The step-by-step telephone switching system: The line finder switch

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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 one of a series of articles on this system, and it describes the *line finder* switch, which is used in the first stage of the switching network. The basic functions of the switch are summarized, and an illustrative schematic drawing is used as the basis for a detailed description of its operation.

1 GENERAL

1.1 The series of articles

This article is one of a series. The "master" article, "The step-by-step telephone switching system: Overview", by the same author, gives background on the historical development of the system, and then describes its overall architecture, scheme of operation, and the technical details of the unique type of switch used in the system. It also gives background on such telephone concepts as battery and ground; tip, ring, and sleeve; and the like. The other articles (including this one) describe in detail (including at the circuit level) the different switches used in the step by step system.

In some cases, information given in the master article is repeated here for continuity.

All the articles are indexed on, and available at, my site, The Pumpkin:

`http://dougkerr.net/pumpkin`

1.2 Types of switches and their roles

The step by step switching system in its most widely-used form uses three kinds of switch, all with essentially the same base mechanism but varying substantially in their complement of relays, function, and operation. The three types are the *line finder*, the *selector*, and the *connector*. The line finder serves to provide a connection from a subscriber line requesting service (the user lifts the handset) into the switching network itself, in the person of a selector switch (this one being a so-called *first selector*). The selectors serve to advance the concretion stage by stage through the “interior” of the switching network, each one in response to a successive digit of the dialed number, not including the last two.

The connectors constitute the final stage of the overall switching network. After all but the last two digits are dialed, the connection has been extended to a connector switch, one which can access 100 line, including of course the one whose number has been dictated by the earlier dialed digits.

The last two dialed digits move the connector to the corresponding line. The connector tests the line to determine if it is busy (on an existing connection). If not, a connection is made to the line and the ringing signal applied. When the called station answers, the ringing signal is removed and a transmission path is completed between the calling station and the called station.

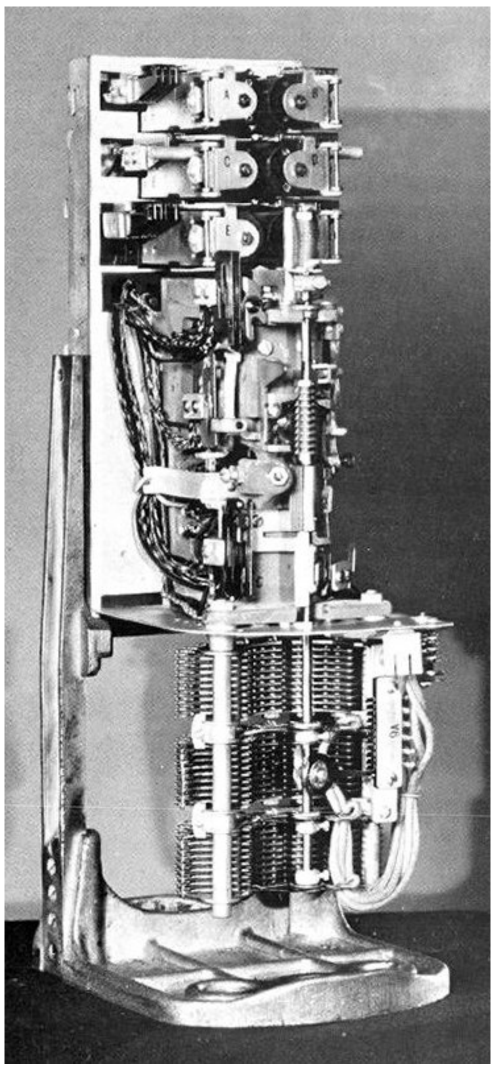

Figure 1. Typical line finder switch

2 THE SWITCH ITSELF

2.1 General

Figure 1 shows a typical “200-point”selector switch, with an unwired bank assembly attached, in a test stand, used to hold the switch while it is being adjusted or tested.

Like all the switches we see in this series, this is a two-motion switch. It can move to any of 100 terminals positions arrayed in a curved contact bank in 10 “levels” of 10 terminals each. It reaches a certain terminal by first moving its shaft (which carries the contact making “wiper”) up in steps to the appropriate level, and then rotating the shaft in steps to the appropriate terminal on that level.

2.2 The “200-point” bank assembly

But in the most-common “200 point” form, at each terminal position, the switch makes contact with the leads of two (unrelated) lines, so that a total of 100 lines can be accessed by a given line finder. A relay in the switch determines which of the two lines at the terminal position to which the switch has moved is actually accessed.

At the bottom we see the bank, or to be more accurate, banks. Plural? Yes. Three leads (conductors) have to be carried through the switching network for each line, the *ring* and *tip* (which carry the line itself) and the *sleeve*[1], which is used for various control purposes.

And because this is a 200-point switch, there are two sets of those three leads at each terminal position, six leads altogether.

It would be easy to imagine that each “terminal” of the bank had six contacts (for tip, ring and sleeve) and that the wiper had six 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 three banks, as we see in some detail in figure 2.

On each bank, at each terminal position are two contacts, rather thin, lying opposite one another on a thin insulating phenolic sheet. There is a thicker phenolic sheet, not shown in the drawing, between these “sandwiches” at the various levels.

On the lower bank, at each position, these contact pairs carry the ring and tip leads of one of the two lines. On the middle bank, at each

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[1] These names all come from the designations of the three contact members of the plugs used in manual telephone switching systems.

position, these contact pairs carry the ring and tip leads of the other of the two lines. On the top bank, at each position, these contact pairs carry the sleeve leads of the two lines.

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).

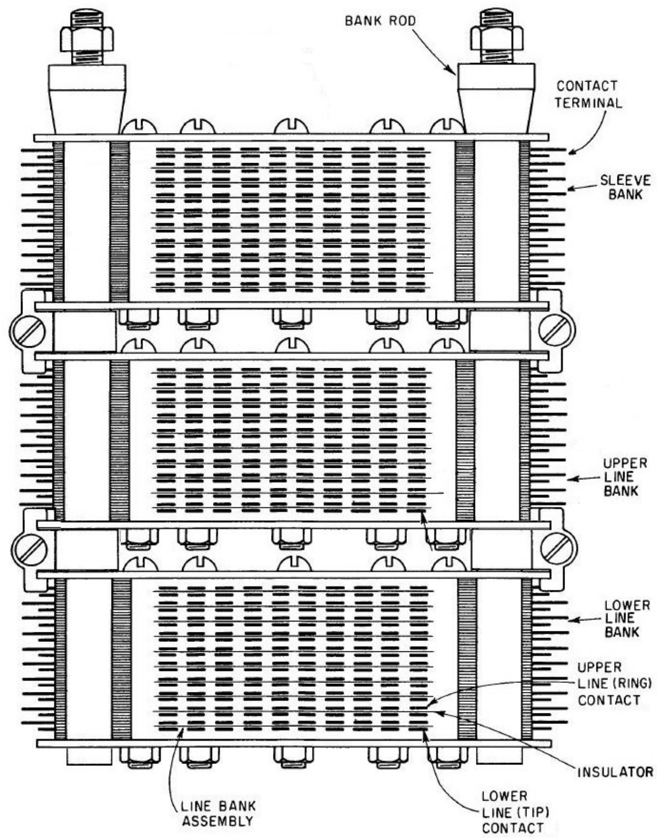

Figure 2. 200-point line finder bank assembly

Accordingly, what we have thought of as “the wiper” of the switch is actually three wipers, one running on each bank. Each wiper has an upper and lower contact “leaf”, insulated from one another (since they will touch separate contacts).

In figure 3 we see such a 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.

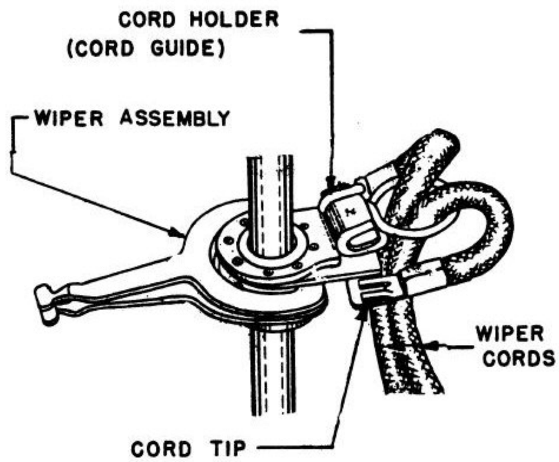

Figure 3. Two-contact wiper

Toward the top of the switch “chassis” we see six 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.

In use, the switches (not including the banks and wipers) are each covered by the iconic “mailbox-shaped” sheet metal cover.

2.3 The vertical commutator

When a line finder is started on behalf of a line requesting service, and we look to it to “find” that line, it is not practical for the line finder to somehow scan over (potentially) over all 100 terminal positions.

Rather, we give it "hint" by telling it on which level that target terminal lies. This utilizes what is called the *vertical commutator*. We see it in figure 4.

It is a little vertical strip of 10 terminals, against which a special wiper runs as the switch steps vertically. (Actually, we see 11 terminals; the lowest one, against which the wiper rests when the switch shaft is in its home position, merely serves to properly align the wiper so that, as the shaft begins to rise, the wiper can move onto terminal 1.)

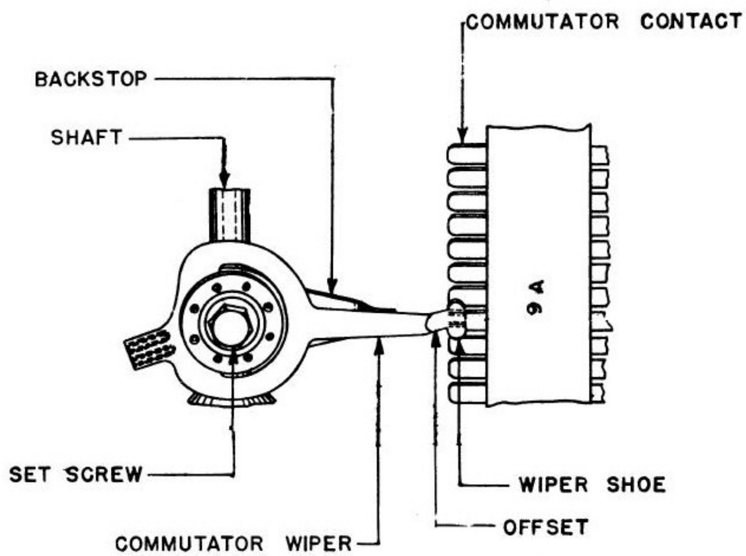

Figure 4. Line finder vertical commutator and its wiper

When the line finder is started, ground is placed on the commutator terminal for the level on which the calling line is located. As the switch steps vertically (autonomously), a relay in the line finder looks for that ground. When it finds it, the vertical stepping stops and the switch begins to step in the rotary direction. The calling line has battery on its sleeve terminal, and now the switch looks for that.

3 SWITCHING NETWORK ARCHITECTURE AND OPERATION

In these articles, "switching network" means the portion of a switching system through which the connection is extended inside the switching system from the calling line to the called line (as distinguished from the use of the term to mean a number of interconnected switching systems).

For context, figure 5 shows the entire "train" through which the call is handled from one end to another. We see a line finder, three selectors (in successive stages), and a connector.

I note here that in fact there are two "schemes" for connecting a line wanting to make a call to a first selector, the line switch scheme and the line finder scheme. This situation is discussed in some detail in section 4 of this article. But of course the central scope of this article is the line finder, so for a while we will assume the use of that scheme.

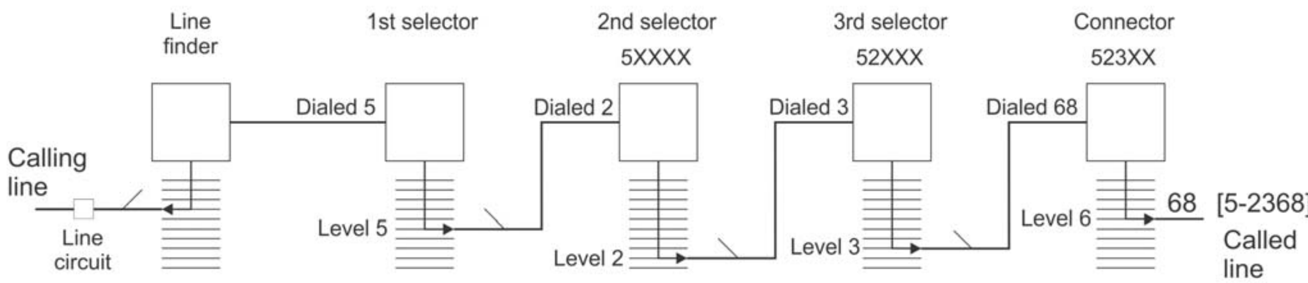

Figure 5. 5-digit switch train

Our model assumes that five-digit telephone numbers are used. This figure shows a completed connection from a certain subscriber's line to the line whose number is 5-2368. (Actually, the number dialed is of no consequence to the line finder.)

Here, since our concern is with the line finder, I will not follow the way in which the entirety of the connection is built up. That topic is covered thoroughly in the "master article".

Imagine now that 200 lines are connected through their line circuits to the 200 "two-line" terminals of several line finders (all in parallel). The little diagonal line (called a multiple symbol" reminds us of this, even though we only see one line finder.

Each line has associated with it a line circuit, comprising two relays. Battery is fed to the ring of the line through the winding of one, the *line relay*; ground is fed directly to the tip.

When the subscriber lifts the handset to place a call ("requests service", we say), current flows in the line. and that operates the line relay. This causes the next one of the group of line finders that is not already busy on a connection to "start". That line finder, by first stepping vertically, and then horizontally, to the position at which the line (with another line) is connected, and then either operating or not the "which of the two lines" relay, connects to the line.

The line finder then grounds the sleeve lead to the line circuit, which operates the second relay there (the *cutoff relay*). This frees the line from the battery and ground applied at the line relay.

Each line finder is permanently (more or less) connected to a 1st selector. They work together at all times.

The 1st selector feeds battery and ground (through two windings of its battery feed relay) to the leads where a line will show up when the line finder has connected to it.

When that happens, the presence of the calling line operates that relay, ”awakening” the 1st selector; it now has a “client”. This 1st selector is now “holding the baby”, and will be, for a short while responsible, for managing the connection (nascent as it is at this point). As part of that, it grounds the sleeve lead going back to the line finder. This tells the line finder that the connection is proceeding as expected.

The continued presence of this ground (which will come back from later and later switches in the connection as it unfolds, ultimately from the connector) tells all the intermediate selectors, and the line finder, “don’t release–this connection is still live”.

4 TWO APPROACHES AT THE BEGINNING OF THE CONNECTION

4.1 Introduction

As I mentioned a while ago, over the range of step by step systems, there are two “schemes” for connecting a line desiring to place a call to a 1st selector so that a connection can start to be built up. These are called the *line switch* and *line finder* schemes. Not surprisingly, given the title of this article, all the discussion above has been predicated on the line finder scheme. But here, we will, for completeness, briefly look into the other scheme, which in fact had two quite different executions.

4.2 Review

By way of review, Figure 6 shows in “single-line” form almost the entire path from a calling line to the line with number 5-2368,

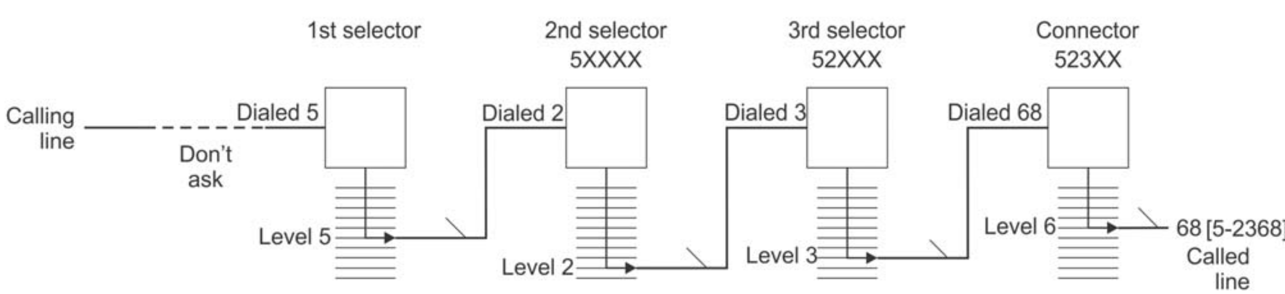

Figure 6. Switch train from the 1st selector

This figure for the moment leaves as a mystery how the calling line gets connected to this particular 1st selector.

In the earliest "demonstration" Strowger systems, serving a very small number of lines, every line had its own first selector, which it could use without further ado any time the subscriber wanted to make a call. Figure 7 in fact shows this arrangement applied to our hypothetical central office.

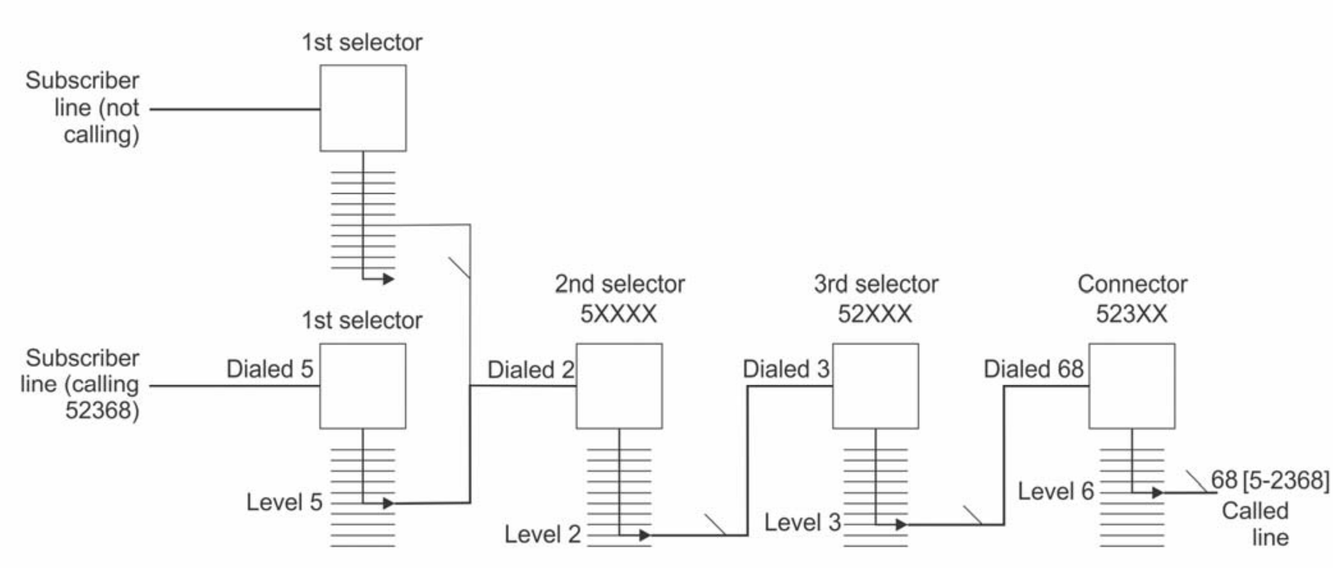

Figure 7. Switch train with individual 1st selectors

The operation of this arrangement should be self-evident, and it would work just fine.

But selector switches are complicated, and bulky, and costly, and involve a gigantic amount of connecting wiring from their banks. If in fact we were to consider a central office serving 10,000 lines, we would have to have 10,000 1st selectors. Yet perhaps only 1000 1st selectors would be adequate to handle the amount of traffic (at the first stage of the switching network) from those 1,000 lines at "busy hour".

So this scheme is, not surprisingly, not found in any "serious" step by step systems.

4.3 The line switch scheme

The earliest "serious" Strowger systems used a scheme called the *line switch* scheme to allow a line requesting service to get connected to an 1st selector as its "doorway" to the switching network proper. Figure 8 shows this concept, in our familiar context.

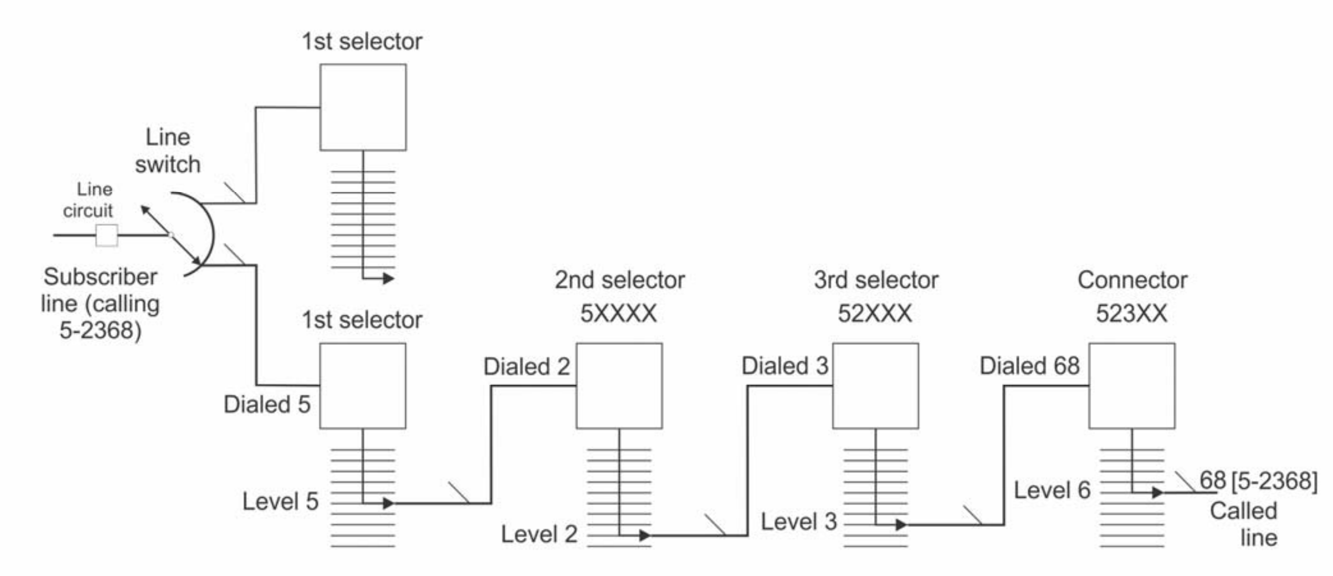

Figure 8. Switch train with line switches

Here, each line is equipped with its own switch, a *line switch*, but this is a much simpler switch than a line finder, using a totally different structure. (Actually, there are two dramatically different kinds of line switches; I will at this point describe the "most obvious" of them.)

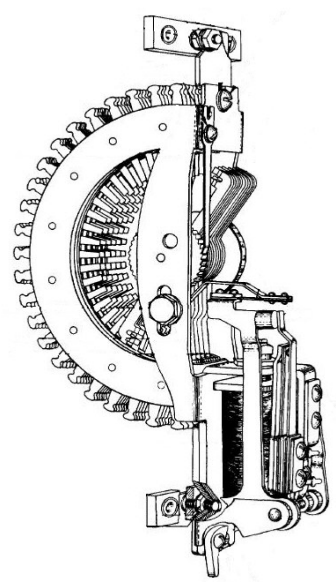

Figure 9. Uniselector

These switches are sometimes called *uniselectors*, and they are *single-motion* stepping switches (that leading to the name). That is, each time their electromagnet operates (and released; in the kind of interest, it actually does its work when it releases). a set of wiper arms is stepped one further position over a group of terminals arranged in a curved bank. But there is no motion in a second direction.

Figure 9 shows one of these little beauties.

The terminals (it is typical for a switch of this type to have 22 terminals, as in the one shown) cover a span a little less than 180° in scope. Each wiper arm is double ended. As the collection of wiper arms is stepped off the last terminal in the bank, the opposite end of each arm comes onto the first terminal in the bank. Thus the wipers are always in contact with one terminal of the bank or another.

We also see in the figure for the first time a line circuit, a small collection of relays. Each line has one.

The terminal of the line switch (each one having three contacts, for the tip, ring, and sleeve of the line; only the tip and ring actually go out to the station) are wired to the "inputs" of separate 1st selectors (typically up to 10 of them). The terminals of the line switched banks for other subscriber lines in a group (perhaps as many as 40 altogether) are all connected "in multiple" to that collection of 1st selectors.

If a selector is busy (participating in an existing connection, its sleeve lead carries ground.

With the line idle, battery is fed through the winding of one of the relays in its line circuit (the *line relay*) to the ring of the line, and ground to the tip. When the subscriber lifts the handset, the resulting flow of current operates the line relay, and this sets into motion a chain of events that results in the line's line switch starting to autonomously step over its bank terminals (that is, over the "candidate" 1st selectors). At each terminal, the state of the sleeve lead is examined by a relay and if it shows ground, the switch steps on. But at the first terminal encountered whose sleeve does not show ground (and is thus "idle"), the switch stop its stepping, and another relay connects the line through to the line switch wipers and thus to the 1st selector.

Then further details of this are beyond the scope of this article.

4.4 Another kind of line switch

Another rather different implementation of the line switch architecture uses what are called *plunger switches* rather than uniselectors. There, all the line switches for perhaps 20 lines are consolidated into a single mechanical assembly.

The connection between the line and the chosen 1st selector is not made with wipers moving over contacts, but rather by a plunger on the unit for the line spreading a set of contact springs that close the path.

We can see the principle in figure 10.

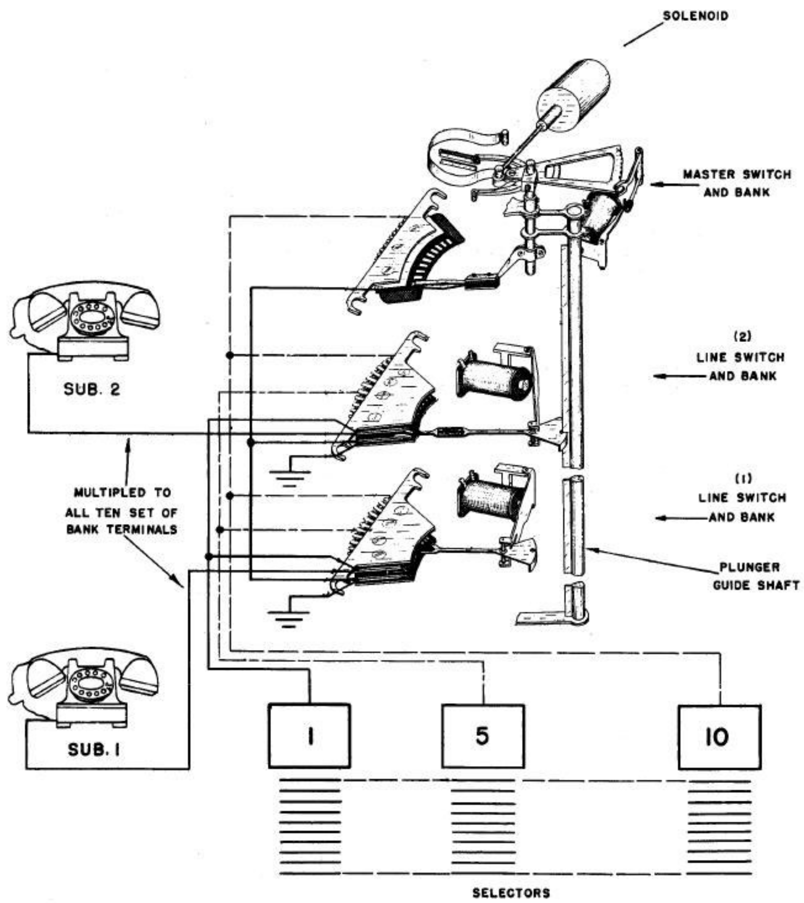

Figure 10. Plunger-type line switch

The assembly includes a common drive element (think “motor”) that couples to the line switch plungers of all lines not requesting service to move them until they align with (and are ready to “plunge into”) the springs that would connect the line to the first currently idle 1st selector.

Oddly enough, this common drive element is called the “master switch”. Of course, it is not a switch at all. Perhaps “switch master” would have been more apt. It is driven by a powerful spring in much the form of a bicycle pants clip (seen in the figure, although its orientation is not that implied there), with a small flyball governor (not shown) to control its speed. When it has come to the end of its travel, a solenoid resets it to its starting position.

When a line comes off hook to request service, the line relay operates, which energizes a magnet in that line’s line switch that makes the plunger “plunge”. making a connection from that line to the currently first idle 1st selector. The “master switch” then moves all the remaining plungers until they are positioned to connect their lines to the now first idle 1st selector

One advantage of this scheme is that the per-line cost of this assembly may be less than that of an equivalent group of uniselectors.

This is a fascinating mechanism[2], but its further description is beyond the scope of this article.[3] Still, just for amazement's sake, figure 11 shows a typical plunger switch assembly, this for 50 lines.

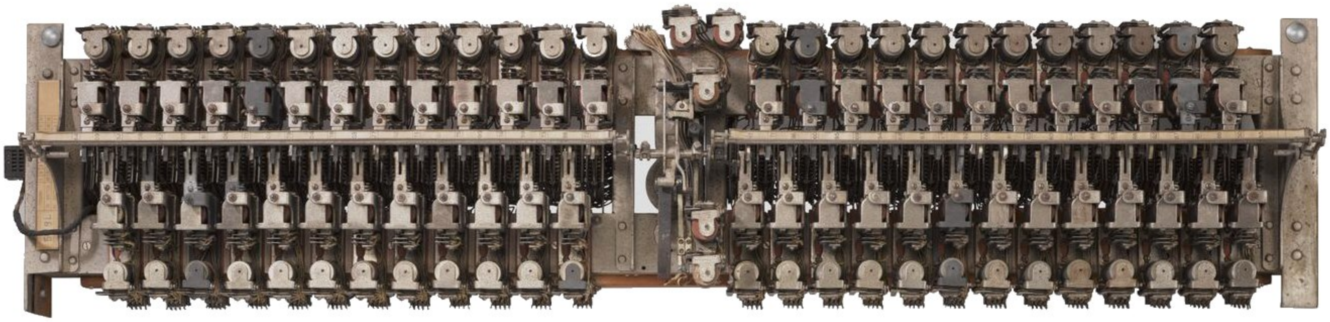

Figure 11. 50-line plunger switch "shelf"

On either side, there is a row of 13 switches and a facing row of 12 more, interleaved. In each switch, there is the plunger magnet and the *line relay*. In the center, there are 5 more relays for the common circuit for controlling the "master switch".

Notwithstanding the greatly different mechanical arrangement, the role of the plunger type line switch in the network architecture is essentially identical to what we see in figure 4.

However, it is very common to have a second stage of plunger type switches in the path to the pool of 1st selectors. This allows any given line to potentially gain access to more than 10 1st selectors. The details of this are beyond the scope of this article.

4.5 Usage preferences

In the Bell Telephone System, except during the first few years of use of the step-by-step switching system, that system was used with the line finder configuration. But for Strowger systems in the U.K. for instance, the line switch configuration, with uniselectors, was the most common.

[2] The design of this mechanism is attributed (*ca*. 1906) to Alexander E. Keith, one of the most prolific and influential inventors in the Strowger company (and its successor, Automatic Electric Company). Especially outside the Bell Telephone System, this mechanism is often called a "Keith switch".

[3] Those familiar with this mechanism will recognize that my concise description is rather "fanciful" in some places. My point was not to describe this mechanism in detail but rather just to give some insight into it.

4.6 The line finder scheme

The scheme for the "front end" of the switching network on which we have concentrated in this article uses a switch called a *line finder*. For recollection, figure 12 shows it in the same context we have seen before.

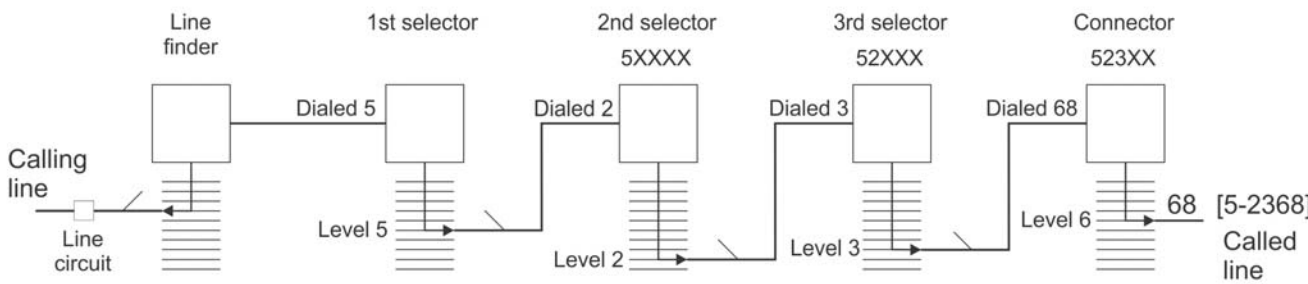

Figure 12. Switch train with line finders

The line finder uses the same basic mechanism as the other switches in the system. But as a system element, it "faces the other way".

This scheme was discussed in detail starting in section 3 of this article.

5 The schematic drawing

5.1 Our subject switch

The schematic drawing and associated circuit operation description do not necessarily represent exactly any of the numerous specific connector switch designs found in the wide range of step by step switching systems. All of them, however, follow almost identical principles, and the hypothetical one we will discuss uses representative circuitry.

5.2 Basic schematic drawing conventions

The schematic drawing employs a system of notation introduced in the Bell Telephone System in the mid 1950s, called *detached contact* notation. In it, the relay contacts are not shown in a form evocative of actual physical contacts, with all the contacts on a certain relay all adjacent on the drawing, much as they are in real life.

Rather, in this system, simple (easily drawn!) geometric symbols are used for the basic contact elements, what would be called in other contexts a "normally open" or "normally closed contact".

The contacts on a certain relay are not gathered together on the drawing, but rather are placed so as to allow the most clear portrayal of the circuit paths. The possibly many contacts of a relay, and its activating coil, are related by each being marked with the same symbol (which in real equipment would likely be marked on the relay itself).

In this context, the two basic kinds of contact mentioned above are not called by the names I mentioned there. Rather, the contact type that in other contexts would be called “normally open” is called a *make* contact; the type that in other contexts would be called “normally closed” is called a *break* contact.

Figure 13 shows the principles of this convention.

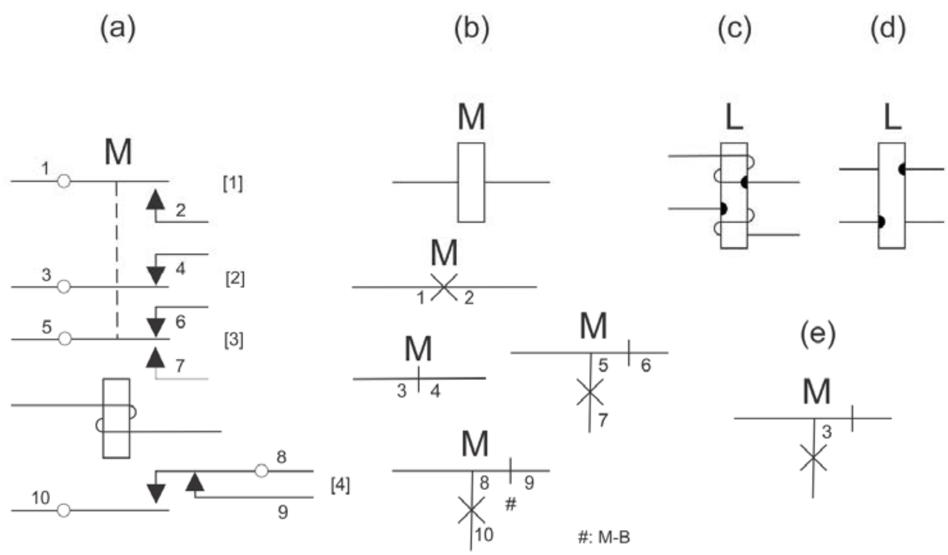

Figure 13. Detached contact schematic symbols—relays

In panel (a) we see a relay, M, under the older *attached contact* convention. This relay has a coil with a single winding and four “spring sets”, each of a different type. Each “spring” is identified by a number (from 1-10).

The dashed line we see between the three spring sets shown above the coil emphasizes that the “moving springs” of all these springs sets move together (toward the coil). Of course, spring 10 on the spring set, shown below the coil moves at the same time (toward the coil), but we are expected to know that.

Spring set 1-2 is a *make* contact (what would be called in other electrical work a “normally open” or “form A” contact). Spring set 3-4 is a *break* contact (a “normally closed” or “form B” contact).

Spring set 5-6-7 (what would be called in other contexts a “form C” contact) is called a *transfer* contact, but is also called a *break-make* contact. This latter name makes it clear that the break occurs before the make (so there is never, even momentarily, a path from spring 6 to spring 7.

Spring set 5-6-7 is also called a *transfer* contact, but is also called a *make-break* contact. This latter name makes it clear that the make occurs before the break (so there is never, even momentarily, no path from spring 8 to one of the other springs, 9 or 10). This is often spoken of in other contexts as a “make before break” contact.

In panel (b) we see this same relay portrayed under the detached contact convention. There I have purposely shown the spring sets “scattered” to remind us that they would not ordinarily be shown adjacent to the relay coil but would be placed on the drawing wherever the circuit paths through them would be easiest to follow.

We see that the coil has a simpler symbol, one not graphically evocative of its winding.

As we see for contact 1-2, the symbol for a *make* contact is a simple cross, centered in the line representing the circuit path. For contact 3-4 we see the symbol for a *break* contact, a simple line across the circuit path.

For the basic transfer contact (*break-make*) (5-6-7), we use a combination of those two symbols, usually adjacent, as we see here. (But if needed for clarity of the drawing, the two parts may be separated.) An interesting convention when the two parts are drawn adjacent is that the junction between their paths does not carry the junction “dot” used elsewhere in a drawing when two paths join.

For the *make-break* contact (8-9-10), the portrayal is the same as for the *break-make* spring set. There is nothing in the graphic representation that distinguishes the *break-make* and *make-break* forms of a transfer contact.

In formal Bell Telephone Laboratories drawings, that distinction was provided in a table that listed each relay and its many properties. But in informal drawings, often some mark was applied to a break-make keyed to a note that told this was a *break-make* contact (the note might even say “make before break”). I do that using the symbol “#”.

In some cases, there are two (in rare cases even more) windings on the coil. We must generally be aware of the “polarity” of the windings, so the current through the two windings produce adding, or opposing, magnetic fields, as needed for the intended circuit operation.

In panel (c) we see a two-winding relay coil shown under the attached contact convention. In panel (d) we see that same coil under the detached contact convention. In both cases, the little half-moon marks show “corresponding” ends of the two windings. (But those were not always shown under the attached-contact convention.)

Especially in the case of more modern relays whose physical construction is not that suggested by the symbol shown in panel (a), the contacts (rather than individual springs) are identified by number. In panel (a), I have shown these contact designations in brackets. In panel (e), we see the contact whose springs would be numbered 6-7-8, but as a contact would be numbered 3, identified by the contact number.

5.3 Identification

In the schematic drawing in this article, the relays in the line finder switch are identified with the designations (the letters A-F) most commonly used in actual practice.[4] For reference in the discussion, the various contacts of each relay are identified by fairly-arbitrary numbers; these do not necessarily follow the numbering system that would be found on the formal circuit schematic drawings.

I will often use a shorthand: to refer to the *make* aspect of contact number 2 on a relay (maybe there is only a make aspect) I will refer to contact 2M. Once I get rolling, I might refer to contact 2M on relay B as just “B 2M”.

5.4 Simplifications

A very few simplifications have been adopted in the drawing. For one thing, it omits various R-C networks used to limit the amplitude of the voltage spikes that occur when the circuit to a serious electromagnet is interrupted. Also eliminated (or in some cases simplified) are some circuit paths devoted to the monitoring of switch behavior by external circuitry.

6 CIRCUIT DESCRIPTION

6.1 The circuit schematic drawing

Figure 16 is the circuit schematic drawing for the hypothetical line finder switch being discussed. It is in fact of the 200-point variety, which is almost universally used in all but the smallest central offices. The drawing also includes the *line circuit* for an illustrative line served by that line finder, and a portion of the *group circuit*, which is responsible for “dispatching” the line finder. (Its other portions deal with many other functions not pertinent to the scope of this discussion).

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[4] Bell System step by step systems use this convention, inherited directly from the practice in systems made by Automatic Electric. Other systems, originally designed in the Bell System would typically use mnemonically-based relay designations, perhaps “BF” for the battery feed relay rather than “A”.

6.2 Initial conditions

With the switch idle, all relays, electromagnets, and contacts are released. The switch wiper shaft is in the idle (full down) position.

6.3 The line circuit

6.3.1 *Introduction*

Each line is provided with a line circuit, which comprises two relays, L (line) and CO (cutoff).

With the line idle (the station off hook and the line not involved in any connection) both these relays are released. Battery is fed through the coil of the L relay and CO relay contact 1B to the ring of the line, Ground is fed through CO 2B to the tip of the line.

6.3.2 *A transmission issue*

I interrupt the main story to note that with the impedance of the coil of the L relay in the feed to the ring but no such in the feed to the tip, the line is unbalanced from a transmission standpoint. The result of this is that if the line takes on any induced voltages or currents (perhaps by passing near electrical equipment or a power line), these will result in a spurious voltage from tip to ring, which would produce noise in any telephone set connected to the line likely a hum or buzz).

For most of the life of a line circuit in this state, there is no telephone set across the line, so the phenomenon is of no consequence. But, as we will see shortly, from the time a station wanting service “comes on the line” until the line finder finds the line and extends it to a 1st selector, such spurious noise could be heard.

The problem could be easily averted by using a two winding L relay (with one winding in the feed to each line conductor), but a two winding relay is more costly than a single winding relay. So the problem is generally considered “not a problem”, and (even in later, more sophisticated switching systems) the single winding L relay in the line circuit became the norm.

6.3.3 *Bank connections*

We see that the tip and ring of the line, plus a sleeve lead from the line circuit I call at this time S_L (that means the sleeve lead for the line’s connection to the line finder system), go to the line’s terminal on the bank of the line finder (actually on the banks of several line finders, any of which may be called upon to serve the line). But because this is a “200-point” line finder, there is a small complication.

At each of its 100 positions, the line finder can connect to either of two lines. One has its ring and tip connected to the two contacts of the terminal on the lower bank (R and T), and its sleeve connected to the lower of the two contacts on the upper bank (S). The other has its ring and tip connected to the two contacts of the terminal on the middle bank (R1 and T1), and its sleeve connected to the upper of the two contacts on the upper bank (S1).

Our illustrative line might be either a “lower” or an “upper”. We accommodate that on the drawing with the optional wiring symbol, where wiring option V would be for a “lower” line and option U would be for an “upper” line.

In addition, the tip and ring of the line plus a different sleeve lead from its line circuit (here I call it S_C) go to the bank of a connector (several connectors, in fact) so the line can receive calls.

In actual drawings and the like, both S_L and S_C are labeled just as “S”.

6.3.4 *The service request*

When the subscriber at an idle station lifts the handset, current flows in the line and operates the L relay in that line’s line circuit. L relay contact M2 grounds a lead that goes to a subgroup relay G-, in the group circuit. The same subgroup relay is used for all lines in the subgroup—that is all lines, upper and lower, that will go to terminals on a certain level of the line finders (20 altogether). Contact 1M of all the G relays go to the ST (start) lead of the line finder group.

L relay contact 1M connects the winding of relay CO to the line finder sleeve lead (S_L) of the line’s connection to the line finder bank. Since there is battery on the opposite end of that winding, and the line finder sleeve is not grounded for any reason, battery will appear on the S_L lead (and thus on the line’s sleeve contact, S or S1, on the line finder bank).

6.4 The line finder

6.4.1 *Initial conditions*

With the switch idle, all relays, electromagnets, and contacts are released. The switch wiper shaft is in the idle (full down) position.

6.4.2 *Starting the line finder*

Assume for simplicity that the line finder we are watching is the first one in its group, and that it is idle. When the G- relay in the group circuit is operated by the line’s L relay, G- relay contact 1M grounds the ST lead, which is connected to the IN lead to our line finder. This goes through D relay contact 1B to the coil of the A relay and then to battery, operating the A relay. This is the “start relay” for this line finder.

Relay G- contact 2M grounds the terminal of the vertical commutator, VC, corresponding to the level on the line finder banks for the lines in that G relay's group. Here we assume that to be level 3.

Relay A contact 2M grounds the sleeve lead that comes from the selector that is associated with this line finder. This is used to as the beginning of the path to operate and/or hold various relays in the line finder during the various phases of its operation.

6.4.3 *The first vertical step*

Ground through A relay contact 3M and through vertical interrupter contact (VI) 1B, RI contact 2B, and winding 2 of relay C, and then through contact D 3B to battery, operates relay C.

Ground through A 3M, C 1M, and E 8B goes to the vertical magnet (VERT) and then through contact D 3B to battery, operating the vertical magnet. The vertical magnet steps the switch shaft up one step (to level 1 of the bank). Vertical off-normal contacts VON are operated was the shaft leaves its home position.

The operation of the vertical magnet operates the vertical interrupter contacts, VI. Contact VI 1B opens the path through winding 2 of relay C, and relay C releases. Contact C 1M opens, opening the path to the vertical magnet, which releases, resetting the driving pawl to take the next step up.

6.4.4 *Level test*

As the shaft reaches level 1, we note that relay E, by way of a path from battery through contact D 3B, winding 2 of relay C, and winding 1 of relay E itself tests to see if there is ground on the vertical commutator at this level. We assume there is not (this not being the bank level where the line we assume is requesting service is connected, so relay E does not operate.

6.4.5 *Later vertical steps*

When the vertical magnet releases, the VI contacts are released, and contact VI 1 closes, re-completing the path that earlier had operated relay C, which re-operates, in turn re-energizing the vertical magnet, which moves the shaft up one further step. And this process can continue as long as needed.

6.4.6 *Arriving at our line's level*

But, in accordance with our example, there is a ground on the level 3 contact of the vertical commutator. And so when the switch has reached, after three cycles of operation of the vertical magnet, level 3, the ground there on the commutator terminal (placed their by our line group's G relay) operates the E relay (though the path described earlier in section 6.4.4.

6.4.7 *Change from vertical to rotary stepping*

Contact E 8B now interrupts the path through which the vertical magnet is operated by relay C (which has now re-operated), preventing any further vertical stepping, and contact E 8M sends that path to the rotary magnet (ROT), which without further ado takes its first step, moving the shaft to its first rotary position.

Contact E 1M now completes a path from battery, contact D 3M, the coil of the vertical magnet, winding 2 of relay E itself, and contact A 3M to ground. This path will hold relay E operated when, because of the rotation of the shaft, the vertical commutator wiper is lifted from the vertical commutator contact, opening the path that initially operated relay E.

In a the same way vertical stepping happened, when the rotary magnet operates, rotary interrupter (RI) contact 2B opens, opening the path to the coil of relay C, which releases.

Contact C 1M opens, releasing the rotary magnet, which resets its driving pawl to prepare if for the next rotary step. Then RI 2B closes, and so forth. This process continues as long as is necessary.

6.4.8 *Testing the line*

As the wipers progress over the bank terminals, relays F and B, though circuit paths we will examine in detail shortly, test each terminal's S and S1 contacts, respectively, to see if either of them shows battery (which the contact for our line would, it being having been extended by the lines A relay contact 1M from the coil of the line's CO relay).

Let's assume that at some rotary step, we have in fact arrived at the terminal where our line appears, and first assume that our line is a "lower" one (wired per option "V", so that its S_L lead is connected to bank contact S).

The battery on contact S and then the S wiper flows through F relay winding 2, D 2B, C relay winding 1, and A 2M to ground, operating relay F and holding relay C operated (its operating path through RI 2B was momentarily interrupted when RI operated).

The current drawn from the line's S_L lead operates the CO relay in the line circuit, removing the battery and ground feed to the line there. Contact CO 3M establishes a continuing path from the S_L lead to the coil of the CO relay, which will keep CO operated after L releases and its contact 1M opens. The L relay releases, and that releases the subgroup relay, G. This removes the start ground (on IN) and relay A releases.

6.4.9 *Cut through*

Relay F contacts 1M and 2M carry the calling line R and T leads from the wipers to the paired 1st selector. The bridge on the line operates the A relay and then the B relay in the 1st selector, and the selector returns ground on the S lead.

That ground goes through E 1M (relay E is still operated) and F 4M to F winding 1 and to battery, holding F operated.

Ground on the sleeve from the 1st selector also goes through contact E 1M and F 5M to winding 1 of relay D, which operates. This confirms the status of this line finder as being "on a connection". D contact 1 B takes the IN lead off the A relay (there no longer being need to "start" this line finder) and D 1M sends it out the OUT lead. That leads to the IN lead of the next line finder in the "rotation", which would be started by a subsequent request for service for another line.

Contact D 3B releases relays C and E.

The path from the S wiper (line S_L lead) through F 3M, B 3B, and D 2M to the (grounded) sleeve from the 1st selector provides a solid ground on the line's SL lead, holding the CO relay operated and marking the line as busy.

6.4.10 *Release*

Suppose the connection has been completed to the called line, and now the caller hangs up. Talking battery has been furnished to the calling line by the A (talking battery feed) relay in the connector, which keeps operated the B relay in the connector, which keeps the "rearward" sleeve lead grounded. This holds all the intervening switches (including our line finder) "up".

When the caller hangs up, the connector A relay releases, and shortly the connector B relay releases, which results in the ground being removed from the sleeve lead.

In our line finder, this allows the F relay to release (and also clears the ground on the S lead to the station line circuit, so the CO relay there releases). When F releases, ground, through VON 1M (the VON contacts are still operated, as the switch is not in its home position), A 1B (we recall a while ago when A released), F 5B (that's what's new just now), E 2B (E released at cut though), and VON 2M through the release magnet, operating that magnet.

The switch releases, the shaft first returning (under the torque of a rotary spring) to its “zero” rotational position and then dropping by gravity to “home”. That releases the VON contacts, and VOB 2M opens, opening the path to the release magnet (whose work is clearly done).

The opening of VON 1M releases relay D, which then declares this line finder ready for its next adventure—it “takes back to hand” its IN lead so it can be started on such an adventure.

But, if there is another line finder looking for a calling line, we don’t want “our” line finder to “jump in.”

So, as lone as the master “start” lead is grounded (by a G relay), there is a holding path for any operated D relays (including ours), by way of D relay contact 1M. Once all the “searches in progress” are done, so no G relay is operated, then any operated D relays in line finders that have in fact been released will be released, allowing those line finders to be willing to take a new “assignment”.

6.4.11 *For an “upper” line*

Next suppose that out line is one assigned to an “upper bank” position on the line finder(s).

In this case, at the pertinent bank terminal, there will not be battery (through the winding of the CO relay in the line circuit) on contact S, but rather on contact S1. Thus, when the switch arrives at that terminal, relay F does not operate (at least not from contact S).

But as the switch steps across, the B relay looks for battery on each contact S1. The path is from ground through A 2M, winding 1 of relay C, B 3B, F 3B, and winding 2 of relay B to wiper S1. When battery is found on contact S1, relay B operates.

A holding path is prepared from battery through winding 1 of relay B and contact B 5M to the 1st selector sleeve (currently grounded by A 2M).

Now, ground from that sleeve lead though E 1M (E is still operated) and F 4M (in the earlier scenario, the holding path for F) to winding 1 of F and then to battery operates F.

When B operated, it transferred the “ongoing” R and S leads from the R and T wipers to the R1 and S1 wipers (which is where the found line has its leads). And when F operated, as in the “lower line” case, the line T and R are extended to the paired 1st selector.

The rest of the scenario proceeds essentially as in the "lower line" case. When the line finder is fully released, (when VON is released), relay B is released.

6.5 Things can go wrong

We see on the drawing some things not yet mentioned that have to do with things that can go wrong.

Various things can cause a line finder to be started when no line is actually requesting service. Some of those things do not result in any G relay putting ground on a contact of the vertical commutator.

To prevent the switch from trying to "go through the roof", vertical commutator (VC) contact 10 has "permanent" ground connected to it. So if the switch hasn't earlier found ground from a G relay, it will find ground at level 10, and transition from vertical stepping to rotary stepping.

But of course the switch won't find battery on any sleeve contact on that level (as no line is actually wanting service). So it just keeps stepping. But when it gets to position 11 (where there is of course no bank terminal), a fin on the shaft operates a set of contacts called the *11th rotary step contacts* (11RS). Through a sequence of events I won't describe here, this causes the switch to stop stepping and then to release. The further implications of this are beyond the scope pf this discussion.

7 THE SLIPPED MULTIPLE

The description above intimates that, when each lie is connected to the banks of all the line finders that can serve it (creating the *line finder multiple*) the line would be connected to the same terminal at each line finder. The description also intimated that the first line finder in the group (the one we examine in figure 16) is the first one to be started (that is, it would be stared if it were not busy, whether or not other line finders were idle.

But there are two disadvantages from this arrangement:

- For a line in, for example, the last group (91-100 or 199-200), the line finder would always have to step 10 vertical steps to reach that line.

- Over time, line finder number 1 would get by far the most use, and the most wear.

To avert both of these, we connect the lines to the various line finder banks in an arrangement known as a *slipped multiple*. We see an illustration of the principle in figure 14.

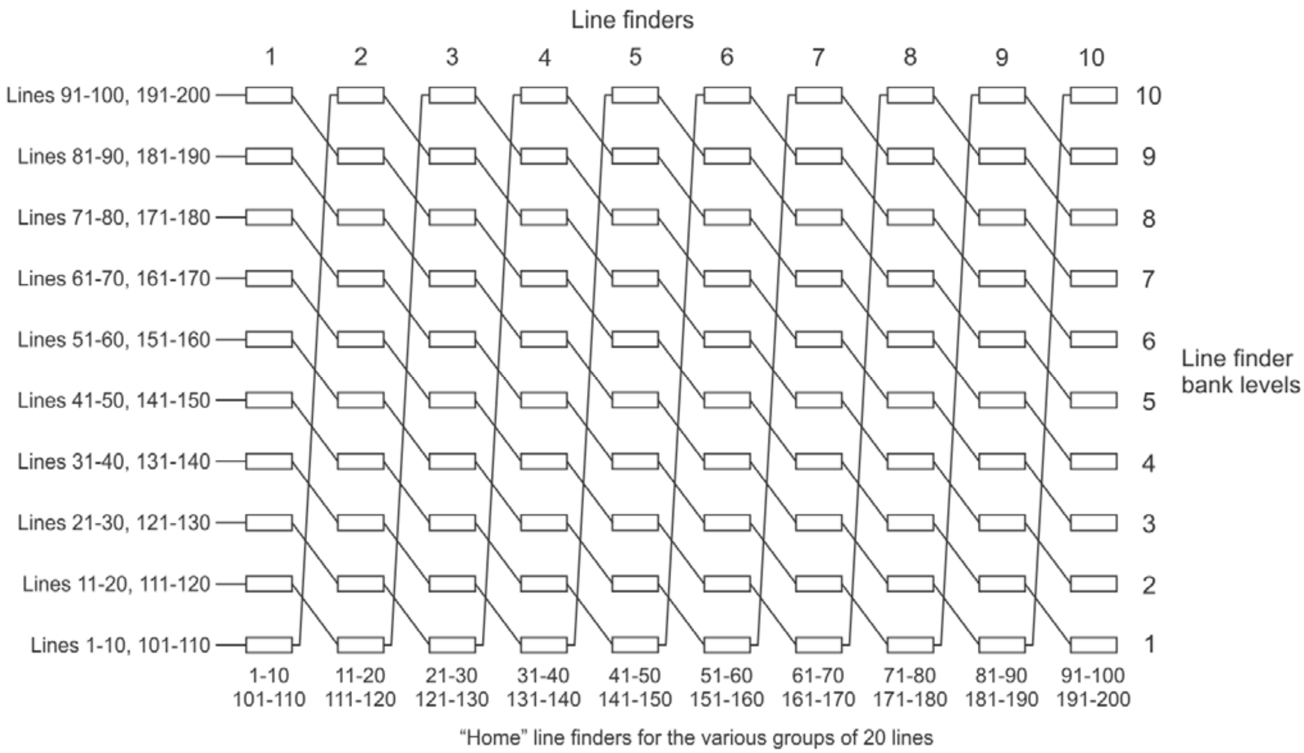

Figure 14. Line finder group with slipped multiple

Each heavy line staring from the left represents the leads (T, R, and S) for the 20 lines in the subgroup (for example, lines 41-50 and 141-150). Each of the little rectangles represents the ten terminals on one level of one line finder in the line finder group.

We see that, as the leads from that subgroup of line goes on from line finder 1 to line finder 2, they are "dropped down" ("slipped") by one level. Of course, for the leads from the first subgroup of lines (1-10 and 101-110), they were on level 1 of the bank of line finder 1, so at line finder 2 they are shifted to the very top level.

Now the second part of this plan is that not for every line would line finder 1 (if idle) be started. Rather, for each subgroup (20 lines), if one comes off-hook to request service, the line finder on whose bank the line appears at the bottom level, if idle, will be started. Thus in the happy situation where the "home" line finder is always idle, then fort every line, the line finder it "draws" will only have to step once vertically to be able to access the line.

We note that for this to work, the leads running to the vertical commutator contacts from the 10 subgroup relays also have to "slip" as they pass from line finder to line finder.

Beyond that, the "chaining" of the start leads to the line finders is done from right to left. Now imagine line 25 wanting service. Line finder 3 is its "home" line finder, and if it is idle, will be started, and will only have to step to level 1 to reach the line. But if line finder 3 is busy, line finder 2 (if not busy) will be started. It will only have to step to level 2 to access the line, still a “conservative” situation.

Figure 15 shows (slightly simplified) the circuit arrangements for this.

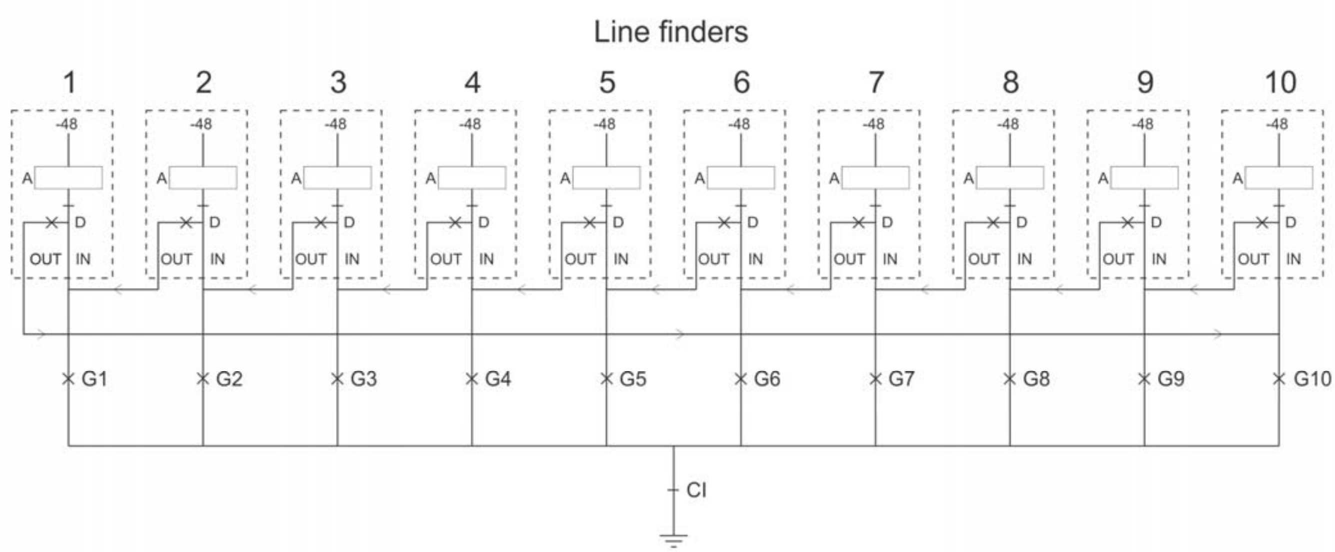

Figure 15. Line finder selection for slipped multiple operation

The A relay contacts of the line circuits for lines in subgroup 1 (1-10 and 101-110) will all operate subgroup relay G1, and so forth.

Under normal conditions, relay CI is released, so its contact seen here will be closed, supplying ground to the contacts of all the subgroup relays.

Consider line 25 wanting service. Subgroup relay G3 will be operated. It applies ground to the IN start lead of the home line finder for that subgroup, line finder 3. If that line finder is idle, this ground will operate the start relay for that line finder, A, and that line finder will start hunting for the line. At that line finder, It will be it on level 1.

Subgroup relay G3 will have grounded the “3” lead to the vertical commutators, but because of the slipping of the commutator leads, at line finder 3 that grounded lead will be connected to commutator terminal 1. Thus the line finder will step to level 1, where it will indeed find the line.

If line finder 3 is busy, its D relay will be operated. So it will take the IN start lead and send it back out through the OUT start lead. This goes to the IN start lead of line finder 2, and the ground from subgroup relay G3 will go there. If that line finder is idle is idle, this ground will operate the start relay for that line finder, A, and that line finder will start hunting for the line. At that line finder, It will be it on level 2.

Subgroup relay G3 will have grounded the “3” lead to the vertical commutators, but because of the slipping of the commutator leads, at line finder 2 that grounded lead will be connected to commutator terminal 2. Thus the line finder will step to level 2, where it will indeed find the line.

Note that this is the opposite order of “handoff” from one line finder to the next than that implied in figure 16, which I used there to make the overall operation “more clear”.

If we consider a line in subgroup 1 (1-10 and 101-110) wanting service, the line relay will operate subgroup relay G1, which will try to start line finder 1

Under various fatal error conditions, relay CI operates. Its B contact takes away the ground from the contact of all the G relays, so that none can (fruitlessly) try to start a line finder.

8 WHAT IF ALL LINE FINDERS ARE BUSY?

Suppose that when a subscriber wants to place a call, all line finders in the serving group are busy. We can easily see the result in figure 15. Suppose the calling line is is subgroup 3. Subgroup relay G3 will operated, and ground the IN start lead to that subgroup’s home line finder, number 3. But since that line finder is busy, its D relay is operated, and so the start lead is sent right back out on the OUT lead, going to the next line finder in the “rotation”, number 2. But its D relay is also operated, and so forth for all the line finders we see. The result is that the start lead network forms a closed loop and doesn’t go to any line finder A relay.

But as soon as any line finder becomes free, its D relay releases, and the start lead grounded by subgroup relay G3 is now allowed to go to that line finder’s A relay, starting it on a hunt for the line.

9 ON “LINE NUMBERS”

Before I launch into this topic, let me remind us that the “line numbers” mentioned in connection with line finder operation are not in any way directly related to the “telephone numbers” of the lines. Regardless of its telephone number, a line is assigned to a certain “position” in a certain line finder group based on making most economical use of the line finders (read, “giving the desired grade of service with the minimum number of line finders altogether”), taking into account the differing typical “traffic” from different kinds of lines. For example, a normal “residential” line might be expected to generate traffic on a certain profile, while a typical “business” line would have a higher-traffic profile, and business lines that are actually trunks into a PBX have an even higher-traffic profile.

That all having been said, next recall that in a connector, the first level is reached by dialing “1”, but the 10th level is reached by dialing “0” as the tens digit, and is thus generally labeled “level 0”. Similarly, the first rotary position is reached by dialing “0” as the units digit, and is thus generally labeled “step 0”.

So, considering the 100 positions on the connector bank, the first position on level 1 is considered to be “11”, the ninth position as “19”, and the tenth position as “10”. On level “0” (the 10th level), the first position is considered as 01, the ninth position as “09”, and the tenth position as “00”.

Now, with this notation in mind, it became the custom to identify the terminals on any step by step switch bank–including those on selectors and line finders– in that same notation.

Then, going further down this trail, it became the custom to identify the lines in a line finder group in terms of, under that notation, the numbers of the line finder terminals the lines would have on their “home line finders”, 100 being added for each of the lines in the “upper” group. Thus the numbers of the first subgroup of lines would comprise:

For the “lower” lines: 11, 12, 13, 14, 15, 16, 17, 18, 19, 10

For the upper” lines”: 111, 112, 113, 114, . . . 118, 119, 110

Then, for the tenth subgroup, the line numbers would comprise:

For the “lower” lines: 01, 02, 03, 04, 05, 06, 07, 08, 09, 00

For the upper” lines”: 101, 102, 103, 104 . . . 108, 109, 100

In any case, in the descriptions in this article, I have avoided the confusion that would cause by using a different notation, more consistent with the usual way of numbering things:

For the first subgroup:

For the “lower” lines: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10

For the upper” lines”: 101, 102, 103, 104, . . . 108, 109, 110

For the tenth subgroup:

For the “lower” lines: 91, 92, 93, 94, 95, 96, 97, 98, 99, 100

For the “upper” lines: 191, 192, 193, 194 . . . 198, 199, 200

But keep in mind that this is not the numbering one would find in an actual step by step office, or in actual drawings or training manuals.

10 ISSUE RECORD

Issue 3 (June 20, 2018) [this issue]: Revised figure 7. Added material on plunger-type line switches. Various editorial revisions.

Issue 2 (April 1, 2018): Various editorial revisions

Issue 1 (March 31, 2018): Initial issue.

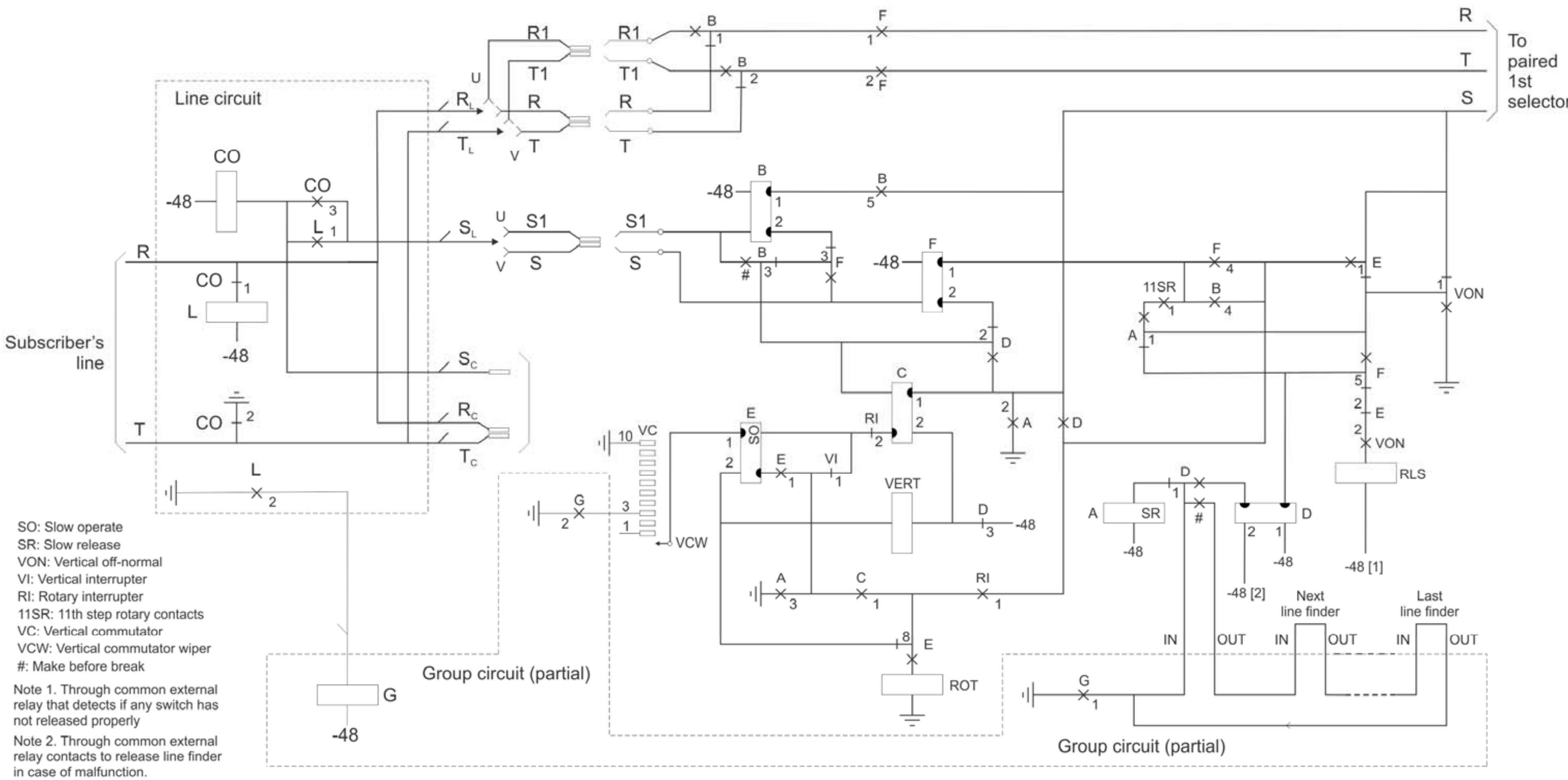

Figure 16. Illustrative line finder circuit (with line circuit and part of group circuit)