The step-by-step telephone switching system: Overview

Douglas A. Kerr

ABSTRACT AND INTRODUCTION

The step-by-step telephone switching system (as it is known in the Bell Telephone System; the "Strowger" system elsewhere) was the earliest "mechanized" telephone switching system to receive broad acceptance, and it remained important for many decades. This is the first of a series of articles on this system, and it gives a detailed overview of the system. First, the history of the system is reviewed. Then the architecture of the system, and the unique switch mechanism it utilizes, are discussed. The overall working of the system in handling calls is discussed in considerable detail, although not at the "circuit" level. Background is given that will be common to the companion articles. The companion articles discuss in greater detail, often at the "circuit" level, the working of major modules of the system.

1   GENERAL

1.1   Companion articles

This article is the first of a series. The companion articles describe in detail (including at the circuit level) the different switches used in the step by step system. All the articles are indexed on, and available at, my site, The Pumpkin:

```
http://dougkerr.net/pumpkin
```

2   HISTORY

2.1   Introduction

When telephones were first used, it was typically in pairs, in what we might today describe as "intercom" operation. Perhaps a pair was used between the ranch house and the bunkhouse, or between the sales office and the adjoining warehouse. These phones were purchased by the user (who, especially in rural areas, might order them by mail from Sears, Roebuck or Montgomery Ward).

But soon the concept of the *telephone exchange* arose. Here, various homes and offices would be equipped with telephones linked by wires to a switchboard, on which a human operator could connect any two

of the telephones for a conversation. These switchboards were the nexus for a new kind of enterprise, the *telephone company*.[1]

At first, the switchboard might be located in a back room at the general store, but as these systems expanded, the switchboards (would could become quite extensive) were typically placed in purpose-built buildings. These buildings, including the switchboards, were in fact often called a *telephone exchange*[2], but later became known as *central offices*.

Manual telephone systems were not, as some might suppose, "primitive". There was enormous ingenuity and attention to detail in the design of the systems and of their "hardware" (notably the switchboards themselves), and the overall system was very complex. There was also a gigantic body of thought underlying the procedures and protocols needed to make what turned out to be a nationwide system operate smoothly.[3]

But, at the bottom line, the system was very labor intensive: it was operated by human beings. The labor cost was gigantic, and as the system expanded, there was concern that there might not be enough personnel available. One pundit had said in about 1910 that soon the telephone system would need to employ every working-age woman[4] in the country as an operator."

2.2   Mechanization

The attention of countless inventors was directed to the prospect of "mechanizing" telephone switching, and zillions of schemes were invented and patented. Many of these were developed into manufacturable, operable systems, and installed here and there for forward-looking telephone companies.

---

[1] At first these often took the form of a *cooperative*, an enterprise owned by the users. Today, there are still some telephone systems operated by an enterprise with that structural concept.

[2] In modern times, in the telephone industry, "exchange" took on a different meaning: a region used to determine the pricing of calls, such as the "Toledo exchange". Later yet, as the industry was restructured through the breakup of the Bell Telephone System, "exchange" came to take on several other meanings.

[3] All this is discussed in considerable detail in the article "Manual Telephone Switching", by the same author, and probably available where you got this.

[4] Yes, how sexist, but in fact, except at the earliest days (when telephone operators were, of course, men), for many decades the profession of telephone operator was almost universally the province of women. The industrial-sociological reasons for this are beyond the scope of this article.

But before long one system had come to the forefront, and became the most widely used system for many years. And it survived many decades—some systems of the type are still in use today. This is the "Strowger" automatic telephone system (known in the Bell Telephone System as the *step by step* system), the one we will learn about in this article.

2.3   Describing mechanized systems

Because (except in the earliest systems) mechanized telephone switching systems for some while were controlled by a dial at the subscriber station, it became common to speak of mechanized systems as "dial" systems, to be contrasted with "manual" systems.

Especially in the decades in which mechanized telephone switching was spreading throughout the telephone network, it became common (especially in the "more technical" publications) to speak of it as "machine switching". And in fact a mechanized switching system itself was often spoken of as a "switching machine[5]", or, perhaps to distinguish it from other technical facilities located in the same central office building, just "the machine"[6].

2.4   Birth of the Strowger system

Almon B. Strowger was an undertaker in Kansas City, Missouri, which was of course served by a manual telephone switching system. Folklore has it that Strowger's interest in emphasizing telephone switching came from his belief that, when someone in his part of town, bereaved over the death of a loved one, picked up the telephone and asked the operator to connect her to Strowger's undertaking parlor, the operators (one of whom was said to be the wife of an undertaker competitive to Strowger) would often connect the caller instead to the competitor.

Strowger thought that if there were no telephone operators involved, this abuse couldn't happen. And that set him on a quest with results far more reaching that his original objective.

His pivotal contribution to what we now think of as the Strowger system was the *two motion stepping switch* (often called the

---

[5] In recent years, it has become common to call a telephone switching system a "switch".

[6] For example, in a large long distance switching center, a technician at a test board where the trunks between this switching center and others around the country were tested, finding that a problem was perhaps caused in the switching system itself (probably located on a different floor of the building), might remark to a colleague, "I'm gonna call the machine and ask them to test that."

Strowger switch). In this switch (in the form we will encounter it), the terminals are arranged around a portion of a cylinder, in 10 levels, 10 terminals around on each level, the whole array being called a terminal *bank*. An electromagnet, in classical "stepping switch" fashion, lifts a shaft carrying the contact wiper in steps, each to a successively higher level. Then a second electromagnet, again in stepping switch fashion, rotates the shaft in steps, each putting the wiper on a successive terminal.

The general central concept (as it had matured greatly into the design used in the actual Strowger system) is shown symbolically in figure 1.
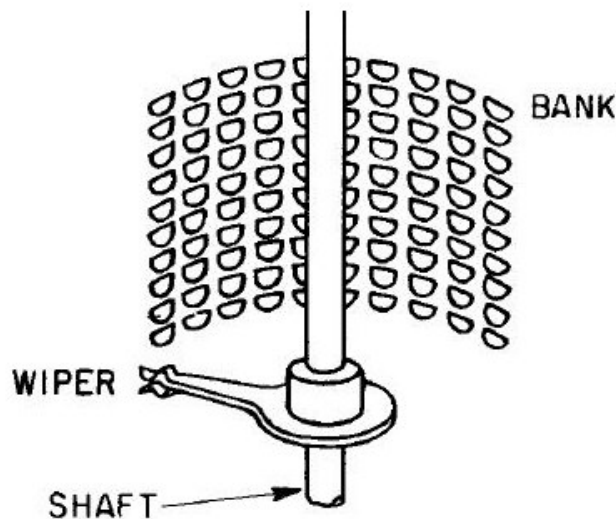

Figure 1. Strowger switch bank and wiper concept

2.5   Strowger's enterprise

Strowger, along with a relative and some colleagues, in about 1891 formed the Strowger Automatic Telephone Exchange Company to develop and produce a working telephone switching system based on Strowger's seminal switch concept. Interestingly enough, it appears that Strowger himself as not much involved in the ensuing development (not a surprise, really, as he had essentially no training in electrical and mechanical engineering).

And of course it was a long way from the switch concept taught in Strowger's patent to an actual telephone switching system, even a small one. Developing the system, and the switches, and even each little pawl or contact in the switch, was overall a stupendous task. But in fact there were capable people in Strowger's company, many of whom got to be famous names in the history of this art. Perhaps the most noted of these was Alexander E. Keith, to whom are attributed many important advances in the system.

The first commercial Strowger switching systems did not use a dial for control. Rather, if we assume a system with a maximum of 1000 lines

(adequate for the small communities where the system was first launched), the subscriber had three pushbuttons at his station. He would push the first a number of times corresponding to the hundreds digit of the wanted number, then the same with the second button for the tens digits, and then the same with the third button for the units digit.

But soon the dial was developed[7], and the familiar *modus operandi* became the premise for the future of the Strowger system.

Strowger's company had several name and structure changes, and finally became Automatic Electric Company, for many years the second largest manufacturer in North America (after Western Electric Company, the Bell Telephone System's manufacturing arm) of telephone switching systems (and telephone sets as well).

The Strowger system was quickly seen as attractive by many telephone companies (outside the Bell Telephone system, as we will see shortly), and began to spread across the US and Canada.

2.6   What about the Bell System?

By the time the Strowger system was hitting its stride, the newly-emergent Bell Telephone System became the elephant in the telephone industry room. American Telephone and Telegraph Company (AT&T) had established telephone exchange service companies in many medium and large cities, and bought numerous such companies already established by others. All these used manual switching, and that art became greatly refined under AT&T.

AT&T was of course earnestly interested in mechanization of telephone service for the economic reasons I mentioned earlier. Automatic Electric saw this as gigantic market for the Strowger system.

But AT&T's priority regarding mechanization was understandably in the large cities, where because of the size of the systems and the amount of traffic the potential economic gains through mechanization were the greatest.

Their sophisticated studies of the matter had shown them that the Strowger system did not have the "intelligence" to provide optimal network behavior in a large metropolitan area context. So they began the development of a switching system using a wholly different

---

[7] Attributed to Alexander E. Keith of the Strowger Company and his two frequent collaborators, John and Charles J. Ericson (not related, as we should guess from their names, to Lars Magnus Ericsson, founder of the famous Ericsson telecommunications company).

concept, the *panel dial* system. And they in effect said to Automatic Electric, "Don't bother me right now".

By 1920 the Bell System had begun to deploy panel dial systems in many of the large cities in which it operated.

But, once the Bell System was well on the way toward mechanizing its large city systems, it turned its attention to the cities in the next tier of size.

And, in order to move on that, they began to buy Strowger systems from Automatic Electric (applying many of their own requirements and specifications). Seeing that this was working out well, their next step was to arrange for a license from Automatic Electric under which they could manufacture Strowger systems themselves (that is, by Western Electric).

The initial versions were essentially "clones" of the Automatic Electric product, but of course soon they added their own features and designs. Still, the basic switch mechanism remained essentially unchanged, and throughout the history of both product lines, switch parts from Automatic Electric and Western Electric were generally interchangeable.

Even when the equipment was purchased from Automatic Electric, the Bell System spoke of the system as the "step by step" system (often abbreviated as "SXS") rather than the "Strowger" system. And I will refer to the system by that name from here on. But I may still on some occasions speak of the switch concept as the "Strowger" switch.

3   SOME TECHNICAL BACKGROUND

3.1   Local battery and common battery operation

In most telephones used until late in the 20th century, the transmitter ('microphone") was of the variable resistance type, and required DC current through it to "energize it". In the earliest telephones of this type, this was provided by a battery of two or three quite large dry cells (the type later identified as the "Number 6"), typically located on the lower part of the telephone set housing. As telephone exchanges emerged, the telephone companies generally insisted on providing the telephone sets themselves, and with that came the responsibility of feeding them, that is, replacing these "batteries" periodically, rather a pain.

Relief from this came from the concept of providing DC current over the telephone line from the central office to energize the transmitter at the station. This scheme was at first called the "central energy" scheme, but soon the term "common battery operation" became most

widely used. Then, to allow the "original" way of working to be distinguished, it became known as "local battery" operation.

3.2 Line and loop

Early telephone lines used one conductor ("wire"), and the circuit returned to ground at each end. This made the line very susceptible to noise from various phenomena. Soon it was concluded that it would be much better to use two conductors for the line.

Transmission of speech signals[8] was on a balanced basis: identical AC signals (as would be measured with respect to ground), but with opposite polarity, appeared on the two conductors. Seen from conductor to conductor, the two signals added, and it was this net signal to which the telephone set responded.

When a DC voltage is applied to the line at the central office (as in *common battery* operation), in order to energize the transmitter ("microphone") at the station, and to allow the central office to determine whether the station is "off hook" or not (see sections 3.1 and 3.5), the current flow is out one conductor and back through the other.

Thus it became common to view this circuit as a "loop", and as a consequence, a telephone line) especially as it exists outside the central office) is often called a *loop*.

3.3 Tip, ring, and sleeve

By way of a tradition referencing the contacts on the plug used in manual telephone switchboards, the two conductors of a telephone circuit are usually spoken of as the *tip* and *ring* conductors (and often we just say "tip" and "ring", not including "conductor").

When speaking of things inside a switching system (or even inside a telephone set), it is common to say "lead" (pronounced "leed") rather than "conductor".

Inside a switching system, the tip and ring leads are almost always accompanied by a third lead, called (by virtue of the same tradition) the *sleeve* conductor.

These three leads are usually designated on drawings and the like as T, R, and S, respectively.

---

[8] Other than in the telephone system context we would probably say "audio" signals, but that term is not typically used in "traditional" telephone system discussions.

3.4   Battery

Central office equipment runs from a DC voltage that is supplied by a large storage battery, which is continuously charged by a rectifier system or the equivalent. In reality, under normal operation, the current to run the equipment comes from the rectifier, and the battery just "floats".

Most central office equipment (including most step by step systems) operate from a nominal voltage of 48 V. For an esoteric but very important reason, this voltage is usually negative with respect to ground (-48 V).

Because of the way in which the power source is organized, the operating voltage is spoken of as "battery".

3.5   Off hook and on hook

In early telephones, the earliest separate hand-held receivers (often today spoken of by civilians as the "potato masher" style) had a large screw eye on their "butt end". This was hung on a hook extending from the telephone set (which of course was on the wall). The hook was movable, and operated contacts inside the telephone set proper. When the hook was pulled down by the weight of the receiver, these contacts disconnected the telephone set circuit from the line, and opened the circuit from the dry cell battery in the base of the telephone set to the transmitter ("microphone") circuit.

Later, when *common battery* operation was adopted, in which the DC to energize the transmitter was fed from the central office, thus eliminating the need for the dry cell battery at the station, a real maintenance pain, a further advantage was that the central office could easily tell when the subscriber lifted the receiver "off the hook" to place a call, since this allowed current to flow in the line from the DC voltage applied at the central office, which could easily be perceived with a relay.

So, even today, the contact set operated in a modern telephone set when the handset is placed in the cradle is called the hookswitch[9]. And the state of the telephone set is spoken of as being *off hook* (when it is active) *vs*. *on hook* (when it is idle).

And in fact, in the broader field of signaling over telephone trunks, the two states of the "signaling channel" are usually designated *off hook* and *on hook*.

---

[9] Curiously enough, the modern term is sometimes "switchhook". I guess this is like the hair style feature made famous by General Burnside becoming called "sideburns".

3.6   Multi-party lines

In a multi-party line (often called by civilians a "party line"), two or more subscriber stations are connected to the central office over one line. This is a gigantic topic overall, with many different schemes being used.

In an important class of schemes, each "party" has a distinct telephone number.

We may say that a step by step switching system with a certain number of stages, fully "fleshed out", can handle up to 10,000 lines, but what we really mean is "up to 10,000 numbers".

But to avoid complicating our discussions, In this article I will assume that all subscribers are served by "individual lines (single-party lines). Then we can speak rather interchangeably of 'lines" and "numbers".

3.7   Talking battery

Because the original motivation for providing DC onto the line from the central office was to energize the station transmitter, the DC that is applied onto a connection from different places in the step by step system (as the connection advances) is often spoken of as "talking battery".

The irony of the term is that, even though the provision of this battery is critical to switching system operation at its various stages, until the connection is completed there is no one to "talk" to.

3.8   The dial

Although (as mentioned in section 2.5) the earliest Strowger systems use pushbuttons at the station to "enter" the desired number, soon the dial (what we today might speak of as a "rotary dial) was introduced for that purpose. The signaling principle is this. If the user wants to "enter" the digit 7, he puts his finger in a hole in the dial finger wheel marked "7", pulls the finger wheel around (against a spring) until his finger hits a stop, and releases the finder wheel.

The spring pulls the finger wheel back to the resting position, at a speed controlled by a little "flyball" governor. As the wheel returns. a cam operates a contact that opens the continuity of the station (and thus the flow of current through the line) 7 times, at a rate of about 10 interruptions per second. These interruptions are called *pulses*.

The "code" is mostly straightforward: 2 pulses for a "2", 7 pulses for a "7", and so forth, but for a "0" (since zero pulses could not be perceived), 10 pulses are sent.

4   THE SWITCHES THEMSELVES

There are three principle types of switch used in the step by step system, all based on the Strowger concept, and in fact having almost identical mechanisms and overall construction: the *line finder*, the *selector*, and the *connector*. The three types, however, differ considerably in their complement of relays; their circuitry; and their role in the switching network and how they operate to fulfill it.

Figure 2 shows a typical step by step switch. This one happens to be a *selector* switch, whose role you will hear of shortly.
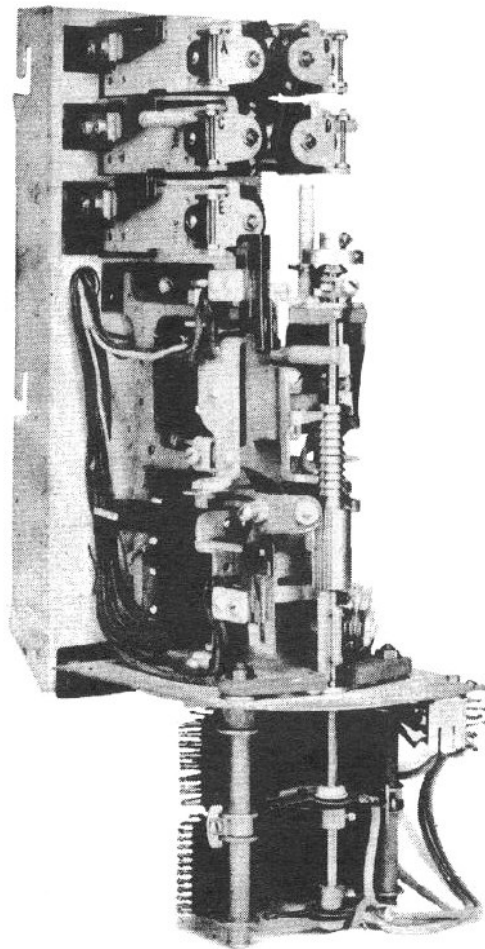
Figure 2. Typical selector switch

At the bottom we see the banks. Plural? Yes. When I introduced the concept of the Strowger bank and wiper system, I was intentionally vague about the nature of the bank "terminals". It would be easy to assume that each terminal of the bank had three contacts (for the tip, ring and sleeve conductors) and that the wiper had three contact-making members to connect to them.

But in reality, we can only readily have two contacts at a bank position. So in fact the "bank" of the switch is actually an assembly of two banks, as we see in some detail in figure 3.
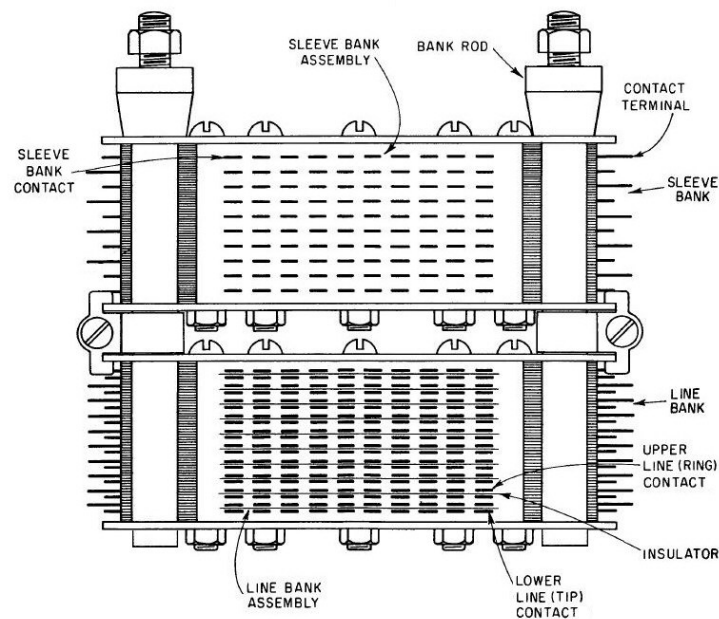
Figure 3. Three-conductor bank assembly

On the lower bank, at each position are two contacts, rather thin, lying opposite one another on a thin insulating phenolic sheet. At each position, these contact pairs carry the ring and tip of the circuit. There is a thicker phenolic sheet, not shown in the drawing, between these "sandwiches" at the various levels.

On the upper bank, at each position, a single contact, a bit thicker than the contacts on the lower bank, projects out from between two thick phenolic sheets. At each position, this contact carries the sleeve of the circuit.

For either bank, the entire stack of phenolic sheets and metal contacts, for all ten levels, is clamped together between steel pates at the top and bottom by long screws extending from top to bottom.

What we have thought of as "the wiper" of the switch is actually two wipers, one running on the lower bank and one on the upper bank. Each wiper has an upper and lower contact "leaf". On the bottom wiper, the two contact leaves are insulated from one another (since they will touch separate contacts, for the tip and ring leads). On the top wiper, the two leaves are electrically connected together, since they will be touching the top and bottom of a single contact, for the sleeve.

The bank assembly is fastened to the switch, in rather precise alignment, by way of the threaded studs seen at the tips of the bank rods (with the nuts seen there).
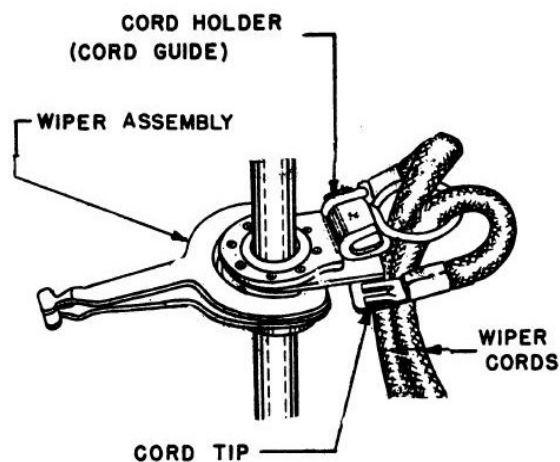
In figure 4 we see a "two-contact" wiper.

Figure 4. Two-contact wiper

As we see, the wiper (which of course moves around quite a bit) is connected to the switch circuitry with two very flexible cords. Their actual conductors use what is called "tinsel" construction. A very thin ribbon of conducting material is wound around a small fabric core, this whole thing then covered by a durable but flexible woven cover. This style of cord is able to withstand literally millions of cycles of flexure and twisting as the switch goes through its motions.

Toward the top of the switch "chassis" we see five relays. The different kinds of switch (line finder, selector, and connector, whose roles will be described shortly) have different numbers of relays, and their functions vary between the type of switch.

These relays are of a basic design long associated with the step by step system. Although, for example, the switching systems designed by the Bell System (and made by Western Electric) used, from the outset, new types of relay, more compact and less costly to manufacture, step by step switches made by Western electric (as well as those made by Automatic Electric) continued to use the relay design we see here.

Just above the bank assembly is the switch mechanism. Its heart is three electromagnets (generally just called "magnets"). One steps the switch in the vertical direction, one steps the switch in the rotary direction, and the third releases the pawls that hold the switch in place (after it has stepped up and around) and allows a spring to rotate the shaft back to it home angular position, and allows the shaft to then drop by gravity to its home position. There are several pawls, latches, and the line involved in this operation.

There are also various contact assemblies that do things like detect if the switch is at its home position or not. These play various roles in the logic executed by the relays in controlling the switch movement and otherwise managing the emerging connection.

4.1   Switches *in situ*
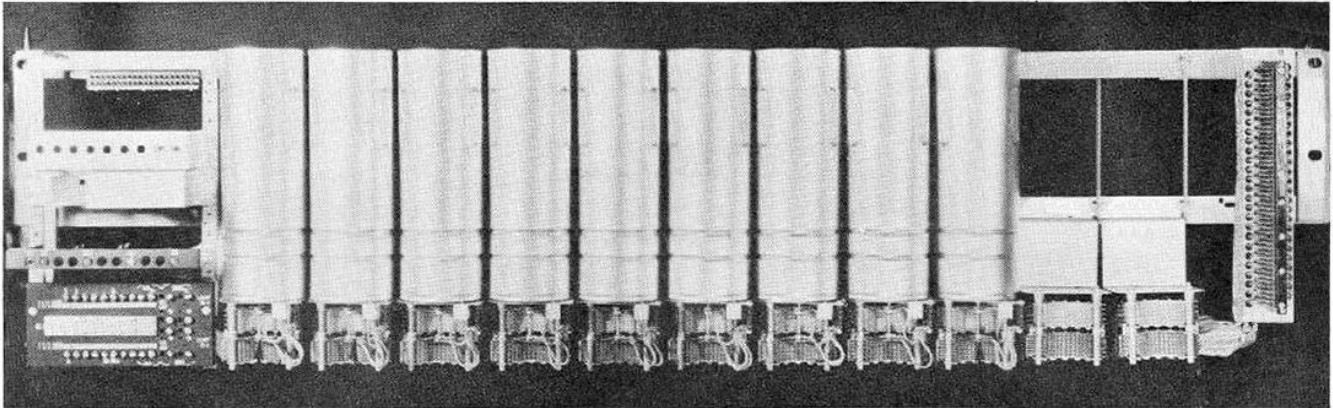
Figure 5 shows a "shelf" of connector switches.

Figure 5. Connector shelf

We see the switches themselves individually covered by the iconic "mailbox-shaped" covers.[10] The covers have a depression on each side (near the top), allowing the cover to be grasped by one hand for removal or replacement. The two ribs near the bottom stiffen the cover in cross section (toward the top, that is done by the top panel of the cover).

The shelf accommodates 11 connectors, of which the leftmost one is never part of an actual switch train but is used for test purposes. Of the remaining 10 positions, only 8 switches are installed at the moment, that presumably being the number reckoned to be needed "now" to accommodate the traffic through this branch of the network with the adopted grade of service[11].

But note that all positions are equipped with banks. The bank wiring (with 300 conductors) which runs from bank to to bank (we'll see why shortly) is so complex that it would not be practicable to wire in a new bank each time a switch was to be added to the shelf.

I mentioned earlier hat the banks were fastened to the switch proper. If one switch is removed (perhaps to replace it with another), that bank is temporarily bereft of support from a switch, but the multiple wiring will adequately support the bank for that period.

---

[10] Sometimes spoken of as "lunchbox-shaped" covers.

[11] *Grade of service* is a target limit for the probability that a call will be blocked at a certain stage of the network because of the lack of an available resource of some sort, such as a connector switch in the group that serves the called line.

But when the shelf is made, and first installed (before any switches are emplaced), or even when (as we see in the figure) a few switch positions are, for the time being, unequipped with switches, we must provide proxies for the switches in their role of supporting the banks. Thus we see, in the two unequipped positions, light-colored sheet metal brackets (*bank supports*), fastened by one screw to the shelf framework, and which support the banks by way of their usual mounting studs.

To the right we see a terminal strip for all the leads of the bank wiring. At the lower left is a fuse panel, which has positions for the unique flat-type alarm indicating fuses ("grasshopper fuses"), used for telephone equipment until the mid-1950s for each switch in the shelf. Also at the left are test jacks and alarm indicator lamps.

Now we can return to the matter of switching network architecture and operation.

5   THE STEP BY STEP SYSTEM

5.1   Classification

The step by step system (in the form we will speak of) is classified as a *direct progressive control* system.

Direct means that the switch is moved (in stepping switch fashion) directly by the individual pulses in a dialed digit or digits.

Progressive means that the successive stages of the overall switching network[12] are moved by successive digits of the dialed number, so the connection progresses "digit by digit".

5.2   Implications of the 5-digit number

In the discussions here, we will assume a system that uses five-digit telephone numbers.

Typically, five-digit telephone numbers were used (before the universal use of 7-digit numbers) in cities with more than one central office but just a few. The first digit tells the central office that serves the line. The numbers are customarily shown, in telephone directories and in advertising and the like this way: 5-2368[13]. This of course would be a

---

[12] *Network* here is used in the sense of the structure in a switching system through which calls flow from one line to another across the system, and not in the sense of a number of interconnected witching systems..

[13] But, in Lorain Ohio, with a handful of central offices, the telephone officials recognized (quite correctly) that the number presented in this form: 89-191 (for a

line served by the "5" office. A line with number 8-5746 would be served by the "8" office.

To keep things simple for a while, we will at first consider the operation of the system on a call placed by a line in the "5" office to a line also served by the "5" office. This is called an *intraoffice* call. When we do, the arrangements for carrying the connection from one central office to another drop out of the picture, allowing us to more clearly see the important concepts.

The way the system works in this case makes it just seem that this is an isolated central office with no more than 10,000 lines but which for some reason uses 5-digit, rather than 4-digit, numbers.

5.3   Network architecture at a glance

In figure 6, we see, in the "5" office, in block diagram form, the path through the switching network for established connection from a line in the "5" office (whose telephone number is of no interest to us) to the line whose number is 5-2368 (also in the "5" office).
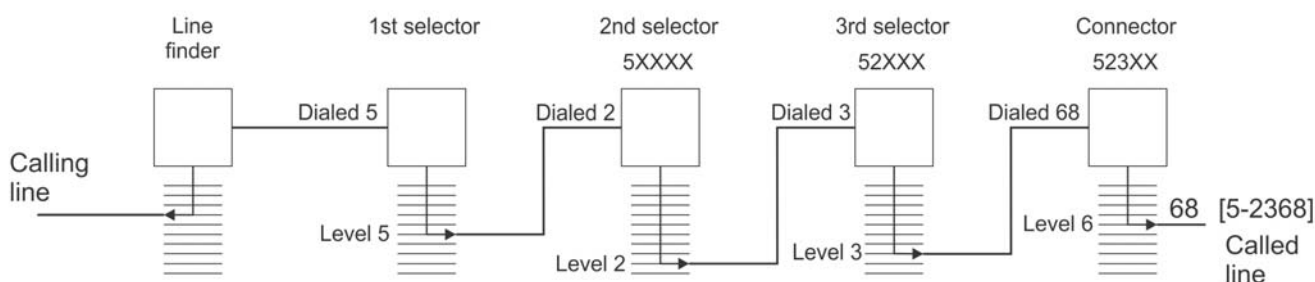

Figure 6. Completed 5-digit connection

By virtue of the direct, progressive nature of the step by step system, the number of stages in the network depends on the number of digits in the number. Here, we have 4 stages (the line finder is not counted as a stage)–we'll see why in a moment.

We see that the connection involves 5 switches, a line finder, three selectors, and a connector

5.4   Handling of the call—overview

5.4.1   *The line finder and 1st selector*

When the calling subscriber lifts the handset, through a process to be described later, the call is assigned a line finder in the group that can access this line (and, for the moment let's say 99 other lines. Those

---

line served by the "8" central office) was even easier to grasp, and so that was done in telephone directories (and by the subscribers in newspaper ads and the like).

lines are connected as well to other line finders in the "group" serving that station (think perhaps 10 altogether in the group), but we only see the one that was called to service for our connection.

When this line finder is called to service, it moves its wipers to the terminal to which the calling line is connected. (The line with the arrow is evocative of the line finder wipers.)

Each line finder is permanently tied to a selector in the first stage, called a *1st selector*, and there is now a path from the calling line to the "input" of the 1st selector tied to "our" line finder. That input provides "talking battery" to the calling line through the windings of a relay that will let the selector see if any current flows in the line.

The first digit dialed (that would be"5") causes the 1st selector to advance the call to a 2nd selector, in particular one in a group we label "5XXXX". That means that it only ever takes part in a connection that is destined to reach a number starting with "5". (in this notation, we do not include the hyphen that is used in "displaying" 5-digit telephone numbers.

Why are there several "5XXXX" 2nd selectors? For the simple reason that, at any given time, there might be more than one connection needed to lines with numbers of the form "5XXXX" (all of which must pass through a "5XXXX" 2nd selector).

How does our 1st selector manage to extend the connection to a particular one of the "5XXXX" 2nd selectors, one that is not already busy?

We will learn the broad answer while looking at figure 7, where we zoom in on the area of the 2nd selectors.
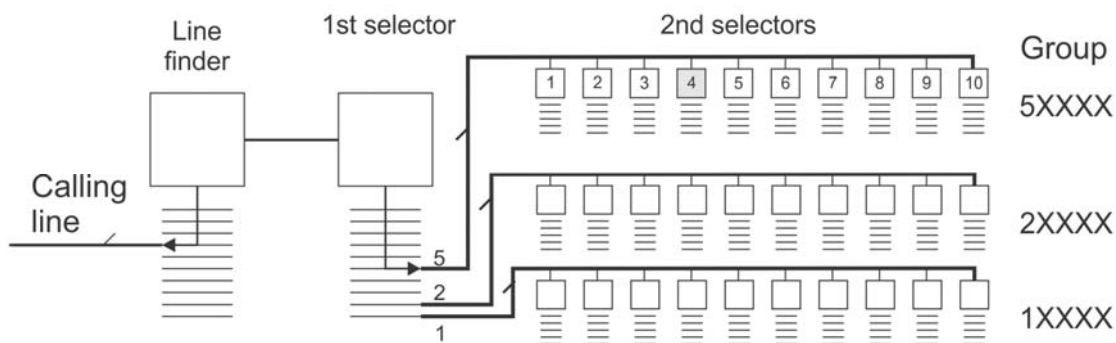

Figure 7. "Fanout" from a 1st selector

We see here "our" 1st selector, as well as three groups of "NXXXX" 2nd selectors, the "1XXXX", "2XXXX", and "5XXXX" groups, with 10 selectors in each group (this being of course only "typical"). As we

saw before, the "2XXXX" selectors, for example, will only be involved in connections to lines with numbers of the form "2XXXX".

The heavy lines each represent a set of 10 circuits (3 leads each), running (separately) from the 10 terminals on one level of our 1st selector to the "inputs" of the 10 second selectors in a group.

Now when, in our scenario, our caller dials the fist digit "5", the five dial pulses (detected by the release of the "talking battery feed" relay in the 1st selector) directly cause the "vertical" magnet to step 5 times, taking it to level 5 of the selector bank[14]. The figure graphically suggests that.

Now, the switch begins to autonomously step in the rotary direction, the wiper in effect scanning the terminals of all the 2nd selectors (10 on this case) connected to terminals on that level.

The terminal for a busy 2nd selector will have ground on the sleeve lead, and when the selector sees that, it keeps on stepping. But when it get to, say, selector number 4 of the group, which is idle, there is no ground on the sleeve lead, The 1st selector, sensing this, stops stepping, and extends the connection, via its wipers and the contacts of that bank terminal, to the input of that luck 2nd selector (its good fortune is shown here by the shading on its symbol).

Now, it is this 2nd selector that supplies talking battery to the called line. It is now, for a little while, responsible for "managing" the nascent connection.

We introduce on this figure an important symbol in this kind of work, the *multiple* symbol[15]. It means that an element shown as connected to another element is also connected to other elements of that same kind and situation.

We see this symbol (a diagonal line arising from a lead or path line) on the calling line, where it is shown connected to the bank of a line finder. The symbol means that the line is also connected to the banks of other line finders (of course, in the group that serves this line). The "free" end of the symbol points toward the element that "there are more of that this is connected to".

We also see multiple symbols on the paths leading from our 1st selector to the three groups of 2nd selectors. That reminds us that

---

[14] In discussions at this level it is customary to speak of "bank" in the singular, meaning what is called in more mechanically-detailed discussions the "bank assembly".

[15] The basis for that name is discussed in section A.2.1 in Appendix A.

there are a number of 1st selectors in the same group as ours, and all of their bank terminals (in this case, on levels 1, 2, and 5) are connected to the same groups of 2nd selectors as our 1st selector.

5.4.2   *Moving on*

You may with to refer to figure 6 now.

In the very same way we saw for the 1st selector, the 2nd digit dialed, "2", moves the "5XXXX" 2nd selector involved (number 4) to its 2nd level, and in the same way we saw before, it finds an idle "52XXX" 3rd selector.

The 3rd digit dialed, "3", moves that 3rd selector to its 3rd level. Here, however, it does not then hunt over 10 4th selectors (there are no such things) but, (in exactly the same way), hunts over 10 *connectors* (these in the group "523XX"). When it finds an idle one, just as before, the connection is extended to the selected connector.

5.4.3   *The connector*

As we might suspect, it is now this connector that supplies talking battery to the calling line. And now, and for the duration of the connection, it is this connector that is responsible for managing the connection, which is soon to be completed.

Connectors are the last switch in the connection train, and they differ substantially from selectors. For one thing, a connector is stepped in the vertical direction by the first dialed digit it receives (always the next-to-last digit of the called line number, its tens digit) and then is stepped in the rotary direction by the next digit it receives (always the last digit of the called station number, its units digit).

The result is that the connector's wipers land on the bank terminal for the called line.

Just as for the links from selectors to switches in the following stage, a busy line shows ground on its sleeve lead.

Now a relay in the connector, by testing the sleeve lead of that terminal, sees if the station is busy (perhaps it is on an existing connection), and if so (*i.e.*, if the sleeve shows ground), the connector returns busy tone "upstream" to the calling subscriber.

If not, the connector applies ringing voltage to the line through a special "ring trip" relay. That relay can determine when the calling station answers, and when that happens, that relay removes ringing voltage from the line, provides talking battery to the called line, and establishes a transmission connection between the calling and called lines.

5.5   The line finder

In the interest of concentrating on one thing at a time, I have dodged the matter of how does a line wanting service find itself connected to a 1st selector so the process of building up the connection from the successive dialed digits can proceed. But it is time to come to grips with that.

In fact, there are two conceptually-distinct ways this is done, one most in vogue in the earlier days of the step by step system, and another most commonly used in "modern" times (since perhaps 1930). I will only discuss this latter approach in this article. It involves a switch, quite different than a selector or connector (although with the familiar mechanism), called (very aptly) a *line finder*.

In figure 8, we see the entire 5-digit switch train, now with a new ingredient, the *line circuit*, which we didn't see before (although it was of course at work in the process we saw).
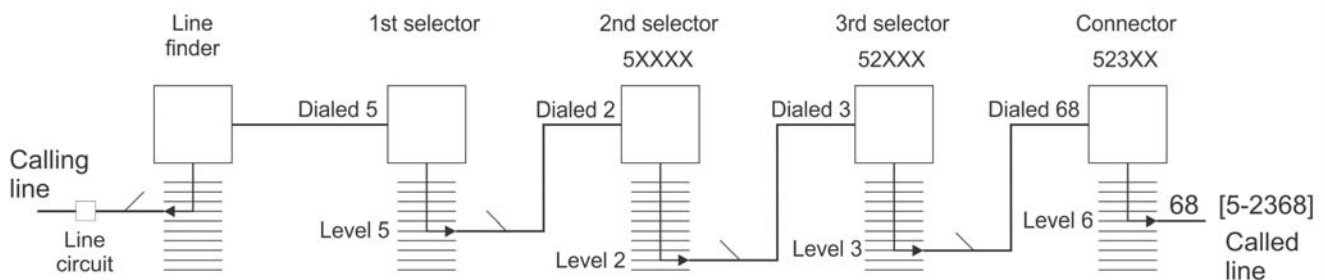

Figure 8. Complete switch train with line finder

As we saw earlier, each 1st selector in the system is semi-permanently paired[16] with a line finder, whose job is to bring the 1st selector work to do. The "bank end" of the line finder faces "upstream" (toward the lines), and 100 subscriber lines[17] are connected to its 100 bank terminals.

We also noted that in fact there were several line finders (perhaps 10) in the "group" that could access our line (and its 99 fellow lines). The multiple symbol on the connection of the line to the line finder we see reminds us of that.

Each line also has its own *line circuit*, which comprises two relays. With the line idle, battery and ground are fed to the line, the battery through the winding of one of the relays (the *line relay*).

---

[16] See section 8 for how that is done.

[17] Or so we will imagine for the moment. That is not usually exactly correct, as we will hear later.

When a subscriber lifts the handset, the resulting flow of current operates the line relay. One contact of that relay puts battery (through the winding of the second relay in the line circuit, the *cutoff relay*) on the sleeve lead of the line's terminal of the line finder banks.

The second contact grounds a lead that goes to a line finder control circuit. Relay logic there identifies an idle line finder (think of it as the "first idle" one) and, in effect, causes that line finder to "scan" the 100 lines it may be called upon to work with, looking for the one that has battery on the sleeve lead.

Of course, it would take quite a while to actually scan all 100 terminals on the bank. The switch would have to (of its own accord) step to the first level, then step across all ten terminals of that level, then (if it did not find its quarry) release, then step to the second level, and so on and so forth.

So instead, the line finder is given a hint as to on which level does the line asking for service lie. There is a little vertical strip of 10 terminals, called a *commutator*, against which a special wiper runs as the switch autonomously steps vertically. We see this arrangement (mentioned earlier) again in figure 9.

When the line relay grounds a lead to the line finder control circuit, it operates a "subgroup" relay there that is common to the 10 lines that will appear on one level of the line finders. It is that relay that actually kicks off the selection of an idle line finder and the starting of its hunt for the service-requesting line. That relay also puts ground on the terminal of the commutator of all line finders in the group for that level.
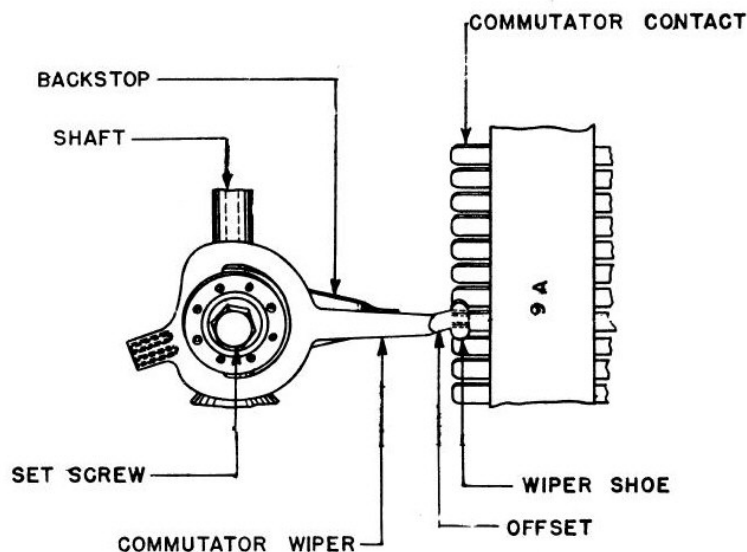

Figure 9. Line finder vertical commutator and its wiper

So, when the lucky line finder is sent off on its hunt, it looks (via the commutator wiper) for ground on the successive terminals of the commutator, and, when it finds it, it knows that the would-be calling line is on that level. Vertical stepping is halted, and the switch then steps in the rotary direction looking for battery on the sleeve lead. When it finds it, the switch stops its rotary stepping and establishes a path from that line to the 1st selector that is the line finder's partner in crime.

You may notice in the figure that the vertical commutator actually has 11 contacts. The first contact, corresponding to the wiper position with the shaft in its home position, is rarely used in any circuit. Rather, it provides for locating the wiper, when the switch is idle, so it can smoothly move to contact number 1 when the switch takes its first vertical step.
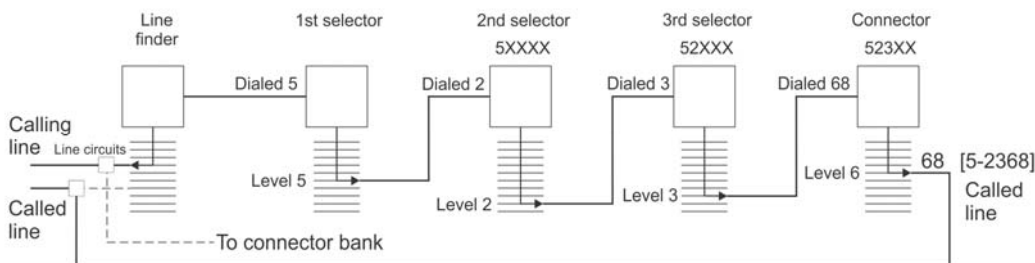
5.6   Completing the picture

Figure 10. Complete switch train with line finder (2)

Finally, in figure 10, we complete the picture.

Here we see that our called line (5-2368) is in fact also connected to a terminal on the line finders (since, of course, it is able to place calls as well). And our calling line also has a connection to a terminal on a connector bank, so that it could be called. Both of these paths are shown with dashed lines as they are not involved in the connection we are following. The various "multiple" symbols are not shown so as to minimize clutter in the figure.

The fact that the connections to the line finder banks and the selector banks are shown emerging from different places on the line circuits. That is to remind us that these two connections are not electrically not the same with regard to the sleeve lead.

It is important to note, however, that while a line with a certain number has an invariable "position" on the connector banks, there is not a fixed relationship between the numbers of the lines and their "positions" on the line finder banks. In fact, the association between lines and line finder terminals is established (through semi-permanent "jumpers" on a cross-connecting facility called the *intermediate*

distributing frame) based on such considerations as equalizing the amount of traffic on different groups of line finders.

And the association of a subscriber's line with a certain connector terminal (this giving it a certain telephone number) is also made with semi-permanent "jumpers" on another cross-connecting facility called the *main distributing frame*. Exactly how this works is described in section 8.

5.7   Dial tone

Dial tone of course advises a calling subscriber that the system (of whatever type) is ready to receive the dialed number. In the step by step system, this is when the line allocated line finder has found the calling line, and the line is now connected to the associated 1st selector, which will accept the first dialed digit.

So, fittingly, it is the first selector that sends dial tone to the station. The dial tone signal is in fact permanently connected to the relay that will feed the station "talking battery" while the line is in the hands of the first selector. (In fact, when the line finder/1st selector pair is idle, the 1st selector sends dial tone upstream, in the direction of the line finder, but it stops there, since with the line finder idle there is no path through it.)

It is the convention that, once a switching system begins to receive dialed digits, the dial tone is removed, as clearly the calling subscriber knows that he can dial (since he is already doing it). This happens rather automatically in the step by step system. After the first digit has been received by the 1st selector, and an idle 2nd selector on the dialed level found, the 1st selector "cuts through", taking the line off its battery feed relay (the one that has dial tone connected to it all the time) and sending it forward through the wipers to the 2nd selector. So, no more dial tone to the calling station.

5.8   Holding the connection

As the connection is progressively extended forward, whichever switch is providing talking battery to the calling station at a certain point in the process (at first the 1st selector, then the 2nd selector, and finally the connector) sends ground upstream on the sleeve lead, which holds all the earlier switches (including the line finder)"up".

5.9   Release

When the calling subscriber hands up, the battery feed relay for the calling line at the connector is released, and shortly the connector removes that upstream ground. As a result, all the switches in the connection release (the connector releases then too), and this connection is no more.

5.10 The 200-point line finder

The statistical behavior of the line finder stage is improved if any given line finder can serve a greater number of lines (and of course the number of line finders in the group is increased accordingly).

For example, suppose that if a line finder can be used by any of 100 lines, and to have a certain (small) probability that there will be no line finder available when a line requests service requires that there must be 14 line finders in the group (0.14 line finder per line). But if instead a line finder can be used by any of 200 lines, then to attain that same small probability that there will be no line finder available when a line requests service might require that there be 22 line finders in the group (only 0.11 line finder per line). So this would lead to a more economical line finder stage.

To that end, in most step by step systems, a line finder is used that in fact can connect to any of 200 lines (called a 200-point line finder).

 No, the bank does not have 200 positions. But the bank system is a "6-contact" system (rather than the customary "3-contact" system). At each bank position, 3 wiper springs make contact with one set of T, R, and S bank contacts, while another 3 wiper springs make contact with a second set of T, R, and S bank contacts. These two sets of bank contacts pertain to two wholly separate lines.

Inside the line finder is a relay that will put into play one or the other sets of wipers.

Thus the line finder can, in effect, "scan" over 200 lines when any of those lines request service.

The "200-point bank" is actually implemented with three banks, each of the "double contact" type. For each position, the lower bank carries the T and R leads for one line, and the middle bank the T and R leads for the second line. The upper bank carries the two sleeve leads, one for each line.

6   MULTIPLE OFFICE OPERATION

In the discussions so far, in order to best set the stage for the various matters, I have assumed two facts that are not wholly consistent:

• There was only one central office in the scope of our interest.

• The subscriber dialed 5 digits to reach the wanted line.

As we heard earlier, the use of five-digit telephone numbers was most commonly associated with the overall system in cities that, because of

their population and geographic size, had several central offices (but not over 8).[18]

Then, the first digit of the telephone number indicated the central office in which the line was served, while the remaining four digits indicated the line within the central office.

It was most common then to present the number, in telephone directories, in newspaper ads, and the like, this way: 5-2368. That was easier to grasp than 52368. And this more clearly separated the digit that indicated the serving central office. The number above was served by the "5" office.

How did this work? And how did it work if the wanted number was in the same central office as the calling line?

In figure 5, we again see the entire switch train for our "5-digit" system, but with a few differences.

For one thing, we now see a dashed line dividing the train into "originating side" and "terminating side" portions. Nothing technical has changed—this is just a new way of looking at what we have. The originating side handles the call up to the point where it goes to the destination office. But for our example call, the terminating side **is** the destination office. And in this context, this is the "5" office. So we don't see anything unusual as our connection passes across that dashed line.
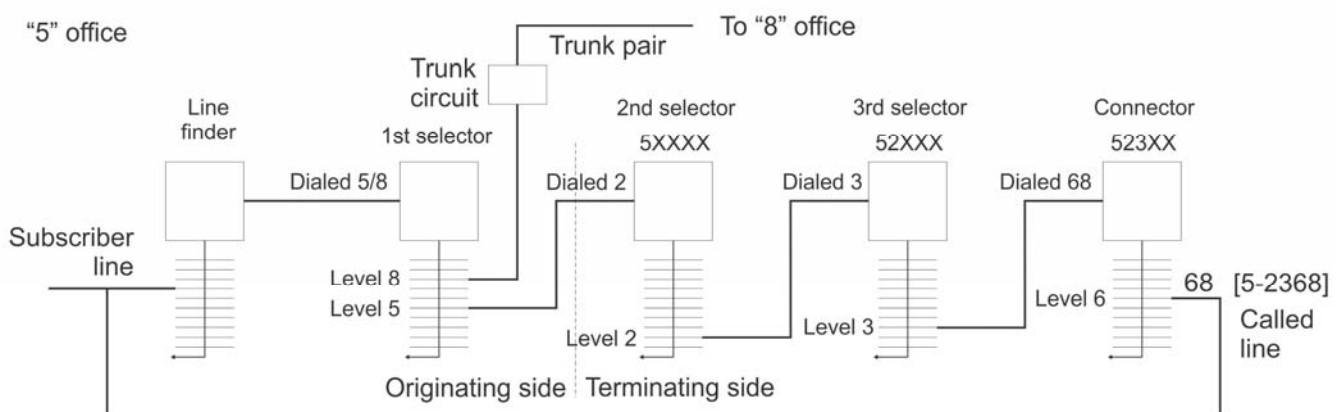

Figure 11. 5-digit train—multi-office context

So, in our earlier example where the calling subscriber dials 52368, the handling of the call is just was we saw before., But now, we view it as the 1st selector routing the call to a 2nd selector in the destination office—but that is the same office.

But next suppose our calling subscriber dials 8-5746. At the first selector, there is nothing different. But the 2nd selectors in the 8XXXX group that the 1st selector examines are all in the "8" office— seen through the trunks from the "5" office to the "8" office [19].

So does that mean that a T, R, and S lead from each of them has traveled all the way from the 8 office to this office ("5"). No. That would not work out, for two reasons:

• It is not economically attractive to carry three conductors over this distance.

• The resistance of the long trunk pair, added to the resistance of the calling subscriber's line itself, might well reduce the current in the connection below the minimum required for proper operation.

So we introduce into the story a *trunk circuit*[20], a relay unit that:

• Toward the calling subscriber, furnishes talking battery just as it would be furnished by the successive selectors, and eventually the connector, on a call to a line in this office.

• Toward the destination office, provides a low-resistance path across the tip and ring of the trunk, to operate the relays at the destination office selectors (and then connector) through only the resistance of the trunk pair, not that resistance plus the resistance of the calling line pair.

On the side toward our 1st selector, the repeater shows ground on the sleeve to indicate that the trunk (actually, the 2nd selector in the destination office to which trunk goes) is busy. The 1st selector has no idea that it is not hunting over 2nd selectors just down the aisle.

So what happens when this call actually gets to the "8" office? We see this in figure 12.

---

[19] Its full name is *trunk circuit*, but I don't use that as we also have a totally different thing called a "trunk circuit". The term is actually taken from railroad practice.

[20] Actually, in the step by step system it is formally called a *repeater*, an unfortunate term since it has another quite different meaning (an amplifier in a transmission circuit). So I call it a *trunk circuit*, the name it would have in any other kind of (Bell System designed) switching system.
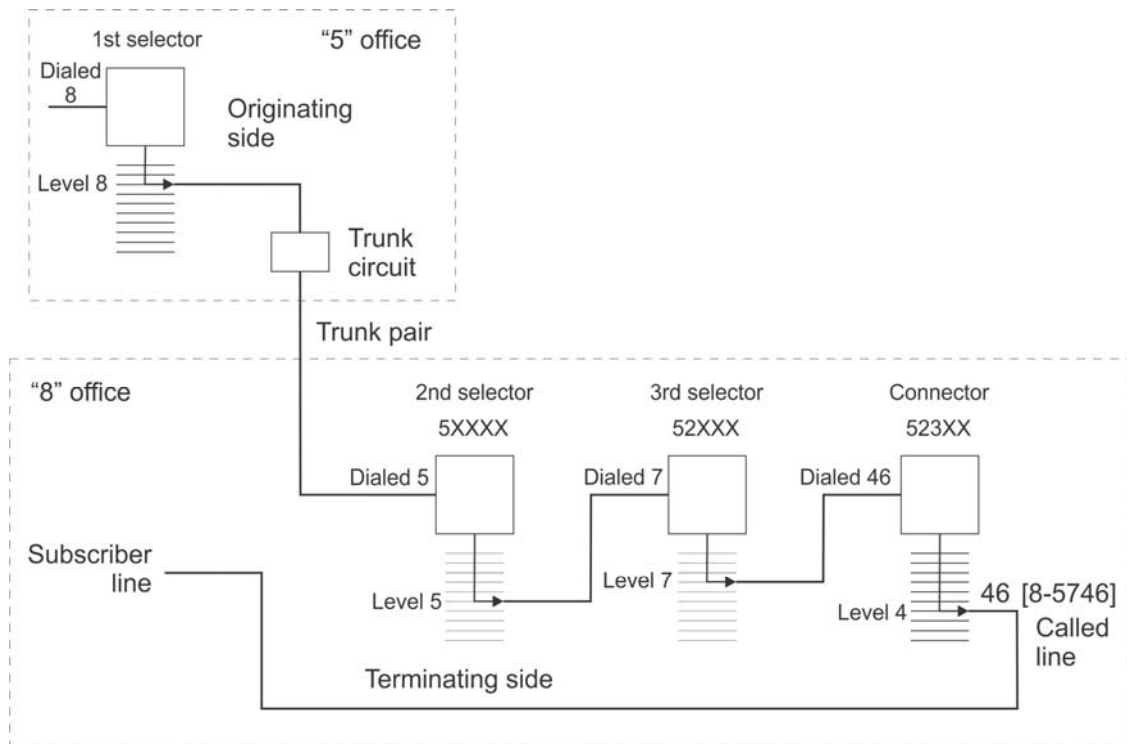
Figure 12. Arrival of an interoffice call

We see enough of the "5" office to see how the call got onto the trunk to the "8" office, and the terminating side of the "8" office.

The 2nd selector at the "8" office operates just as if the connection had been extended to it from a 1st selector in this office. And the rest of the process proceeds in the way we saw earlier.

7   "MULTIPLE CENTRAL OFFICE" CENTRAL OFFICES (!)

So far, our assumed context is a medium sized city with a few central offices. Each of these can potentially handle up to 10,000 lines.

But suppose the region served by the "5" central office grows so that more than 10,000 lines must be served. Well, we can install another set of step by step equipment in the same building (perhaps making an "addition"), and assign the new lines numbers beginning with "6". Thus we have created the "6" office, in the same building as the "5" office.

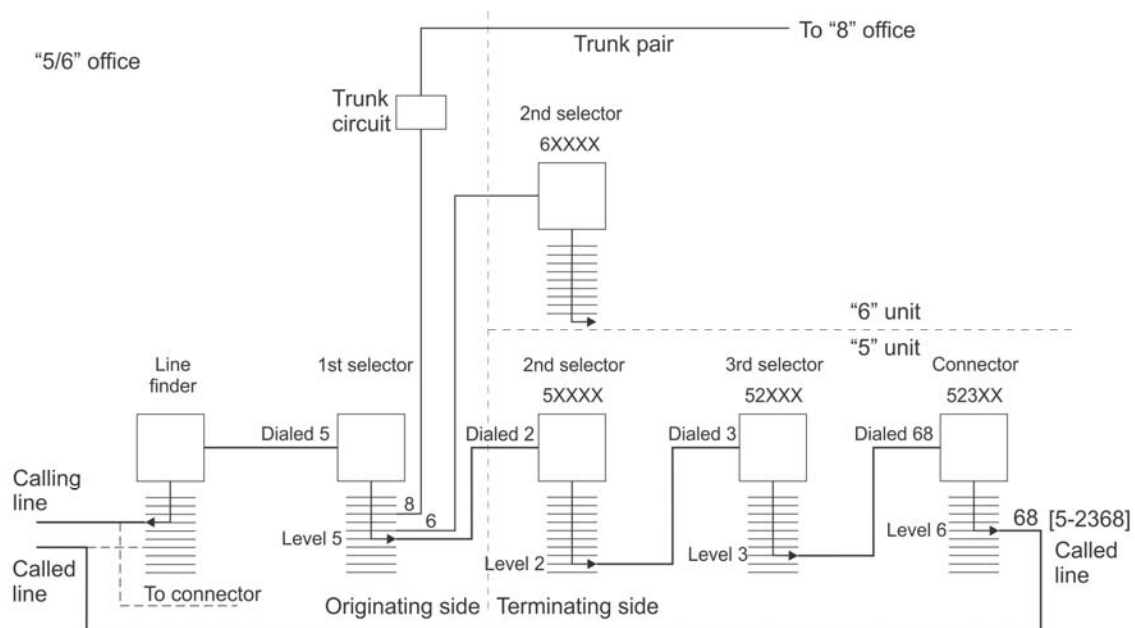Figure 13 shows this arrangement. The familiar example call is shown as up.

Figure 13. Two-unit central office

The way this works should be clear from what we have seen so far. But there is now a terminology problem. Is this building "a central office", or does this building now house two "central offices" ("5" and "6")? Keep in mind that we describe the first digit of the number as the "central office code", in that it tells the system in what "central office" the line is served.

In fact, there is no really good solution to this—no unambiguous syntax. Most commonly, the building is (under the numbering scheme we have been assuming here) usually spoken of by a name, such as the "Maple Avenue central office", or often, for the first one that had been established in a town, the "Main central office".[21]

Then, within that building, the two collections of switching equipment, one for the "5" numbers and one for the "6" numbers, are spoken of as "units". ("I had three connectors fail in the 6 unit last night, so of course I had to go to the second floor)." But more commonly, "I had three connectors fail in the 6 office last night. . .")

Again, this all notwithstanding that we speak of the "5" and "6" as being "central office codes".

-----

[21] In larger cities, when the "central offices" (in the sense of central office codes) had names, and the codes were dialed as the numerical equivalents of the first letters of that name (as "63" for the "MElrose" central office), the buildings were often called by that name. Of course, in that building there were eventually established "units" with the central office names ATlantic and OLympic. However, the building still kept the name "Melrose". But in some cases the building had a composite name from two of the "central office" names there, such as "Main Cherry".

A further complication is that in the originating side of the system, the line finders and first selectors are not necessarily segregated by the numbers of the lines served. (We were reminded earlier that the relationship between a line's telephone number and the line finder group and terminal that served it is not fixed.) So the originating side of the system was not necessarily organized in "units".

In any case, in figure 13, I have faked it by labeling the central office involved (in the sense of the building) as the "5/6 office".

8   THE DISTRIBUTING FRAMES

In section 5.5 I mentioned that the association of a subscriber line with a certain connector terminal and a certain line finder terminal was done on two equipment items known as distributing frames, the *main distributing frame* (MDF) and the *intermediate distributing frame* (IDF).

In the traditional implementation (much used during the prime era of step by step switching), these are large structures reminiscent of a "jungle gym", with terminal blocks on both sides, in vertical columns on one side and horizontal rows on the other side.[22]
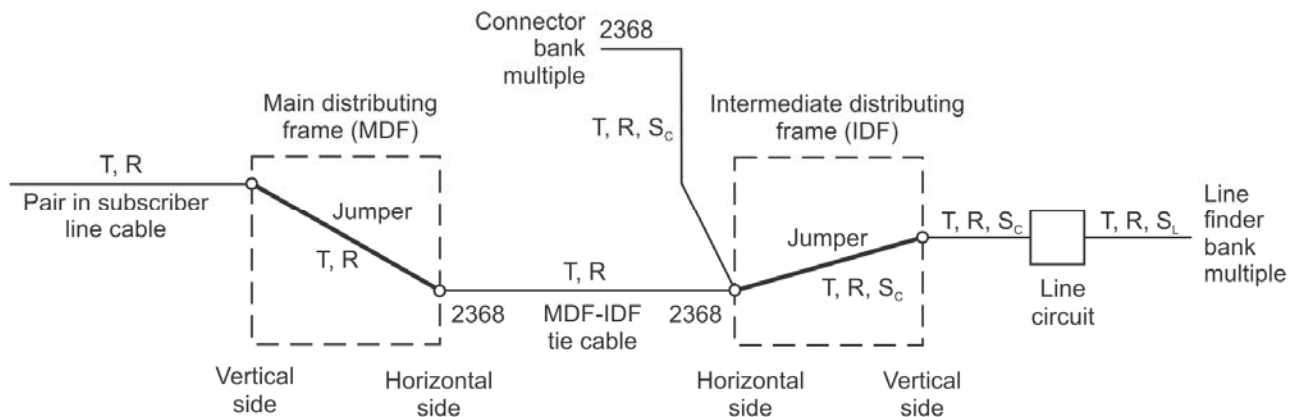

Figure 14. Distributing frames in a step by step system

Semi-permanent connections are made between terminals on the two sides with lengths of durable wire, called *jumpers*.

Figure 14 shows, in schematic form, the way in which these semi-permanent connections are made in a step by step system.

For clarity, I have used the S_C and S_L designations for the two different kinds of sleeve leads. Of course, in formal drawings and

---

[22] Readers interested in their traditional construction will find considerable detail in the article :"Manual telephone switching", by the same author, available at the site referenced at the top of this article.

such, both are just called "S" (and one must keep track of where one is).

In section 5.5, I also mentioned that each line finder is "semi-permanently" connected to a 1st selector. That association is also, made by way of a jumper, in a different section of the IDF (not seen on this figure).

9   MORE COMPLEX WIRING PATTERNS

Our work so far has, for simplicity, been predicated on "obvious" patterns of wiring the various selector bank terminals to the following switches, or wiring the lines to the various line finder bank terminals. In reality, it is not nearly that simple. More complex patterns of this wring are used for such purposes as:

• Equalizing the wear on the switches in a group.

• Allowing a group of selectors to have access to more than 10 selectors on the following stage for a given dialed digit.

• Minimizing the hunting time of selectors over the following switches.

• Minimizing the hunting time of line finders in finding a line requesting service.

This is all a gigantic and very complicated topic, and it is mostly beyond the scope of this article. None of it in any way interferes significantly with the principles of system operation presented in the article.

In any case, two examples of this are discussed (in principle) in Appendix A.

10   THE DREADED "PRELIMINARY PULSE"

10.1 Introduction

Especially with the use of the deskstand telephone set (sometimes known to civilians as the "candlestick" style), when lifting the receiver from its forked "hook" one might fumble, and in doing so have the switchhook contact close the line, then (inadvertently) open in for a short period, the close it persistently.

Now is indeed during the initial close a line finder was able to connect to the line and bring into the scenario a 1st selector, then the short open period would be interpreted as a dialed digit "1". In this context, this phenomenon is described (aptly) as a *preliminary pulse*.

So. if the caller has in mind to dial 52368, to the system it will appear that he dialed 152368. There is of course in our presumed little city no such telephone number. The call will somehow be frustrated, and depending on how the system is set up, the caller might just hear nothing. This frustrates the caller, and results in some switches being "tied up" to no benefit.

The initial solution to this problem is very clever. and resulted in some conventions begin established that were later of great consequence. We see the scheme in figure 15.
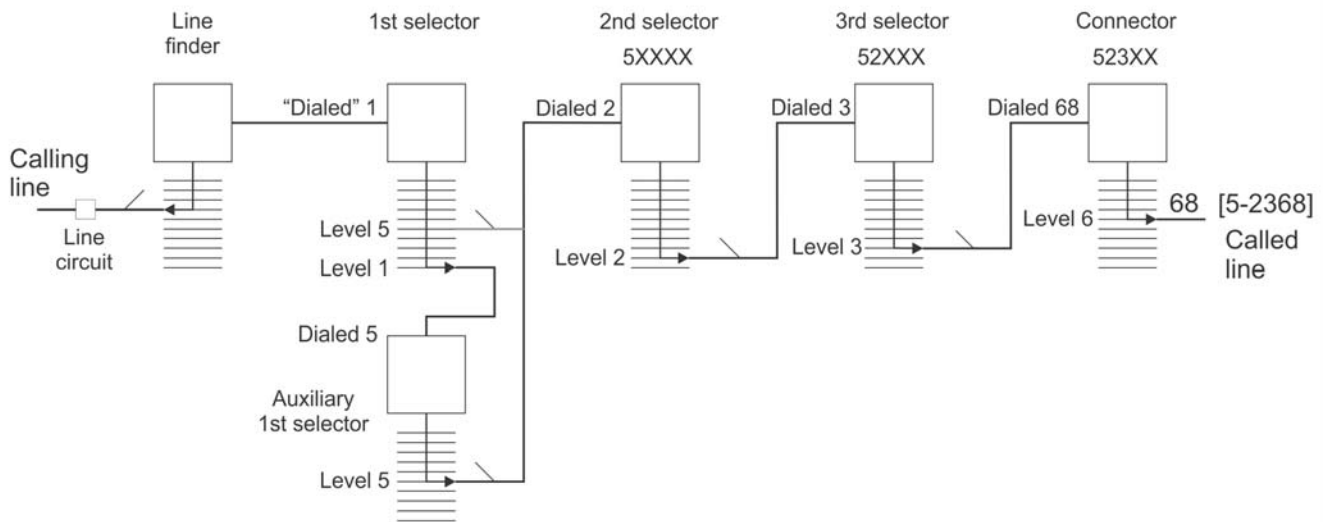
Figure 15. Auxiliary 1st selector

Her we see a new special kind of 1st selector, the auxiliary 1st selector.

When the calling line "dials" a 1 (that is, creates a preliminary pulse), the serving 1st selector steps to level 1 and hunts for a second selector. But on that level are links to auxiliary 1st selectors. The banks of these special 1st selectors are, at all but their level 1, multipled to the banks of other 1st selectors.

Thus when the caller actually dials 5, it is received by the auxiliary 1st selector, which moves to its level 5, and then hunts over the 5XXXX 2nd selectors. The rest of the process proceeds as we saw earlier.

Very clever. But of course this requires the office to be equipped with additional selectors, at substantial expense.

As an aside, the auxiliary 1st selectors give dial tone to the caller just as the regular 1st selectors do.

Later, another way was devised in the step by step system to dispose of preliminary pulses without using an auxiliary 1st selector. In this scheme, the fist selectors were arranged so that if the first digit dialed

were a "1". after the digit was completed, the switch released (thus essentially having ignored the "preliminary pulse".

11   SERVICE CODE ACCESS

11.1 Background

We saw how here the step by step system could readily dispose of a preliminary pulse in a clever, albeit roundabout, way. In "common control" systems. such as the panel dial system, this was just done by relay logic in the unit that receives the dialed number and then dispatches all the switches to make up the indicated connection. This logic was set up to ignore any number of apparent digits "1" at the start of dialing.

When the panel dial system was about to be introduced, the initial installations were in a fairly large cities, and the real plan was to deploy it soon in very large cities, such as New York and Chicago.

This meant numbering plans in which the central offices were indicated by 2 digit codes (three digits in the very large cities).

With manual switching, the central offices in a city had names, in smaller cities perhaps "Main" and "West", but in larger cities perhaps "Adams" and "Madison".

In order to facilitate the gradual transition from manual switching to dial operation with the panel dial system, W. G. Blauvelt of AT&T devised a clever scheme: The telephone dial would have letters associated with the various digits. Then, to place a call to a number in the Madison central office, the user would dial the 2 digits next to which appeared the letters M and A. (In the very large cities, where three digits were required to denote the central office, he would dial the 3 digits next to which appeared the letters M, A, and D.

But, because of the matter of the preliminary pulse, numbers beginning with "1" were not legitimate. Thus no central office code could begin with "1". And so, in the Blauvelt scheme, no letters were associated with the digit "1" on the dial, and the first three letters (A, B, and C) were associated with the "2" on the dials, in the now familiar pattern.

To complete the story, it was the practice for the subscriber to dial "0" to reach "the operator" (what we would today call the dial assistance operator).

Thus, no central office code could begin with "0". And thus, in the original scheme, no letter appeared on the digit "0" on the dial.

And since the first two digits (three in the very large cities) were dialed based on the first 2 (or 3) letters of the central office name, and there were no letters associated with the "0", no central office code could include a "0", either.

11.2 Implementation

Back to the auxiliary 1st selector. The designers of the system found a way for the auxiliary 1st selectors to actually do something "useful". In these systems there was need for the caller to be able, by dialing a short code, to reach such "services" as the long distance operator, repair service, and even the business office. In figure 16 we see how that was done.
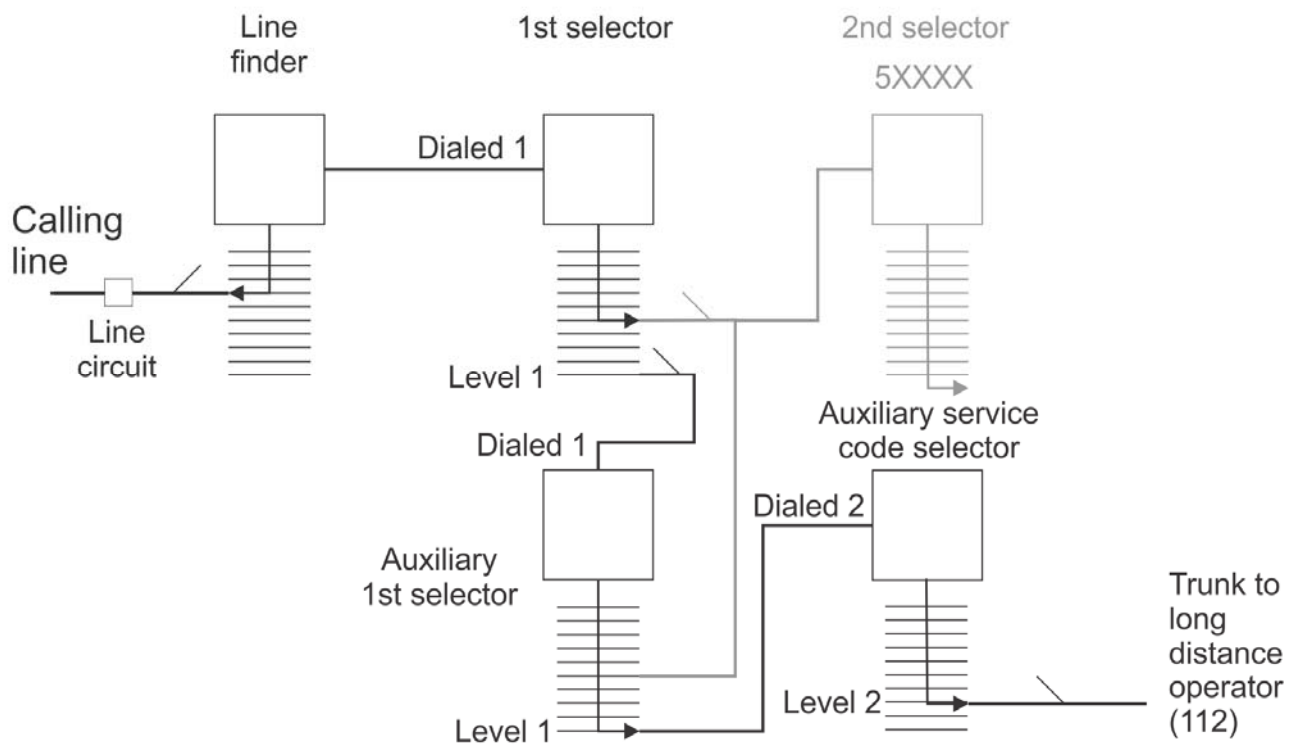
Figure 16. Service code access

The specific example deals with access to the long distance operator. It turns out that the standard code for this "112". But that format was chosen based on a combination of two factors, one of which as the implementation we see in the figure (about which we will hear shortly). The other was that, for the reason described in section **Error! Reference source not found.**, No central office code could begin with "1", or have "1" as its second digit, and so by assigning "112" for "long distance", we did not "waste" any potential central office code.

So, this concept having been accepted, other "11N" codes were assigned for similar "service" purposes, typically "114" to reach what was then called "Information" (now, "Directory Assistance) "116" to

reach repair service, and "118" to reach the telephone company business office.

In the figure we see, as we saw earlier, that if an apparent digit "1" (perhaps actually a preliminary pulse) was the first thing received, the 1st selected extended the connector to an auxiliary 2nd selector. If the next digit was not "1", then it was presumed to be the first digit of the number, and the process proceeds as discussed above.

But if the auxiliary 1st selector received an apparent "1", we conclude that this all was no accident but in fact the user had dialed "11". Thus the call is extended to a auxiliary service code selector. Then when the user dials "2", that selector goes to its 2nd level, and hunts over trunks to long distance operators.

11.3 In larger cities

I note for completeness of context that in lager cities, the use of "11N" codes for services such the long distance operator was not adopted. The reason is that the common control switching systems used there (*e.g.*, the panel dial system). Rather, there, codes of the "N11" form ("211", "611", "811") were used. Of course these would not have been usable as central office codes (because of the "1" in the second digit position) and thus again no valid central office codes were "wasted: by this scheme.

12   THE DIGIT-ABSORBING SELECTOR

Later, another way was devised in the step by step system to dispose of preliminary pulses without using an auxiliary 1st selector. In this scheme, the fist selectors were arranged so that if the first digit dialed were a "1". after the digit was completed, the switch released (thus essentially having ignored the "preliminary pulse". But it could not be arranged to do this multiple times (because of the earlier decision to use "11N" codes for various services).

The way this works out is seen on figure 17.If the subscriber dials 112, the first "1" is absorbed (it might, after all, have been a preliminary pulse). The second "1" is not absorbed (that's how the logic of the digit absorbing selector works) and so the 1st selector, which has gone to level 1, hunts over a group of service code selectors and has settle on the one we see. There, the digit "2" takes that switch to level 2, where it hunts over a group of trunks to long distance operators.
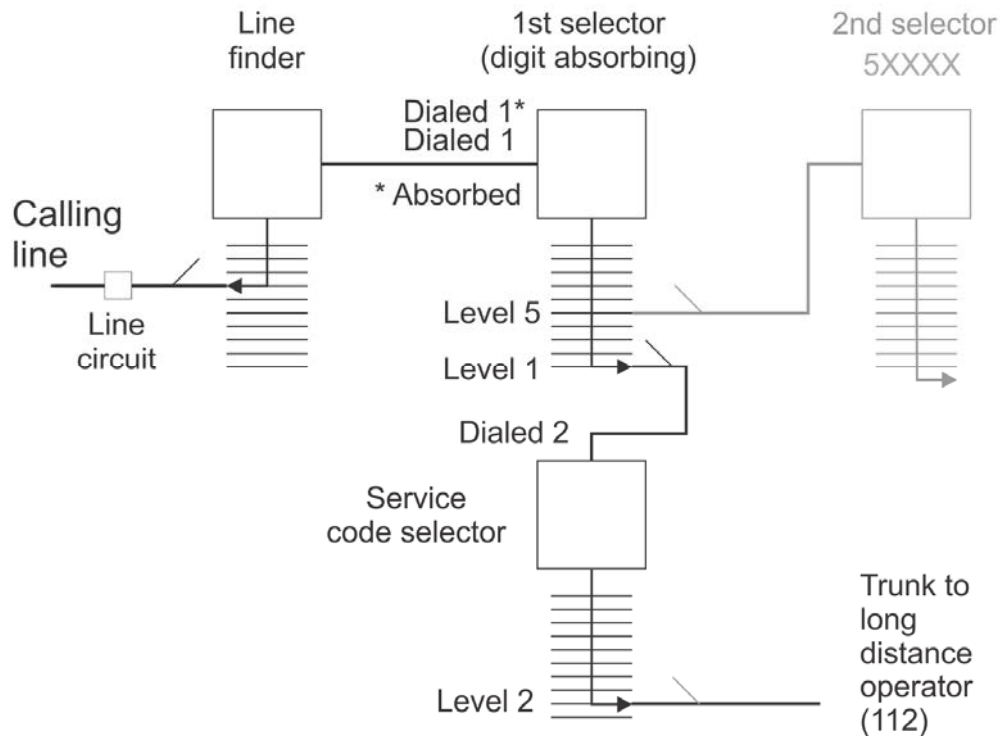
Figure 17. Digit absorbing selector and service code selector

If the caller dials a number starting with "5" (an intraoffice call such as we have often followed in the past), the 1st selector goes to level 5 and the connection proceeds in the ordinary manner.

If the subscriber, trying to call such a number, first generates a preliminary pulse, the apparent first dialed digit"1" is absorbed. But the rest of the connection proceeds in the usual matter.

Suppose the caller, intended to all the long distance operator at 112 first generates a preliminary pulse. The apparent "1" as the first digit is absorbed. The first actually-dialed "1" takes the 1st selector to level 1, where it searches for and finds a service code selector. The second actually-dialed digit takes the service code selector to level 1, where it searches for some not busy thing. But there are no "things" connected to the terminals of that level—and every terminal is marked permanently "busy". When the switch comes to the end of that level without any success, it returns "fast busy tone" to the caller, saying, in effect, "this call isn't going to work out."

13   EXPANSION OF THE NUMBERING PLAN

As of perhaps 1945, we found the following situation with regard to numbering plans:

- In the largest cities (New York, Chicago, etc.), 7-dgiit numbers were in use. The first three digits denoted the central office. They

were related to the first three letters of the central office name. In directories, advertising, and such the numbers were presented this way: SPRing 4632 (for the 777 central office code).

- In the largest cities (Cleveland, etc.), 6-digit numbers were in use. The first two digits denoted the central office. They were related to the first two letters of the central office name. In directories, advertising, and such the numbers were presented this way: LAkewood 5569 (for the 52 central office code).

- In medium size cities, 5-digit numbers were often in use. The first digit denoted the central office. Sometimes In directories, advertising, and such the numbers were presented this way: 3-2876 (for the 3 central office code). But sometimes letters were used, perhaps like this: D-2368. Sometimes these in fact related to the earlier manual central office name (perhaps in this case "Davis"). But maybe not.

- In even smaller systems, telephone numbers with a smaller number of digits were used. Generally these were just presented as is: 2783, or maybe (in an even smaller system) 785.

  A disadvantage of the scheme used in the largest cities was that, as the number of central offices increased, and more central office codes had to be assigned, it became increasingly difficult to find desirable (even credible) names whose first three letters matched the three digits of the code. Thus, at some point (I'm not sure just when), the practice there was changed to show that number as SPring 7-4632 (again for the three-digit central office code 777).

  This situation of different length telephone numbers made it extremely difficult to arrange the overall network so that a long distance call could be set up, all the way to the called line, by a single long distance operator (the one originally contacted by the caller. And the situation was also problematical with regard to the future plan for "Direct Distance Dialing" (DDD), in which subscribers could directly dial long distance calls without the intervention of any operator at all.

To relieve the numbering plan impediments to both these functionalities, the numbering plan was changed in two phases, starting in the mid-1950s:

a. Every telephone line in the United States and Canada would now have a 7-digit telephone number, which was to be presented in the "new New York" scheme. Thus, Joe's Bait Shop in Fillimac, Alaska, whose telephone number for years had been 543, was now MAdison 1-1543 (621-1543). And the family in a Cleveland

suburb whose number had for years been LAkewood 5569 (52-5569) now instead had LAkewood 1-5569 (521-5569).

In general, the new central office codes had "1" as the third digit. It mostly really didn't matter at first, and that was easier to remember, and took less time to dial than any other digit.

And the subscribers were gravely irritated.

This numbering plan was known as the "2L 5D" plan (2 letters, 5 digits), often just shortened when the context was obvious to the "2-5" plan.

b. The U.S. and Canada had earlier, in connection with the plan for completion of long distance calls by a single operator, been divided into Numbering Plan Areas (NPAs), each of which had a three-digit Numbering Plan Area Code (which are known today by civilians as Area Codes). In this second phase of the numbering plane renovation, it was arranged that no to central offices in an NPA would have the same central office code. The result was of course that in an NPA, no two lines had the same telephone number. The combination of the NPA code and the 7-digit "local" number for a line (that is, its 10-digit telephone number was in fact unique across all of the U.S. and Canada.

This of course meant that many central office codes had to change. If there was, for example, in Cleveland, the central office code MAin 1 (621), and in Smallburg, in the same NPA, the Central office code Madison 1 (621), one of these had to go. Which one? Well, there were many considerations, but perhaps the greatest was that the area engineering headquarters of Ohio Bell Telephone Company was in Cleveland. So, for some reason, Smallburg ended up with Madison 4 (624).

The execution of phase (a) in a "6-digit" city like Cleveland, served by panel dial and crossbar switching systems, was an immense undertaking. In every central office, in each of the units responsible for recording the dialed number and dealing with it (and there were literally hundreds of these in each central office), one or more plates of relays had to be added and wired in, providing relays for storing and accessing the additional digit. Other changes had to be made in the common equipment responsible for "translating" the dialed central office code into "address instructions" for the early switch stages.

But our real interest here is in the step by step system., How was it arranged to deal with the onset of universal 7-diit numbers?
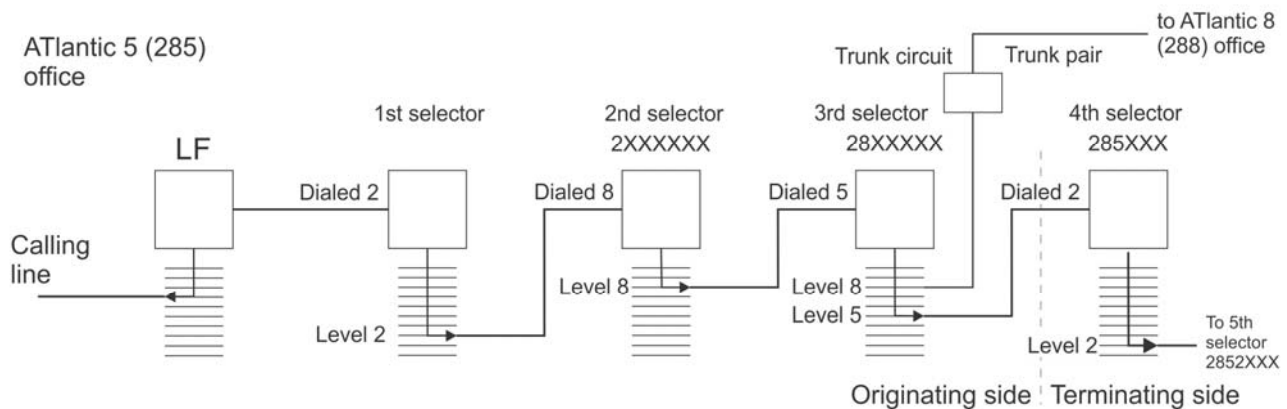
It could have been done as seen in figure 7.

Figure 18. 7 digit numbers the hard way

Here, if we consider starting with a 5-diti system, as we have contemplated in much of this article, we have now added two switching stages, each equipped with the requisite number of selectors. Now the train will have 5 stages of selectors (each of which will consume one of the dialed digits) and a connector (consuming the last two digits). I seems sensible enough. But we have added selectors without in any way increasing the "breadth" of the switching network.

In this figure we assume that our smell city, formerly having central offices (well, actually "units") 5, 6, and 8 (that we saw) is lucky enough to now have central office names ATlantic 5 (285), ATlantic 6 (286), and ATlantic 8 (288). That having been said, the operation of the system is fairly self-explanatory.

It turns out that we now "only" need 2nd selectors (as the first new stage is labeled) in the 2XXXXX group and 2nd selectors in the 28XXXX group. But there need to be enough of each to handle **all** expected busy hour traffic (since it will all pass through selectors of those groups). And that is a big cost. Which seems to do little but satisfy a new number format.

But now imagine that our city's assignment of central office names, perhaps after phase (b), comprises ATLantic 5 (285), MAdison 4 (624), and SPring 1 (771) [23]. Now we must have ("need them or not") 1st selectors in the 2XXXXXX, 6XXXXXX, and 7XXXXXX groups, with 2nd selectors in the 28XXXXX, 26XXXXX, and 77XXXXX groups.

So this is not going well.

---

[23] Presumably the engineers would have been able to avoid having it come out this way, but I use this extreme situation to make a point..

In fact, there is a way to more "fake" the expansion to 7-digit numbers. We learned in section 12 of the digit-absorbing selector, used there to ignore a preliminary pulse (which appears to be a dialed digit "1".

If we are lucky enough (or have planned well enough) that all the central office codes in our little city now have distinct third digits (perhaps the digits that identified the different central offices under the 5-digit plan), we can arrange the digit-absorbing selector to just release after the dialing of the first two digits (if they are not "1", which would mean that a service code was being dialed). We see this at work in figure 7.
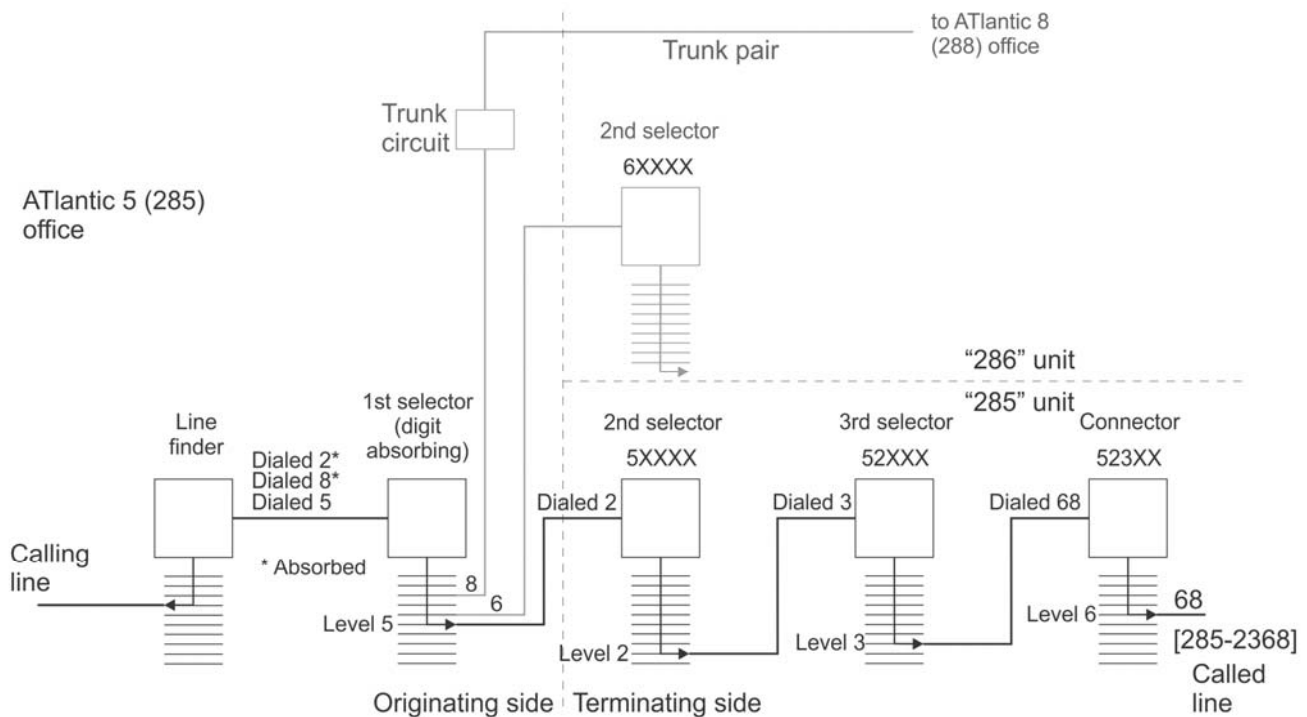

Figure 19. 7-digit dialing with digit-absorbing selector

Here, the switch train has the same number of stages we saw previously. If the calling subscriber dials 285-2368, the first digit (2) steps the 1st selector to level 2. From that level number, in a way we will discuss a little later, the switch realizes that this digit should be "absorbed", and the switch releases. (It takes away dial tone, however!)

Then the caller dials 8, and again the switch realizes (from the level number) that this digit should be absorbed, and the switch releases again.

Now the caller dials 5. The switch recognizes from the level number that this digit should not be absorbed, and so goes on about its business in the way we saw earlier.

We note that in this implementation, a caller wanting to reach Mary at 285-2368, where her number was formerly 5-2368, could just dial 5-2368 and reach her. And in such case, this took away much of the subscribers; irritation with the conversion to universal 7-digit dialing.

But we recognize that this implementation only worked because of the way the central office codes were assigned.

In other case, where it didn't work out this way, a more sophisticated type of digit-absorbing selector was used. I effect, here, whether the dialed digit was "absorbed" depended both on what the digit dialed was and whether it was the first or second digit dialed. There were various logical patterns that could be put into place. This is beyond the scope of this article.

14   THE DREADED "PERMANENT SIGNAL"

Sometimes a subscriber will inadvertently take his station set "off hook" when not intending to make a call. (Perhaps the cat has knocked the handset out of its cradle.) Of course the system dutifully starts a line finder to find the line and give it the service of a 1st selector, but that is all for naught. No digits are going to be dialed, and there will be no connection.

This is of course disadvantageous, among other reasons that this line is now "out of service" and can't be reached by callers. And of course this time up a line finder-selector pair, maybe for a long time, without any benefit to the subscribership generally.

Of course the very same thing could happen in a manual switching system. When the cat takes the station off-hook, a line lamp lights and an operator plugs a cord from a cord circuit into the line and says (in a major city) "number please" (or in a small city, "Hey, Burt, what can I do for ya?").

But Burt's not on the line. If the operator decides that this call is a non-starter, and just pulls out the cord, the line lamp will light again. So the "line wanting service" signal is "permanent". This led to the term *permanent signal* being applied to this situation, even in a dial switching system.[24]

To provide amelioration of these events in the step by step system, when a selector (at any stage) has been "seized" and has not yet advanced the connection to the next stage, it gives a signal on a lead (common to all selectors in then group) going to a common alarm

---

[24] Another term used is "receiver off hook (ROH)", not too apt, as of course the "receiver" is off hook during any actual call.

circuit. We can think of what happens there as a timer seeing if any selector has been in this state for over a certain period of time. If so, an alarm signal comes in, and a technician will look into the matter. What happens next is beyond the scope of this article.

15   ACKNOWLEDGEMENT

Appendix A
Multiple wiring schemes

A.1   Introduction

In the body of this article I referred to "complex patterns of wiring" for the bank terminals of a selector or line finder in pursuit of various operational advantages. In this appendix I discuss the basic concepts of two of these, so as to give some idea of what this matter is all about.

A.2   The term "multiple"

A.2.1   Introduction

Many of the comp[ex wiring patterns I mentioned are spoken of by terms involving the word *multiple*, such as *slipped multiple*, *reversed multiple*, and *graded multiple*. So what does "multiple" mean in this context?

The use of the term in telephone switching goes back to manual switchboard operation.

A.2.2   In manual switchboards

Imagine first a very small town served by a manual switchboard. There are perhaps only 100 lines in the whole system. The switchboard has only a single "position" (an operator's "work station"), and the switchboard is worked at any given time by one operator.

Each line "appears" on a jack in a jackfield on the vertical front of the switchboard. To complete a call to any line, the operator plugs a cord from cord circuit into the jack for the wanted line.

Now imagine instead a manual central office in a much larger town. Perhaps the switchboard there is set up to serves 8000 lines. Of course, the rate at which calls arise requires that there be many operators, each working at a separate *position*. Suppose that this switchboard has 30 positions (all of which will be occupied by operators during the busiest parts of the day).

Each line is not connected to a single jack but rather to several jacks, spaced out along the length of the switchboard at intervals of, say, 1⅔ times the width of a position. (That would work out to 18 jacks for each line for the whole length of the switchboard.) The three leads of each line (tip, ring, and sleeve) are connected in parallel to all these jacks. The jacks are all marked with the telephone number of the line (and are in consecutive order by that number).

The result is that when a certain operator is handling a call that turns out to be for a certain number, a jack for that line will exist either

within the jackfield of her position or within the nearest 1/3 of the jackfield of her colleague to the left, or within the nearest 1/3 of the jackfield of her colleague to the right. In either case, she can reach that jack to plug the cord circuit cord into it.

So, yes, that means that within any "region" on the switchboard face that is 1⅔ positions wide (and the full height of the jackfield) we will find jacks for all 8000 possible telephone numbers this switchboard is set up to serve.

Quite sensibly, this whole arrangement is spoken of as a *multiple jack* arrangement, in contrast to the *single jack* arrangement we spoke of earlier for the very small town switchboard.

And as a consequence, the entire collection of jacks on the fact of the switchboard (yes, 144,000 of them) is spoken of as the *line multiple.*

If we go to the back of the switchboard, we see the full horror of this in terms of wiring. Running across the back of the switchboard is a veritable river of conductors—24,000 of them in fact (three for each of 8000 lines).

And in the context of the hardware itself (rather than the operator's view of it), the entire collection of 144,000 jacks, and the associated run of 24,000 conductors, is also spoken of as the *line multiple*.

And because all the jacks for one line in the line multiple are connected in *parallel*, it became the custom in the telephone world to speak of things that are connected in parallel (perhaps even two resistors) as being "in multiple."

A.2.3 In a step by step system

In a step by step system. we have a similar situation. Imagine a "shelf" of 10 2nd selectors. On the bank of each one are 300 contacts (a tip, ring, and sleeve for each of 100 terminals). In the most straightforward situation, the 300 contacts on each of these selectors are wired in parallel (on a contact to corresponding contact basis) to the 300 contacts of the other 9 selectors. In the resulting set of 300 leads. they go in sets of 30 (from the terminals at each level of all the banks) to a group of 10 3rd selectors.

And indeed, if we look at the back of the collection of banks, we will see a small "river" of conductors, "only" 300 in this case, flowing across the banks of all the selectors on this "shelf" and then to a set of terminal strips from which they will go the various groups of 3rd selectors.

Because of the great parallel between this and the situation in a manual switchboard, this wiring of the selector bank is called the

selector multiple (and sometimes the term is used to include the banks themselves).

To connect this discussion with the way we have been looking at the step by step system, in figure 20 we see in a little more detail the situation shown (more symbolically) in figure 7.
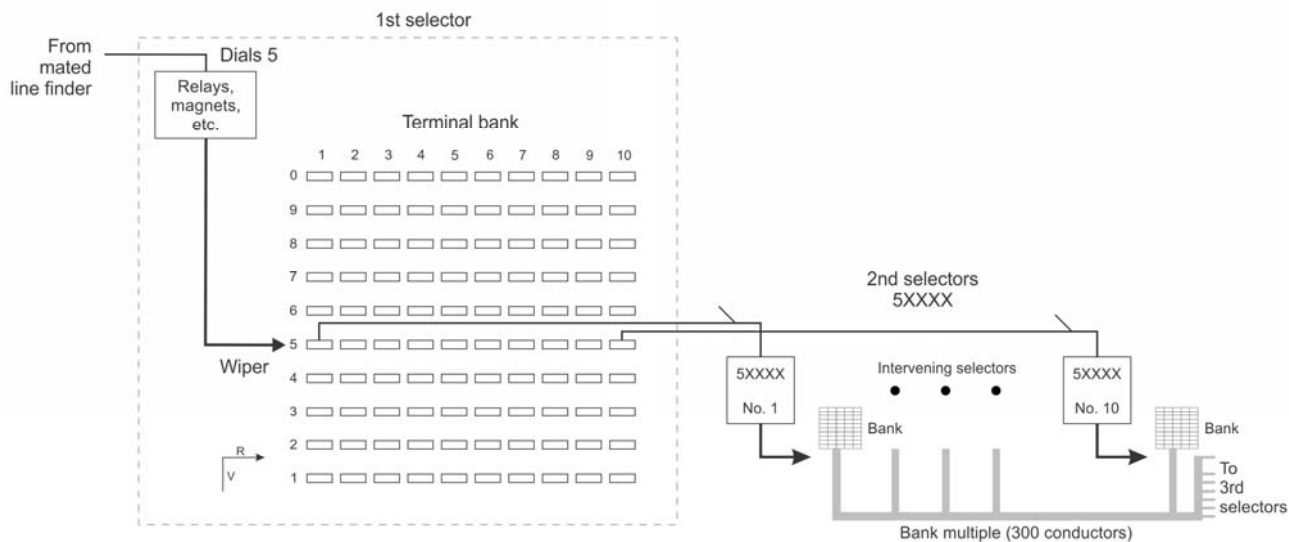

Figure 20. The selector multiple

Note, as before, the "multiple" symbols that remind us that the bank wiring from the several 1st selectors (although we only see one) are all connected to this group of 5XXXX 2nd selectors.

The fat gray lines at the lower right are in turn symbolic of the wiring from the banks of all 10 3rd selectors (the famous *bank multiple*), which is actually in 10 portions of 10 circuits each (one for each bank level). These portions each lead to one of 10 groups of 3rd selectors— the 51XXXs, the 52XXXs, the 53XXXs, and so forth.

A.3   Multiple wiring schemes

A.3.1   Introduction

In figure 21 we will, for our illustrative connection, look in a different way at the 5XXXX 2nd selectors.

Imagine that there are 100 2nd selectors in the 5XXXX group[25], arranged in 5 subgroups of 20, each made up of two shelves of 10 selectors each. In the figure, each shelf of 10 selectors is represented by one "proxy" symbol. We only see two of them.

---

[25] As may well be required to handle the "busy hour" traffic to 5XXXX numbers for the possibly 10,000 lines served by this office.

The bank multiple wiring in this figure is what is called "straight". It is just what we implied in the body of the article.
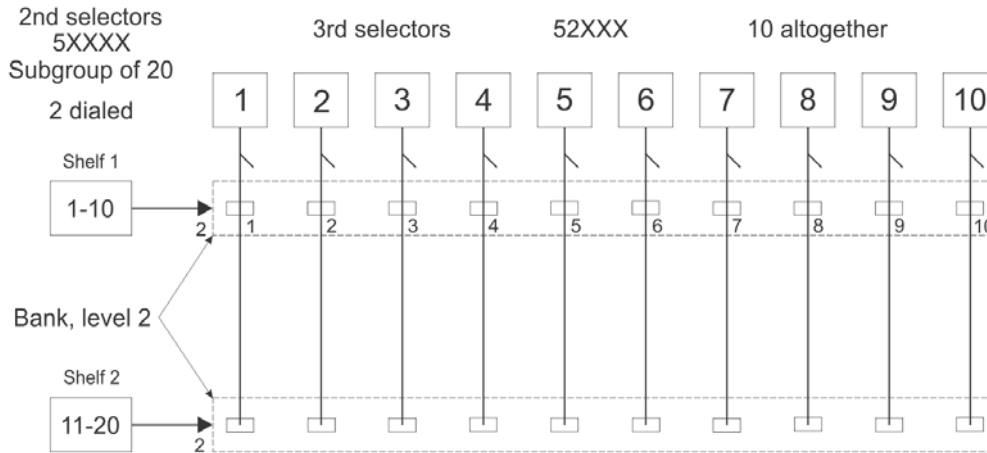
Figure 21. A "straight" selector multiple

Inside each dashed line box we see rectangles that represent the terminals of the 10 positions on level 2 of the banks of all the 2nd selectors in the shelf (the leads multipled across all 10 banks). Then the leads are multipled across the two shelves of selectors, and then go to 52XXX 3rd selectors 1-10. The multiple symbols on the selectors remind us that there are other 5XXXX 2nd selectors that can access these 3rd selectors (those in the 3 additional subgroups we do not see on the figure).

A.3.2 The graded multiple scheme

But suppose that traffic engineering analysis shows that for the 53XXX selectors, 16 53XXX selectors, not 10, are needed to provide the desired grade of service for the projected busy hour traffic to that range of numbers. Perhaps there is a large department store, with 30 lines going to it, whose number is in the 53XXX range.
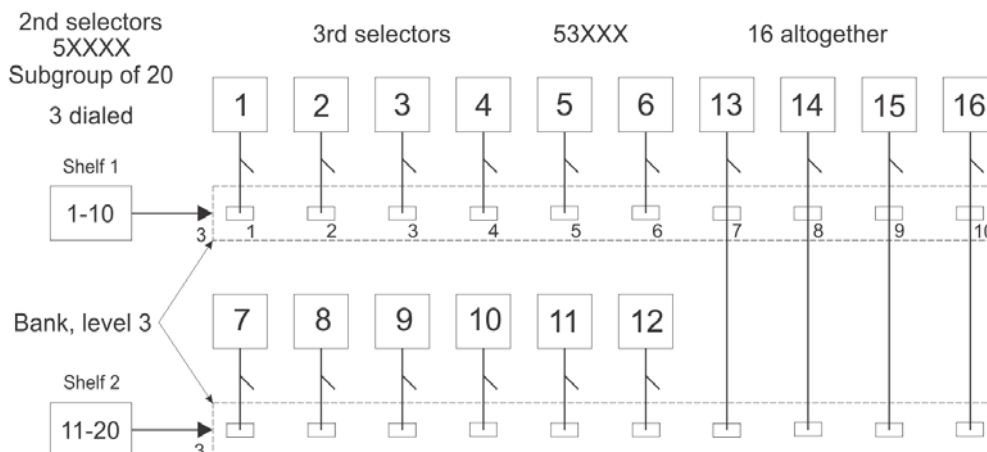
Figure 22. Graded selector multiple

We cannot just add 6 more selectors to the scheme we saw in figure 21—there are not 6 more terminals on each level of the selector, just 10 altogether. So instead, we adopt a slightly more complicated scheme, seen in figure 22.

Again, for the 10 5XXXX 2nd selectors in a shelf, the banks are multipled in the normal way. But, for terminals 1 through 6, these "minor" multiples for each shelf go to separate 53XXX 2nd selectors (2nd selectors 1 through 12). Then, for terminals 7-10 on level 3, the "minor multiples" for each shelf of 1st selectors are gathered into a "major multiple" across the entire subgroup of 1st selectors, just as we saw before.

The result is that there are now 16 2nd selectors in the 53XXX category to handle traffic to 53XXX lines, as was suggested by traffic engineering considerations.

And, with this scheme, during periods of modest traffic, when only a fraction of these selectors will be busy, this arrangement means that on the average, a 1st selector will have to hunt a smaller number of rotary steps to find an idle 2nd selector (which, among other things, reduces the wear on the switch mechanisms,)
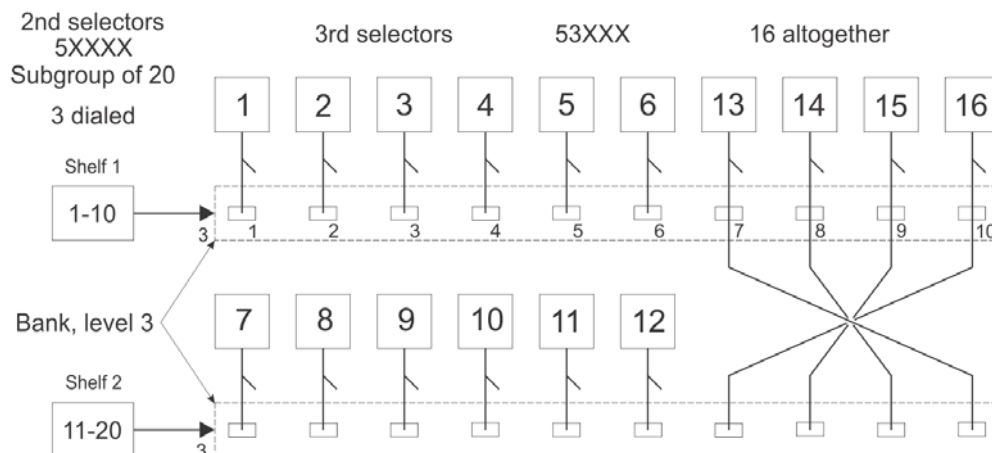

Figure 23. Graded and reversed multiple

A.3.3 The "reversed multiple" scheme

Next I will add another multiple wiring scheme (two or more schemes are often combined). Figure 23 shows it, in the same format we have seen just previously.

Here the basic architecture is a graded multiple scheme, as we saw in figure 22. However, in the area of terminals 7-10, where all 10 1st selectors in the subgroup access a common 2nd selector at any terminal, for terminal 7, for the first shelf, that is 2nd selector 13, while for the second shelf, that is 2nd selector 16. In effect, passing

from the first two groups to the last two groups, the multiple is "crossed over", or "reversed" .

And in fact, this scheme is spoken of as a *reversed multiple* scheme.

The advantage is that, during times of moderate traffic, when the selectors might have to step as far as terminal 7 to find an idle 3rd selector, on the average the 1st selectors will have to search fewer rotary steps to find an idle 2nd selector. In effect, half of the 10 1st selectors in the subgroup hunt over the cohort of 2nd selectors 12-16 from one end, and the other half from the other end.

This results in, on the average, less wear on the mechanisms of the 20 5XXXX 2nd selectors, and tends to somewhat equalize the wear on the collection of 16 53XXX 3rd selectors.

In actual practice, when reversed multiple is used, the last terminal is exempted from that scheme, as we see in figure 24.
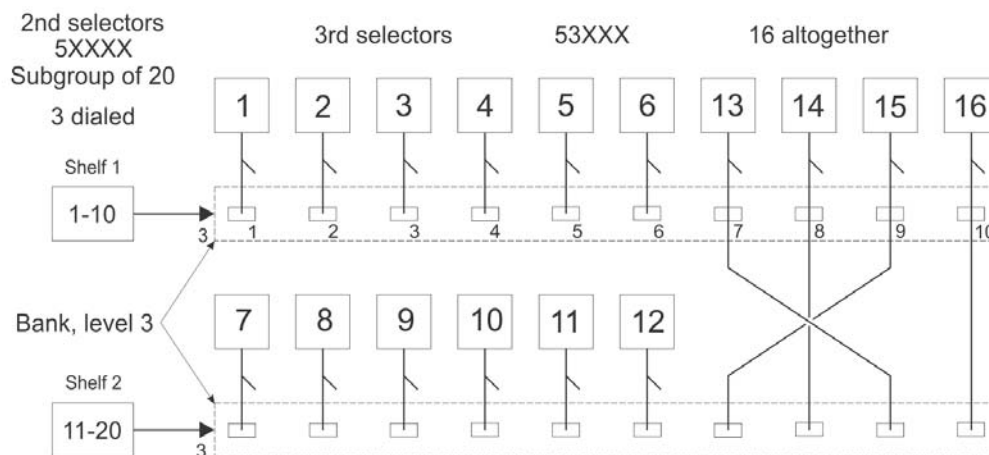

Figure 24. Graded and reversed" multiple (2)

This facilitates certain matters that are beyond the scope of this article.

Also. in reality, for the "10 3rd selectors requires" situation we saw at first, a reversed multiple is often most commonly used, as we see in figure 25.
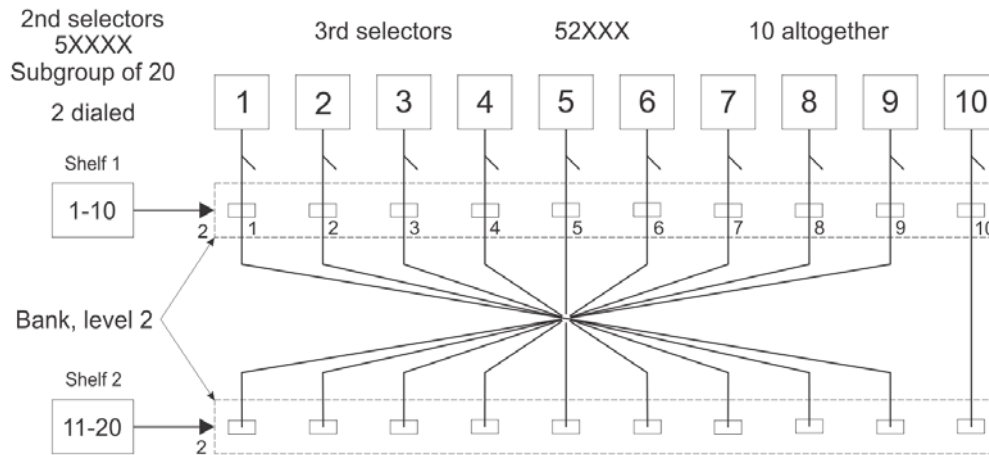
Figure 25. Reversed multiple

As we saw just before, again the last terminal is exempted from the reversal.

A third multiple wiring scheme, the *slipped multiple*, is primarily used on line finder banks. It is discussed in the companion article on the line finder switch.

A.4   The broader picture

Of course, the employment of the special multiple wiring schemes, as they apply to different situations, is a complex art all its own, which we will not have time to examine here.

-#-