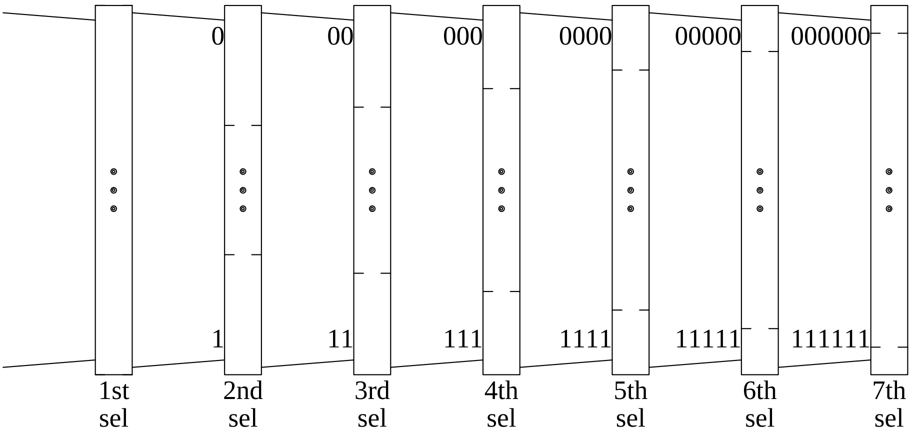


**Figure 6.4.** Hypothetical selector subfabric.

The outputs of the seventh selector stage are the subscriber's terminating appearances on the fabric. Each subscriber's tip, ring, and sleeve are connected, between his dedicated line circuit and the terminating side of the fabric, as shown on the right of Figure 6.1. This termination must be to a unique output of the unique segment of the final selector stage, which corresponds to the subscriber's directory number.

The first selector stage in Figure 6.4 has only one selector group, and this stage/group serves all calls through the fabric. The first dialed digit steers the switch train to the appropriate group in the second selector stage. Typically, digits 1 and 0 are used for toll and operator calls, respectively, and do not steer the switch train into the second selector stage. The second selector stage in Figure 6.4 is partitioned into 10 selector groups. These groups are identified by 1, 2, ..., 9, 0 in the figure, corresponding to the first dialed digit; but some (at least 1 and 0) are not equipped. Each group serves all calls through the fabric in which the called party has the corresponding same first digit in its directory number. The second dialed digit steers the switch train to the appropriate group in the third selector stage, and so forth. The seventh selector stage in Figure 6.4 is partitioned into one million selector groups. These groups are identified by six-digit numbers, corresponding to the first six dialed digits; but most groups are not equipped. Each group serves all calls through the fabric in which the called party has the corresponding same first six digits in its directory number. The seventh dialed digit steers the switch train to the called party.

For the moment, ignore the fact that calls, in which the leading digit is 0 or 1, trunk out of the fabric from intermediate stages. If we assume, instead, that all calls proceed through all the selectors in the fabric, then the $N$th selector stage in Figure 6.4 is partitioned into $10^{N-1}$ selector groups. These groups are identified by $(N - 1)$-digit numbers, corresponding to the first $N - 1$ dialed digits; but many may not be equipped. Each selector group in the $N$th selector stage serves all calls through the fabric in which the called party has the corresponding same first $N - 1$ digits in its directory number. The next dialed digit steers the switch train to the appropriate group in the $(N + 1)$th selector stage.

Consider the selector group reached by the dialed number $d_1 d_2 \cdots d_N d_{N+1}$ in this

($N + 1$)th selector stage. The separate selectors in this group are reached from different rotary positions on the $d_{N+1}$th row of any selector from the same group in the $N$th selector stage. This group in the $N$th selector stage was reached by the dialed number $d_1 d_2 \cdots d_N$. Because as many as 10 selectors in this $N$th selector group are wired to the same ($N + 1$)th selector group, hunting for an individual idle selector is necessary.

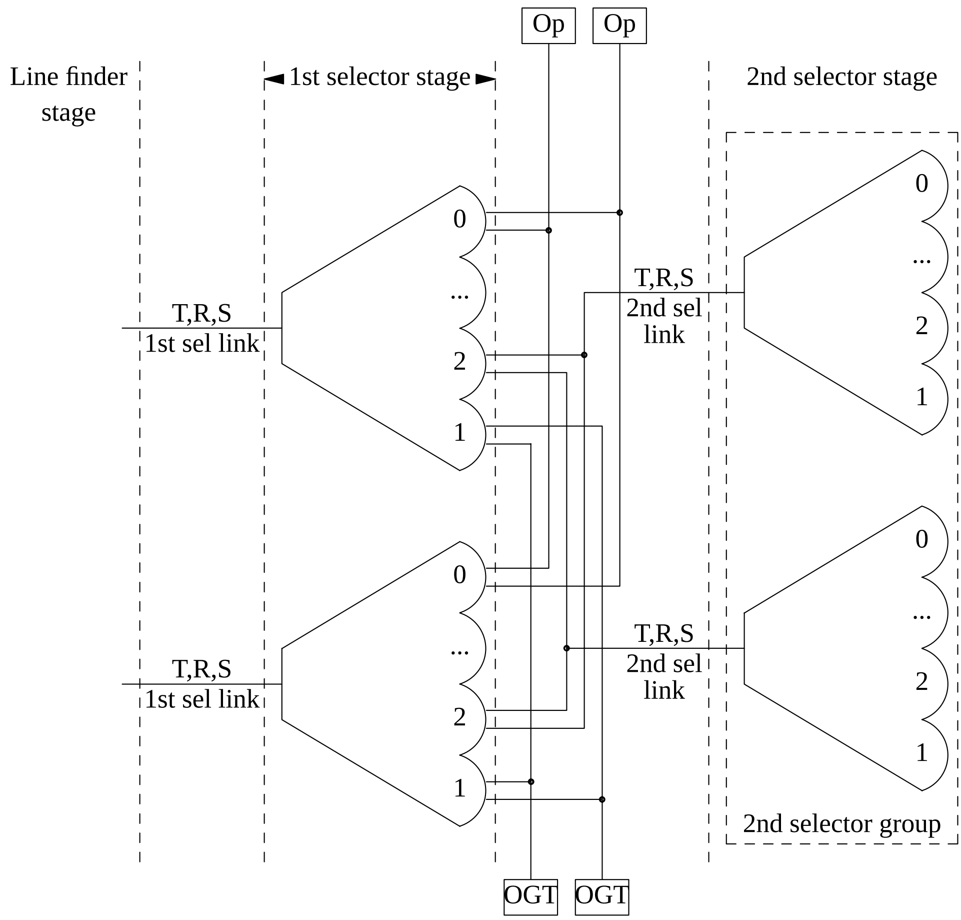


**Figure 6.5.** The first selector stage.

### 6.4.2 Simplified Operation

Figure 6.5 shows a Step-by-Step building in more detail, including the line finder stage to the left, the first selector stage in the center, the second selector stage to the right, and several operators and outgoing trunk circuits.

A first selector is paired with every line finder in the office, input-to-input with the switch in each [line finder, first selector] pair facing in the opposite direction. The tip, ring, and sleeve wires connecting a switch-pair together are called the first selector link. One first selector link and switch-pair are required for the duration of every call, assigned at the time of origination. The first selector returns talking battery and dial tone to the calling party, and accepts the first dialed digit (it will be shown in Section 6.5 to accept the first three).

Every stage of selectors contains many selector switches, all operating in [select, hunt] mode. A digit dialed into a selector directly moves its shaft vertically, one position for each pulse in the digit. At the end of the digit, indicated by the released C relay, vertical movement ceases and rotary hunt begins. The selector then searches radially for an open circuit on a sleeve contact, indicating a path out to an idle selector in the appropriate group in the next stage of the fabric.

The top row of the bank of contacts in each first selector, reached by dialing 0, is connected to 10 or fewer local operators. The bottom row, reached by dialing 1, is connected to 10 or fewer outgoing trunks to the toll office. These trunks carry calls to those offices to which this office does not have direct trunking, including long distance calls, typically outside the flat-rate billing area. Other trunks, to nearby offices with direct trunking, are connected to selectors deeper in the fabric (not a true statement) because they are reached by dialing the three-digit office code into this office. Dialing instructions, provided in the telephone book, inform the subscriber whether the 1-prefix is required. Intermediate rows on the bank of contacts in each first selector, corresponding to a first digit of 2 – 9, are connected to groups of second selectors according to the dial plan in the office.

### 6.4.3 Digit Disposition and Network Blocking

Each dialed digit is handled in this oversimplified selector subfabric in one of five ways:

- The digit advances the switch train one stage deeper in the fabric or to an outgoing trunk and the subscriber continues dialing;
- The incomplete call is blocked inside the fabric for lack of enough trunks or selectors in the next selector group and the subscriber hears path-busy tone;
- The digit is inconsistent with the office dial plan and the subscriber hears reorder tone;
- The digit completes the call to an idle called party and the subscriber hears ring-back tone;
- The digit completes the call to a busy called party and the subscriber hears busy tone.

Strowger switches, equipped for hunt mode in the rotary direction, have a tab on the shaft that operates a contact stack when the shaft reaches the 2 o'clock position. If the shaft hunts completely across a row without finding an idle path to the next selector group, a contact operated by this tab connects path-busy tone to the tip and ring.

Selector positions reached by invalid digit sequences have open-circuit sleeve connections so they appear idle and stop hunt mode. The corresponding tip and ring are wired directly to reorder tone. Completion of dialing occurs in the connector stage and is described in Section 6.6.

### 6.4.4 Multipling in Selector Groups

If the paths to the operators were wired to the 0-row of every first selector in the same order, a pattern called uniform multipling, the operators would be nonuniformly busy. The operator wired to the first position would be the first one hunted by all traffic and would be the busiest, and so forth. Similarly, mechanical equipment, like trunks and next selectors, would wear unevenly. So the same row of every selector switch in the same group, while wired to the same set of equipment, is deliberately wired to that equipment in a different order, in a pattern called slipped multipling.

In Figure 6.5, consider the two indicated second selector links between the two selectors in the first selector stage and the two selectors in the 2-group of the second selector stage. The upper first selector hunts over these second selectors so that it would choose the lower one first, if it were idle. The lower first selector hunts over these second selectors so that it would choose the upper one first, if it were idle.

Suppose traffic requires more than 10 operators in the building, or more than 10 trunks in a trunk group, or more than 10 switches in a group of second selectors. Since a given row of a given selector can only reach 10 servers, a similar multipling issue arises. Such server groups, and the selector groups that reach them, could be wired as subgroups of 10 each; but this would violate the full-access principle. Instead, one first selector is wired to servers 1 through 10, the second to servers 2 through 11, the third to servers 3 through 12, and so forth. This pattern distributes traffic better than subgrouping would.

For example, let a first selector stage have 324 selector switches. If there are nine outgoing trunks to the toll office, the 1-level of each first selector is wired to all nine trunks, with the last rotary position permanently marked busy. Thirty-six selectors would be wired to hunt in the order 1, 2, 3, ..., 9; 36 would be wired to hunt in the order 2, 3, ..., 9, 1; 36 to hunt in the order 3, ..., 9, 1, 2; and so forth. If, instead, there are 12 outgoing trunks to the toll office, the 1-level of each first selector is wired to only 10 of the 12 trunks. Twenty-seven selectors would be wired to hunt in the order 1, 2, 3, 4, ..., 10; 27 would be wired to hunt in the order 2, 3, 4, ..., 10, 11; 27 to hunt in the order 3, 4, ..., 10, 11, 12; 27 in the order 4, ..., 10, 11, 12, 1; and so forth.

## 6.5 DIGIT ABSORBING

An optimization mentioned above is that the first three dialed digits, the office code, typically do not require three stages of selectors. In most Step-by-Step offices, the first selector alone handles the entire office code and the remaining selector stages (and connectors) handle the remaining digits, typically four. This optimization is best explained by example.

**TABLE 6.1.** Three hypothetical step communities

| Community | Office code(s) |
|---|---|
| Blacksburg | 552, 953 |
| Christiansburg | 382 |
| Radford | 639, 741 |

Consider buildings in three communities: Blacksburg, Christiansburg, and Radford. Let each be served by Step-by-Step buildings with mutual direct trunking. Let Blacksburg and Radford each be large enough to need two offices and let the office codes be as tabulated in Table 6.1. For the reader familiar with these three communities in southwestern Virginia, the office codes have been slightly altered to make the example work out better. Furthermore, Steppers do not really serve these three communities.

If the first digit dialed by any subscriber is a 9, the only valid second digit is 5 and the only valid third digit is 3. If the second and third digits used selector stages, its switches would be sparsely wired and only serve as dial plan filters. The motivation for optimizing out the second and third selectors is seen.

### 6.5.1 Counter-Based Digit Absorbing

Assume there is a digit counter in each first selector that allows it to distinguish the first three digits. Each first selector can act on any digit in one of three ways:

- Absorbing (A) means the selector does nothing except increment the digit counter.
- Blocking (B) means the selector connects reorder tone because this digit in this position is inconsistent with the dial plan.
- Connecting (C) means the corresponding row on the selector's output is wired to more equipment.

The dial plan in Blacksburg requires that all first selectors connect (C) to toll trunks and operators if the first digit dialed is 1 and 0, respectively. Wires to originating trunk circuits and operator switchboards are physically connected (C) to the rotary positions on the 1 and 0 levels of these Strowger switches. These first selectors must absorb (A) first digits of 3, 5, 6, 7, and 9 and second digits of 3, 4, 5, and 8 as assumed parts of valid office codes. These first selectors must connect (C) to each of the direct-trunked offices off the third digits of 1, 2, 3, and 9. All other digits would be blocked (B).

**TABLE 6.2.** Treatment of three digits of office code

| Digit | 1st | 2nd | 3rd | 1st | 2nd | 3rd |
|---|---|---|---|---|---|---|
| 1 | C | B | C | C | B | B |
| 2 | B | B | C,C | B | B | B |
| 3 | A | A | C | A | A | C |
| 4 | B | A | B | B | C | B |
| 5 | A | A | B | A | A | B |
| 6 | A | B | B | A | B | B |
| 7 | A | B | B | A | B | B |
| 8 | B | A | B | B | C | B |
| 9 | A | B | C | A | B | C |
| 0 | C | B | B | C | B | B |

Summarizing, each first selector in the Blacksburg building would be controlled according to the leftmost columns of the table in Table 6.2. However, the same selector cannot connect (C) to the 552- and 382- offices off the same third digit, neither can it physically connect (C) to toll trunks and to the 741- office off a dialed 1. While there is a logical difference, they require the same rotary positions on the same levels of the same physical switches. One solution is for selectors to connect (C) to the 741- office and to the 382- office off the second digit of their office codes. Those offices, at the other end, must absorb (A) their respective third digit in their second selector stage.

There can be at most one C in any row of the table. The rightmost columns of the table in Table 6.2 has C in the second column of row 4 and B in the third column of row 1 because this office trunks out to the 741- office on the 4 instead of the 1. The table has C in the second column of row 8 and would have B in the third column of row 2 because this office trunks out to the 382- office on the 8 instead of the 2. The entry in the third column of row 2 is C and not B because this office trunks out to the 552- office on the 2. Similar tricks that can be used are to connect (C) on the first digit or to change the dial code for accessing toll trunks.

Notice that the subscriber who dials 359 is trunked out to the 639- office because a first selector cannot distinguish those two sequences of digits; this is felt to be acceptable. Digressing, the reader should appreciate the complexity of implementing a change in the dial plan whenever a new office code is added; every first selector in a building must be physically rewired.

### 6.5.2 Counter-Free Digit Absorbing

If the counter is removed or not used, the first selector cannot distinguish first, second, and third digits. The following three rules translate between counter-based arrangements and counter-free arrangements. If the counter-based arrangement has a B in all three positions, then the counter-free treatment is B. If the counter-based treatment has A and B in all three positions, then the counter-free treatment is A. If the counter-based treatment has a C in any (one) position and the other two are B, then the counter-free treatment is C. A conflict occurs if the counter-based arrangement has a C in any (one) position and either of the other two is A. Applying these rules to the rightmost columns in the table of Table 6.2, this conflict occurs in rows 3 and 9.

**TABLE 6.3.** Counter-free arrangement of the office codes

| Digit | Action |
|---|---|
| 1 | C to toll |
| 2 | C to 552 |
| 3 | A |
| 4 | C to 74(1) |
| 5 | A |
| 6 | C to 6(39) |
| 7 | A |
| 8 | C to 38 |
| 9 | C to 9(53) |
| 0 | C to 0 |

This conflict is resolved if the Blacksburg building trunks to the 639- office on the leading 6 and to its own 953- office on the leading 9. Each of those offices must absorb the last two digits of its respective office code. The arrangement of office codes by a counter-free first selector is shown in Table 6.3. If the 639- office has less than 8000 subscribers, its second selectors can absorb the 3 and 9, counter-free, if these numbers are avoided as thousands digits for directory numbers. If the 953- office has less than 8000 subscribers, its second selectors can absorb the 5 and 3, counter-free, if these numbers are avoided as thousands digits for directory numbers.

Without counters in the first selectors, the following dial sequences all select the 552-office: 552, 972, 97972 and just 2. This is viewed as acceptable and the 2 shortcut is even a benefit. Such a shortcut is usually made public within the community. While a subscriber with directory number 552-1097 can be dialed up with 2-1097 in a local call, a subscriber making a nonlocal call to this number cannot use the shortcut.

### 6.5.3 Implementation

The first selector stage in a Step-by-Step office is more easily implemented if office codes have been chosen carefully so all out-trunking is on the third digit and all digit absorbing is counter-free. When out-trunking is not on the third digit, the target second selectors must perform digit absorbing, preferably counter-free. Counter-based digit absorbing, in first or second selectors is more difficult and expensive.

A Strowger switch may have an auxiliary shaft, attached to the main shaft between the vertical ratchet and the rotary return spring, behind the main shaft and projecting above it. A bushing at the top of this auxiliary shaft has 10 flexible metal tabs on each side. These tabs may be bent inward with pliers. The *N*th tab on one side, if not bent back, operates switch contacts when the shaft is in the *N*th vertical position.

In counter-based digit absorbing, one side is used as a 1-bit binary code for the first digit and the other side is used as a 1-bit binary code for the second digit. In counter-free digit absorbing, both sides are used as a 2-bit binary code to encode the A, B, and C states. Every time the dialing plan changes, these tabs must be changed on all selectors equipped for digit absorbing.

## 6.6 CONNECTORS

The terminating side of the fabric in a Step-by-Step office is called the connector stage. The connector stage is a collection of connector groups and each group is a collection of individual connector switches. An individual connector is a Strowger switch configured to operate in [select, select] mode. The purpose of the connector stage is to provide *expansion* from few active paths to many terminating appearances.

Use of a connector stage instead of the hypothetical sixth and seventh selector stages in Figure 6.5 is discussed. A connector group is described and its operation is discussed, when the called party is both idle and busy.

### 6.6.1 The Truth about the Selector Subfabric

According to the description of the hypothetical selector subfabric, shown in Figure 6.4, the sixth and seventh stages accept the last two digits of the called party's directory number, as dialed by the calling party. Also, according to this description, a selector accepts its appropriate digit during its vertical motion, in select mode, and then finds an idle next selector during its rotary motion, in hunt mode.

If a seventh selector really worked this way, there would be nothing for it to hunt over during rotary motion, because the seventh, and last, digit would have uniquely identified the called party during vertical motion. So, the seventh selector stage is eliminated and the rotary motion of all the sixth selectors is changed to accept the seventh digit in select mode. This merger of the hypothetical sixth and seventh selectors, into one stage whose switches operate in [select, select] mode, is called the connector stage. The outputs of the connectors are the subscriber's terminating appearances.

Consider the hypothetical selector subfabric, shown in Figure 6.4. Section 6.5 showed that those stages, identified in Figure 6.4 as the second and third selector stages, really don't exist because the first selector stage handles the first three digits. It has just been shown that the stage, identified in Figure 6.4 as the seventh selector stage, really doesn't exist because the sixth selector stage handles the last two digits. Renaming and renumbering the selector stages, the hypothetical subfabric, shown in Figure 6.4, becomes the subfabric, shown in Figure 6.1.

- The first, second, and third selector stages in Figure 6.4 become the first selector stage in Figure 6.1 and it handles the first three digits.
- The fourth selector stage in Figure 6.4 becomes the second selector stage in Figure 6.1 and it handles the fourth digit.
- The fifth selector stage in Figure 6.4 becomes the third selector stage in Figure 6.1 and it handles the fifth digit.
- The sixth and seventh selector stages in Figure 6.4 become the connector stage in Figure 6.1 and it handles the last two digits.

In a small office, serving fewer than 1000 subscribers, the subscribers could be assigned a six-digit directory number. If the office is a Stepper, it would not have a third selector stage. In a PBX, subscribers do not dial an office code for intraoffice calls. If the PBX is a Step-by-Step PBX, like the 701, it would not have the equivalent of the first selector stage.

### 6.6.2 Connector Groups

The outputs of the connectors are the subscriber's terminating appearances. Just as each subscriber has originating appearances on several line finders, every line finder in one line finder group, each subscriber has terminating appearances on several connectors, every connector in one connector group. While originating appearances are arbitrarily assigned to a line finder group, terminating appearances are assigned to a connector group according to the subscriber's directory number.

Consider the subscriber with directory number 876-5432 and let the office with office code 876 be a Stepper. One connector group in the connector stage in that 876- office is reached by dialing 876-54. The tip, ring, and sleeve from the terminating side of this subscriber's line circuit are wired to each Strowger switch in this connector group. The connection is to the second post in the third row of the contact banks on each connector in this group. There is no odd multipling; all connectors in a group are wired identically.

The number of connectors in a connector group is determined by the traffic intensity of the 100 subscribers served by the group; the 100 people in the office whose directory number has the same five-digit prefix (876-54). Copying the example from Section 6.3.3, let the typical line be busy an average of 1.8 minutes out of every hour on calls this line terminates. Calls that originate from this line do not tie up a connector. Then, each subscriber is responsible for 0.03 Erlangs of traffic intensity at the connector stage in the Step office. With 100 subscribers, maximum, in a connector group, a full group must handle 3 Erlangs total. By Figure 5.4, eight connectors would serve this group of 100 lines with a $P_b = 0.012$ and 37.5% occupancy. While an individual connector provides 1:100 expansion, the group described above provides for $8:100 \approx 1:13$ expansion.

The quality of service provided by a connector group is sensitive to variations in traffic intensity, especially with the access at only 100 lines. Consider subscribers, like pizza parlors, who terminate many more than the average number of telephone calls or host computers that terminate calls with long holding times from callers with terminals and modems. When such a subscriber is added to a connector group, or when existing group members suddenly change their calling patterns, it can be noticeable to the other subscribers in the group. If all the connectors in a group are busy, a potential call will be blocked and the calling party will hear path-busy tone. The called party doesn't know, directly, that service has been affected. Since most people don't distinguish the tones for path-busy and called-party busy, the people that call a subscriber in an underserved connector group, accuse him of talking on the telephone too much.

For example, consider a connector group served by eight connectors, based on 0.03 Erlangs per subscriber. Let only two of the subscribers be the called party for hours on modem-connected calls. The remaining 98 subscribers are served by the six remaining connectors. At 0.03 Erlangs each, the net traffic intensity is $0.03 \times 98 = 2.94$ Erlangs and, from Figure 5.4, $P_b = 0.08$, a little too high. The telco must either add more connectors to this group or move some terminating appearances to another group. Moving line appearances on the terminating side of a Step fabric, however, is a large problem, because each moved party must agree to change his directory number.

### 6.6.3 Operation of the Selector Subfabric

Consider that some subscriber has lifted the handset of his telephone with the intention of calling the party with directory number 876-5432. Let both parties be served by the same Step-by-Step building, not necessarily the same office. This calling party's line is found by the operation described in Section 6.3.2 and is connected to a first selector by the operation described in Section 6.4.2. This calling party hears a dial tone.

This calling party dials 8, stepping this first selector up eight levels. A tab at the top of its shaft forces this first digit to be absorbed, the switch normalizes, and dial tone is removed. This calling party dials 7, stepping this first selector up seven levels. Another tab at the top of its shaft forces this second digit to be absorbed and the switch normalizes again. This calling party dials 6, stepping this first selector up six levels. A different tab at the top of its shaft forces this third digit to be connected and the switch begins rotary motion in hunt mode. Rotary motion stops on the first post in this sixth row that has an open-circuit condition on its sleeve. Tip, ring, and sleeve are connected to a second selector link and onto a previously idle Strowger switch in the second selector stage. The switch is in that group that corresponds to the 876- dial prefix; the left edge of the 876- office's fabric in this building's subfabric. The D relay operates in this first selector and the A relay operates in this second selector — advancing supervision.

This calling party dials 5 and this fourth digit steps this second selector up five levels, where the switch begins rotary motion in hunt mode. Rotary motion stops on the first post in this fifth row that has an open-circuit condition on its sleeve. Tip, ring, and sleeve are connected to a third selector link and onto a previously idle Strowger switch in the third selector stage. The switch is in that group that corresponds to the 876-5 dial prefix. The D relay operates in this second selector and the A relay operates in this third selector — advancing supervision. This calling party dials 4 and this fifth digit steps this third selector up four levels, where the switch begins rotary motion in hunt mode. Rotary motion stops on the first post in this fourth row that has an open-circuit condition on its sleeve. Tip, ring, and sleeve are connected to a connector link and onto a previously idle Strowger switch in the connector stage. The switch is in that group that corresponds to the 876-54 dial prefix. The D relay operates in this third selector and the A relay operates in this connector — advancing supervision.

### 6.6.4 Connector Operation

The example continues. This calling party dials 3 and this sixth digit steps this connector up three levels, where the switch waits for the next digit. This calling party dials 2 and this seventh digit rotates this connector by two positions.

Let the called party be idle; the case where the called party is busy is covered in the next paragraph. The line circuit has caused an open-circuit condition on the sleeve wired to this position. The sleeve of the switch train is connected to the sleeve of the called party. The ground condition on the sleeve of the switch train operates the cut-off relay in the called party's line circuit. The connector retains supervisory control of the call, connects ring signal directly to the called party's tip and ring and, after attenuation, to the tip and ring of the switch train for the calling party. When the called party answers, the ringing signal and the attenuator are disconnected, and the tip and ring of the switch train are connected directly to the tip and ring of the called party.

Reconsider the call to the subscriber with directory number 876-5432. Let this called party be busy when the calling party's seventh digit, a 2, rotates the chosen connector by two positions along its third level. The called party's line circuit has caused a ground condition on the sleeve wired to this position. Then, this connector connects the busy tone to the tip and ring of the switch train which is heard by the calling party. Even if the called party hangs up immediately afterwards, the call will not be completed.

Sometimes a connector can be made to revert to hunt mode over one row or even part of one row. A hunt group is a set of consecutive posts on a rotary that are hunted over by a connector. The application is discussed in Section 10.3.1.

## 6.7 EXAMPLE

Consider a Step system that serves a small community with 500+ people.

### 6.7.1 Initial Deployment

This system has a small main frame and 500+ line circuits. Assume that each user is busy 6% of the time, on the average, during peak busy hour. If originating and terminating traffic is balanced, then each user originates 0.03 Erlangs of traffic intensity and each user terminates 0.03 Erlangs of traffic intensity. So, the fabric must handle 500 $\times$ 0.03 = 15 Erlangs of traffic load on its originating side and another 15 Erlangs of traffic load on its terminating side.

Since a line finder group serves at most 200 originating parties, three line finder groups are required to handle any number of originating parties between 401 – 600. If we assume that originating traffic divides uniformly over the three groups, then each group must handle 15/3 = 5 Erlangs. Using $P_b = 0.01$, Figure 5.5 shows that 5 Erlangs requires 11 servers. Thus, each line finder group needs 11 switches and the line finder stage has 33 switches total. Since every line finder switch is wired directly to its own dedicated first selector switch, the first selector stage also has 33 switches.

### 6.7.2 Trunking

Let the office code of this office be 654. Let the office code of two nearby local offices, to which this office has direct trunks, be 873 and 952. Let the toll prefix be 1 and the operator code be 0. Thus, all 33 first selectors are wired to absorb digits 5 – 9. Links to the second selectors are wired to the 4-level on all the first selectors. Trunks to the 873-office are wired to the 3-level on all the first selectors. Trunks to the 952- office are wired to the 2-level on all the first selectors. Trunks to the toll office are wired to the 1-level on all the first selectors. Links to the operators are wired to the 0-level on all the first selectors. In this example, we'll ignore operator traffic.

Let's assume that originating traffic is split 60/40 between intraoffice and interoffice calls, respectively. Let's further assume that interoffice calls are split 50/25/25 among calls to the toll office and calls to each of the two nearby direct-trunked offices, 873 and 952. Thus, this office's originating 15 Erlangs are split up as: 9 Erlangs (intraoffice) to the second selector stage, 3 Erlangs to the trunk group connecting to the toll office, 1.5 Erlangs to the trunk group connecting to the 873- office, and 1.5 Erlangs to the trunk group connecting to the 952- office. Let's assume that the toll office and the two local offices are close enough that one-way trunks are economically justified. Then, using $P_b = 0.02$ for trunks, Figure 5.4 shows that the outgoing toll trunk group requires eight trunks and the outgoing trunk groups to offices A and B require five trunks each.

Thus, on all 33 first selectors the first eight rotary positions on the 1-level are connected to originating trunk circuits on outgoing toll trunks, the first five rotary positions on the 2-level are connected to originating trunk circuits on outgoing trunks to the 952- office, the first five rotary positions on the 3-level are connected to originating trunk circuits on outgoing trunks to the 873- office, the higher positions on these 1-, 2-, and 3-levels are connected to the network busy tone, and all 10 rotary positions on the 4-level are connected to second selector links (more on this below).

The wiring to the trunk groups is in slipped multipling. For example, if the five trunks to the 952- office are called a, b, c, d, and e, on six of the 33 first selectors the first five rotary positions on the 2-level are wired to a, b, c, d, and e, respectively; on six of the 33 first selectors the first five rotary positions on the 2-level are wired to b, c, d, e, and a, respectively; on seven of the 33 first selectors the first five rotary positions on the 2-level are wired to c, d, e, a, and b, respectively; on seven of the 33 first selectors the first five rotary positions on the 2-level are wired to d, e, a, b, and c, respectively; and on seven of the 33 first selectors the first five rotary positions on the 2-level are wired to e, a, b, c, and d, respectively.

### 6.7.3 Fabric

Back to the output of the first selectors, we've seen that this office's originating subscribers generate 9 Erlangs of intraoffice traffic. This traffic flows over second selector links to a pool of second selectors that handles intraoffice calls. If we had full-access connectivity between the first and second selectors, Figure 5.5 shows that 17 second selectors would be needed. But we don't have full access because this pool of servers is reached only from the 4-level of the first selectors (after the originating subscriber dials 654); so each first selector can access only 10 servers. Economy of scale suggests that the number of intraoffice second selectors is ≥ 17.

If we segregated the 33 first selectors into two distinct groups and allocated a separate pool of second selectors to each of these two distinct groups, then each second selector group would have to handle 4.5 Erlangs and would require 11 second selectors per group (10 of them would cause $P_b = 0.02$). Thus, 22 second selectors in a 2-group segregated-access arrangement will handle the traffic; but this still doesn't satisfy the first selectors physical limitation of 10 servers per row. Twenty second selectors in a 2-group segregated-access arrangement will almost handle the traffic and still satisfies the first selectors physical limitation. If we segregated the 33 first selectors into three distinct groups and allocated a separate pool of second selectors to each of these three distinct groups, then each second selector group would have to handle 3 Erlangs and would require eight second selectors per group. Thus, 24 second selectors in a 3-group segregated-access arrangement will handle the traffic and still satisfy the first selectors' physical limitation.

Since a slipped-multipling arrangement performs worse than a full-access arrangement, but better than a totally segregated-access arrangement, intuition suggests that the number of servers should be between 17 and 24. Intuition and experience suggest that using slipped multipling to distribute intraoffice traffic, the required number of servers is roughly in the middle of this range. While 20 servers were insufficient for segregated access, it is probably a sufficient number for a slipped multiple. Since three groups of eight each can handle 3 Erlangs each, the number of intraoffice second selectors is ≤ 24. Another way of looking at this is to observe that if 20 servers in two segregated groups block at 0.02, then 20 servers using slipped multipling ought to block at a lower probability. So, we guess that ≈ 20 switches should handle this load.

So, first selectors 1 and 21 are wired from their 4-level to second selectors 1 – 10; first selectors 2 and 22 are wired from their 4-level to second selectors 2 – 11, ...; first selectors 11 and 31 are wired from their 4-level to second selectors 11 – 20; first selectors 12 and 32 are wired from their 4-level to second selectors 12 – 20 and then 1; first selectors 13 and 33 are wired from their 4-level to second selectors 13 – 20 and then 1 – 2; first selector 14 is wired from its 4-level to second selectors 14 – 20 and then 1 – 3, ...; and first selector 20 is wired from its 4-level to second selectors 20 and then 1 – 19.

Let's assume that interoffice traffic is balanced, with equal originating and terminating traffic in each destination. The incoming toll trunk group also has eight trunks and the incoming trunk groups from the 873- and 952- offices also have five trunks each. If we a assume that this office's 654 office code is absorbed at the originating office, then all incoming trunks must connect to second selectors. While we might consider an arrangement similar to line finders to provide concentration between the trunks and the second selectors, trunks can be assumed to be very highly occupied (if they are not, we would need fewer of them). Thus, each of the 18 incoming trunks is connected to its terminating trunk circuit and then to a dedicated second selector.

This office has 38 second selectors — 20 in the pool that is slip-multipled to the 4-level of the 33 first selectors for intraoffice calls and 18 that are each directly wired to an incoming trunk. This office does not have a third selector stage, and the people in the community have a six-digit telephone number.

Since a connector group handles up to 100 terminating appearances and since this office has slightly more than 500 telephones, the office has six connector groups. The 500+ telephone numbers are between 654-111 and 654-600 (0 is 10). There is allocation for 600 numbers. If the traffic to the 500+ terminating parties is distributed uniformly over the six connector groups, then each group must handle:

$$\frac{\text{15 Erlangs of total traffic}}{\text{6 groups}} = \text{2.5 Erlangs/group}$$

and each group requires eight switches. There are 48 connectors in the office.

This building/office requires 33 + 33 + 38 + 48 = 152 Strowger switches.

### 6.7.4 Growth and Change

Let this community grow gradually. With any growth, the capacity of the power and tone plants must be increased, the main frame must be expanded, line circuits must be added, and more trunks might be needed. In addition, as the number of subscribers approaches 600, switches must be added gradually to the various groups in the various stages of the fabric. In addition to this, when size passes 600, 700, and so on, new line finder and connector groups must be added, and some terminations on the fabric may be rearranged. In addition to this, when size passes 1000, a third selector stage must be added and seven-digit dialing must be introduced to the community.

While a Strowger switch is not expensive, installing and rewiring switches and otherwise changing a Step-by-Step office is labor intensive. The level of skill and training of the framemen that do this work is extremely high. Compounding this, Step is highly susceptible to external effects. Changes in the dial plan, growth in neighboring communities, and even changes in traffic patterns in neighboring offices cause major changes in a Step office. The addition of a new office code to some building causes a major rewiring of all the first selectors in all the old offices in that building and in any Step offices in other buildings with direct trunking to this building.

## 6.8 DISCUSSION

Issues presented are cost versus size, growth, OA&M, call tracing, and Touch Tone provision. General pros and cons of Step-by-Step systems are discussed.

### 6.8.1 Cost versus Size

Step is the epitome of the cellular architecture, discussed in Section 2.4.5. The cost-per-line curve is that of the cellular system in Figure 2.7.

- In small offices, Step-by-Step is less expensive than common control or modular systems. Step has little common equipment, equipment required in a switching office regardless of its size, compared to the other systems that will be described.
- As a cellular system, Step grows in small increments by the addition of individual Strowger switches. Thus the cost-per-line curve is smoother than that of a common control or modular system.
- The average slope of this cost-per-line curve, the incremental cost per subscriber, is higher than that of the common control or modular systems.
- In large offices, Step-by-Step is more expensive than common control or modular systems. In a large common control or modular office, the cost of the common equipment is spread over enough subscribers that the cost per line is less than that of Step.

- The cost-per-line curve of Step crosses over that of a typical common control or modular system. Over the years, this crossover point has moved to the left, toward smaller office sizes.

### 6.8.2 OA&M

Operation, Administration, and Maintenance (OA&M) is the cost of running a switching office. Most of this cost is labor personnel, the highly skilled framemen and switchmen. OA&M has many cost components.

- New subscribers, and any additional switches they need in line finder and connector groups, must be added. Subscriber appearances on the fabric must be moved because of changes in class of service or traffic balancing.
- Digit absorbing must be reconfigured and previously unused first selector rows must be equipped in response to changes in the dial plan.
- Detection and location of points of high blockage in the fabric are difficult. Interpretation of subscriber complaints requires experience and thorough knowledge of the office. Switches must be added to switch groups that are suspected to be undersized.
- Detection and location of faults in the fabric are also difficult. Again, patterns must be derived from subscriber complaints. Since Step has no built-in automatic testing procedures, the fabric must be manually tested periodically to locate faulty switches and broken links. These faults must be repaired manually.
- Repairs and changes are time-consuming and must be performed on-line; the office cannot be brought down. Class of service is temporarily changed and faulty switches are simulated busy by holding contacts operated with toothpicks. Permanent changes are performed later.

All the varieties of switching office have an average annual OA&M expense. But cost of OA&M is higher in Step than in more modern systems. More OA&M is required because the architecture is more sensitive to change. The OA&M is more labor intensive because electromechanical equipment is more difficult to keep working, requires significant preventive maintenance, and the changes and fixes are performed manually with soldering irons, wire strippers, and plyers.

Step requires a large amount of floor space. While this has a direct expense, it also contributes to increased time in simply walking from one point in the fabric to the next. Furthermore, all this labor takes place in an extremely noisy environment.

On the positive side, Step-by-Step is simple to understand. Training the craftsmen for Step-by-Step is easier than for ESS. Craftsmen are not specialized to pieces of equipment because so much of the equipment is made from the same piece part.

### 6.8.3 Limitations

The Step architecture is further limited because (1) calls are set up through the fabric directly as the number is dialed, and (2) there is no common place where the called number resides so it might be read, altered, interpreted, or translated.

Obviously, the fabric has many different paths that provide a switched connection between a given pair of calling and called parties. In Step, if the switch-train is blocked at some point in the fabric, it cannot back up and try an alternate path. In a fabric with end-marked control, the controller investigates all alternate paths until one is found that completes the desired connection.

Call tracing is difficult without common control. When the police request a call trace for a given party, the framemen in a Step office are prepared for rapid response. When this party is called, these framemen inspect the connectors in the called party's connector group, looking for the one in use on this call. Then they inspect the third selectors that are wired to this connector, and so forth. They run around the office with the wiring diagram of the fabric until they have worked their way backwards through the fabric to the line circuit of the calling party. In the typical kidnapping story on television, the called party must keep the bad guy on the line so the telephone company has time to trace the call. This drama is passé, because it only relates to electromechanical offices.

Let a subscriber served by a Stepper dial 1 or the office code of a distant local office that is direct trunked. Unlike dialing out of a PBX (Section 10.4.4), the current numbering plan does not require this subscriber to pause or to wait for dial tone from this receiving office before continuing to dial. This receiving office detects a seizure on this trunk and must be prepared to receive dialed digits immediately. If this receiving office is also a Stepper, the trunk is directly wired to a selector switch, another reason that such trunks are not wired to the line finder stage. If this receiving office has common control, a dial pulse receiver must be connected to the trunk. But a typical connection through the fabric takes longer to complete than the interdigit interval. So a special arrangement is necessary, described in Sections 8.4.5 and 9.2.5. When the transmitting office has common control, the receiving office can signal its readiness to receive the digits and this special arrangement is unnecessary.

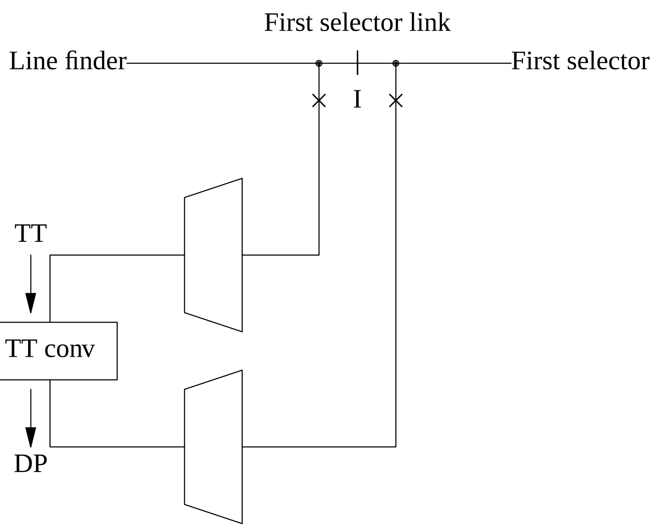


**Figure 6.6.** Touch Tone interception.

### 6.8.4 New Services

Touch Tone digits cannot pulse a Strowger switch. Step offices are equipped for Touch Tone by changing certain first selector links so that additional equipment may be added, in series, during dialing. This change includes inserting an *interception circuit,* two make contacts and one break contact of an interception relay, in the paths of the tip and ring of the link. The additional equipment includes a Touch Tone converter (TTC), that accepts Touch Tone digits and converts them into dial-pulse digits, and matched concentrators. See Figure 6.6, where a line represents a tip/ring twisted pair.

Immediately after going off-hook, a Touch Tone subscriber's line is found by a line finder and connected to a first selector link. The I relay is operated and an idle Touch Tone converter is assigned. The matched concentrators connect the line finder side of the link to the Touch Tone input of this TTC and the first selector side of this same link to the dial pulse output of this same TTC. The Touch Tone converter returns dial tone to this subscriber. As Touch Tone digits are input to the TTC, they are recorded and dial-pulsed into the first selector. Since the Touch Tone digits may be input faster than the corresponding dial pulses can be output, the TTC stores the intermediate digits. After the TTC has output the last dial-pulse digit, several seconds after the subscriber is done dialing, the I relay is released. Then, the link is cut through, and the TTC is available for another call.

Every first selector link that any Touch Tone subscriber might reach must be changed for Touch Tone interception. By segregating all Touch Tone subscribers into common line finder groups, the number of links that must be changed is reduced.

Step modernization was proposed many times. The first selector link would be intercepted, as in Touch Tone provisioning, except that the Touch Tone digits received from the subscriber would be examined by a processor before they were dial-pulsed into the Step fabric. The processor could reside in the Step office or one remote processor might serve several offices via a data link between it and each TT-DP converter. Adding intelligence to Step in this way enables the kinds of services that were introduced with ESS and also enables a primitive form of alternate routing. In abbreviated dialing, the subscriber stores, say, 10 full directory numbers in a shared memory and then uses, say, #8 to signify a request to call the eighth of those numbers. Abbreviated dialing and other similar services are obviously impossible in a regular Step office and require this kind of interception. In addition, the processor could initiate automatic redial in case the fabric blocked the initial call attempt.

### 6.8.5 The Partition

Step has no physical partition between switching hardware and control because the signaling path is inseparable from the data path and the control subsystem is inseparable from the connection subsystem. But a logical partition exists; it is a temporal partition.

The temporal duration of a call is partitioned into setup time and connect time. During call setup, the integrated system is in control mode and expects signaling only; you can't speak and expect anything to happen or expect anyone to hear you. During connect time, the integrated system is in talking mode and expects conversation only; you can't dial your telephone and expect anything to happen. You can't talk during dialing and you can't dial during talking.

This partition requires three triggers (triggers will be discussed again in Chapter 18) to effect the transitions from: idle mode to call setup mode to talking mode and back to idle mode. These triggers are supervisory signals. When the calling party raises the handset off his nonringing telephone, he triggers the system from idle mode to call setup mode. When the called party answers his ringing telephone, he triggers the system from call setup mode to talking mode. When the calling party hangs up (assuming calling-party supervision) he triggers the system from talking mode back to idle mode.

One of the biggest economic problems with Step (or with any distributed-control cellular architecture) is that the control intelligence remains associated with the call not just during call setup, but for the entire duration of the call. And, in spite of the control intelligence being present, it can only be used when the mode is right.

## EXERCISES

6.1 On a phototcopy of the block diagram of a Step office in Figure 6.1, add the connection to a two-way toll trunk (see Figure 4.5) and a two-way interoffice direct trunk.

6.2 Consider an electronic integrated circuit, called a selector, that has one three-wire input and 10 three-wire outputs [3 – 5]. A selector accepts one bit-serial BCD digit (after conversion from Touch Tone) over two of the input wires and then connects its input pair to the output pair that corresponds to the digit. The third wire in all ports is used for supervision and busy indication. Subsequent signals, including other BCD digits, pass through this connection. Consider another electronic integrated circuit, called a hunter, also with one three-wire input and 10 three-wire outputs. When a hunter is connected at its input, after testing the third input wire, it connects the input pair to an idle output pair in some priority order. Subsequent signals, including other BCD digits, pass through this connection. For each of the three applications of the Strowger switch, sketch its equivalent implementation using these electronic circuits.

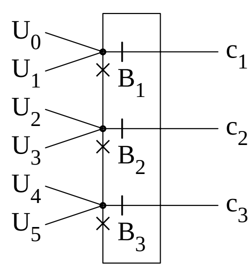


**Figure 6.7.** Preference chain.

6.3 Consider the relay contact circuit for an allotter preference chain shown in Figure 6.7. In the figure, the rectangle is not a box, but is a wire from the make contact of $B_3$ to the common of $B_1$. Since this is not a series/parallel circuit, it is difficult to analyze and should be appreciated as a clever design. Let $U_0 - U_5$ be the start wires from six line circuits. Let $B_1 - B_3$ be the rest position transfer contacts, indicating the busy/idle status of three line finders. Let $c_1 - c_3$ be the outputs of this allotter, the control wires to these same three line finders. For each line

(0 – 5) specify the first, second, and third preference, as determined by this circuit, for the three line finders.

6.4 Suppose a Step office has 20 first selectors and 20 local operators. Sketch two different wiring patterns. (a) Ten of the first selectors connect to one group of 10 operators, and the other 10 first selectors connect to the other 10. (b) The 20 operators are ordered and slipped multipling is used so that each first selector begins hunting with a different operator.

6.5 Describe how the following classes of service would be implemented in a Step PBX that homes on a Step CO. (a) Internal calls only, no dial-9 calls. (b) Internal and external local calls only, no long distance. (c) Originate only, no terminating calls. (d) Terminate only, no originating calls.

6.6 In the extended example of Section 6.7, if all the one-way trunks were replaced by two-way trunks, how many trunks would be needed in each trunk group? How does this change the number of switches in the office?

6.7 Suppose a Step office has 150 Touch Tone subscribers, which are segregated into one line finder group. (a) If these subscribers average 1.5 originations during the PBH and they average 4 minutes on each call, what is the TI on the LFG? (b) How many line finders are required in the LFG for $P_b < 0.01$? (c) If these subscribers average 10 seconds to dial a telephone number, what is the TI on the group of TT-DP converters? (d) How many TT-DP converters are required? (e) What are the dimensions of the two concentrators in Figure 6.6?

6.8 Completely lay out the fabric of a base-3 Step-by-Step central office that serves 27 subscribers. Use the following assumptions.

- Assume you live in a base-3, or ternary, country, where the dial telephones have three holes in the dials instead of 10. Subscribers can only dial 1, 2, or 0.
- In this country, Strowger switches are manufactured, not as $10 \times 10$, but as $3 \times 3$, with nine contacts on the back of a switch. Thus, there are nine subscribers per line finder group or connector group. There is no doubled access by tripled banks in line finders.
- Each subscriber in this office has a 4-digit directory number, 2-xxx (each x = 0, 1, or 2), and originates an average of one 3-minute call every 4 hours.
- All interoffice calls are toll switched and the toll access code is 1. The operator access code is 0. Forty-five percent of all originating traffic is intraoffice, 45% is outgoing to toll, and 10% is to the operator. There is one incoming toll trunk, carrying 0.076 Erlangs, that connects directly to a second selector.
- Use $P_b = 0.01$ throughout, except for 0.1 at the operators.
- Show all switches, operators, start circuits, allotters, and trunk circuits as blocks, and all the wiring that interconnects them. Use the symbol of Figure 6.2 for a Strowger switch, except with three bumps instead of 10.

Use slipped multipling, but let the tip, ring, and sleeve leads be represented by one line.

- Show two typical subscribers, connected to line circuits (as blocks) and to the originating and terminating sides of the fabric. Identify their directory numbers.

Hints: (a) first, find the number of line finders in a line finder group and the number of connectors in a connector group and then the number of groups; (b) next, find the number of outgoing trunks and operators; (c) you should need to use only five connections at the back of each first selector; (d) you should need to use 21 Strowger switches in the total office.

## REFERENCES

[1] Bambos, N., "Toward Power-Sensitive Network Architectures in Wireless Communications," *IEEE Personal Communications,* Vol. 5, No. 3, Jun. 1998.

[2] Woesner, H., et al., "Power-Saving Mechanisms in Emerging Standards for Wireless LANs," *IEEE Personal Communications,* Vol. 5, No. 3, Jun. 1998, pp. 40 – 48.

[3] Thompson, R. A., "A Chronology of the Design and Development of an Electronic Telephone System," *Report to Office of Experimental R&D Incentives of the National Science Foundation,* Nov. 1973.

[4] Thompson, R. A., "Experiment Definition: R&D Incentives of an Electronic Telephone System," *Final Report to the Office of Experimental R&D Incentives of the National Science Foundation,* May 1974.

[5] Thompson, R. A., "The Management of Industrial R&D at the University," *IEEE SouthEastCon,* 1975.

## SELECTED BIBLIOGRAPHY

Brooks, J., *Telephone — The First Hundred Years,* New York, NY: Harper & Row, 1976.

Clarke, A. C., et al., *The Telephone's First Century — and Beyond,* New York, NY: Thomas Y. Crowell, 1977.

Joel, A. E., Jr., *Electronic Switching: Central Office Switching Systems of the World,* New York, NY: IEEE Press, 1976.

Miller, K. B., *Telephone Theory and Practice, Vol. II,* New York, NY: McGraw Hill, 1933.

Noll, A. M., *Introduction to Telephones and Telephone Systems,* Norwood, MA: Artech House, 1986.

Pearce, J. G., *Telecommunication Switching,* New York, NY: Plenum Press, 1981.

Rey, R. F. (ed.), *Engineering and Operations in the Bell System,* Second Edition, Murray Hill, NJ: AT&T Bell Laboratories, 1977.

Schindler, G. E. (ed.), *A History of Engineering and Science in the Bell System,* Murray Hill, NJ: Bell Telephone Laboratories, 1982.

Talley, D., *Basic Telephone Switching Systems,* New York, NY: Hayden Book Company, 1969.