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

Douglas A. Kerr

Issue 6
October 22, 2020

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, its basic operation is described, and an illustrative circuit 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.

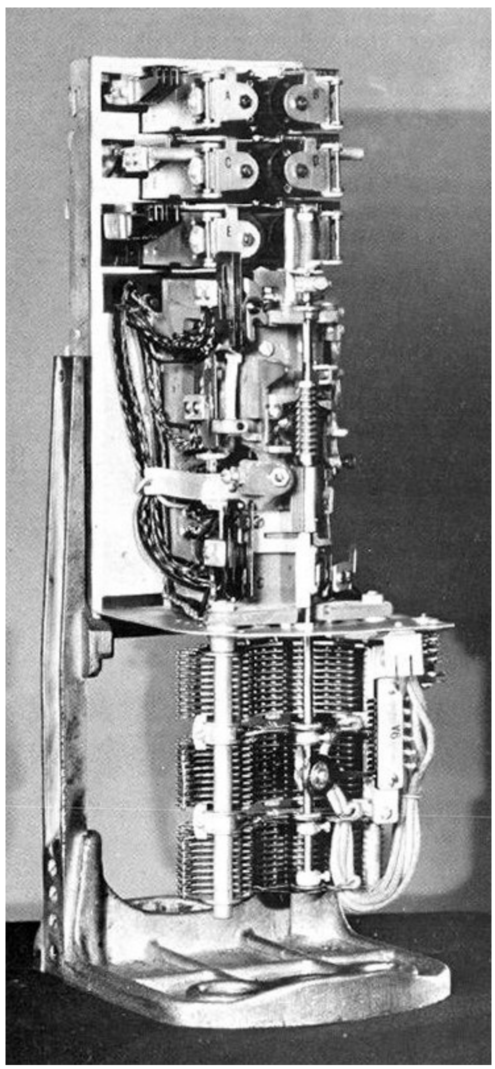

Figure 1. Typical line finder switch

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

[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).

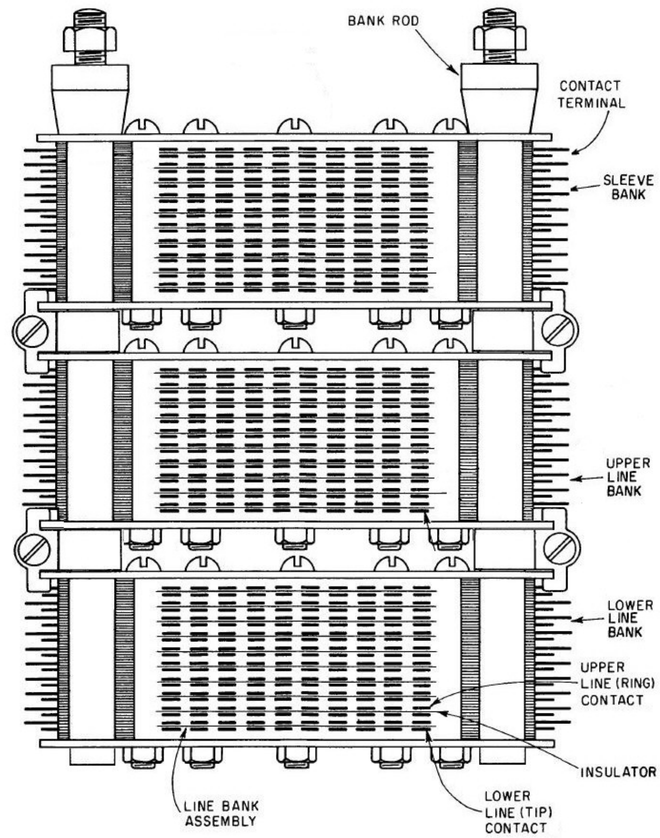

Figure 2. 200-point line finder bank assembly

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.

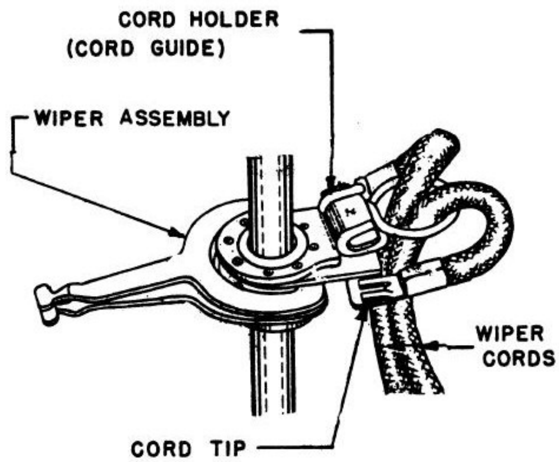

Figure 3. Two-contact wiper

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 "dogs" (retaining pawls) that hold the switch in place after it has stepped up and around, allowing a spring to rotate the shaft back to its home angular position, and then allowing the shaft to drop by gravity to its home position.

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 11 terminals, against which a special wiper runs as the switch steps vertically. The lowest terminal, against which the wiper rests when the switch shaft is in its home position, is typically not connected to anything, but merely serves to properly align the wiper so that, as the shaft begins to rise, the wiper can move onto terminal 1.

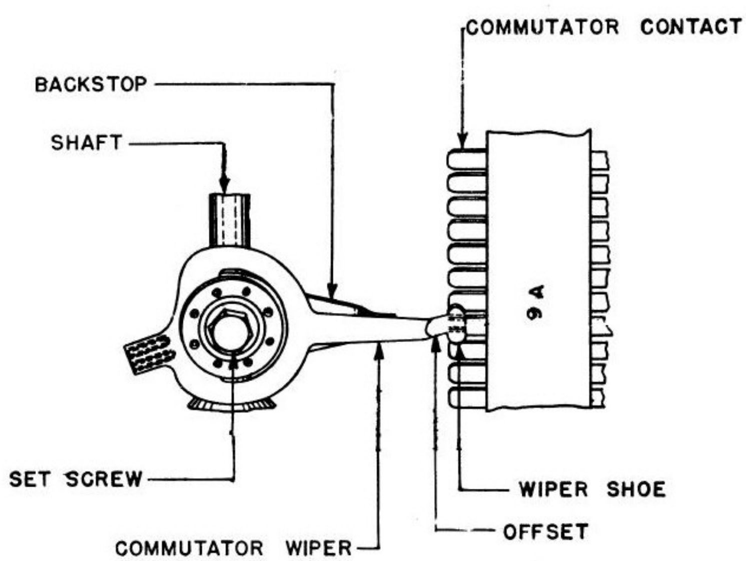

Figure 4. Line finder vertical commutator and its wiper

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).

To set a specific context for discussion of the role of the line finder, we will consider a city in which there are several central offices, and in which a 5-digit numbering plan is used. The first digit identifies the central office in which the line with that number is served.

Figure 5 shows the entire "train" through which the call is handled from one end to another. It 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.)

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.

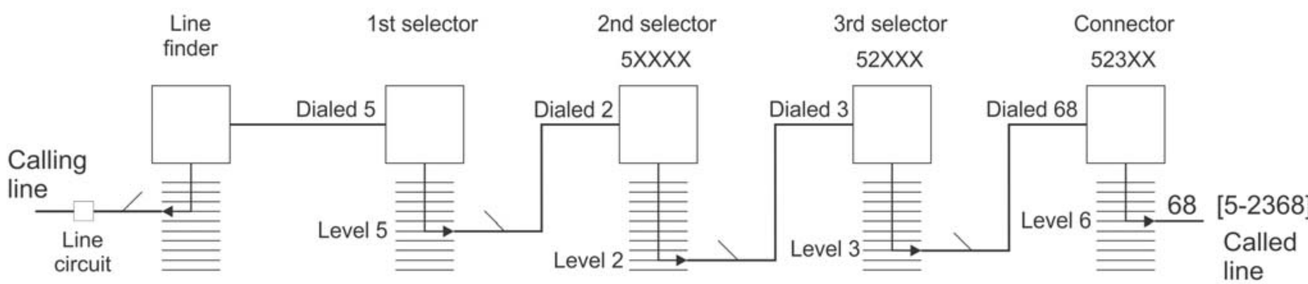

Figure 5. 5-digit switch train

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", which also presents a broader outlook on network architecture.

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"), 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 in rotation, 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 station allows current to flow in the line, operating 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,

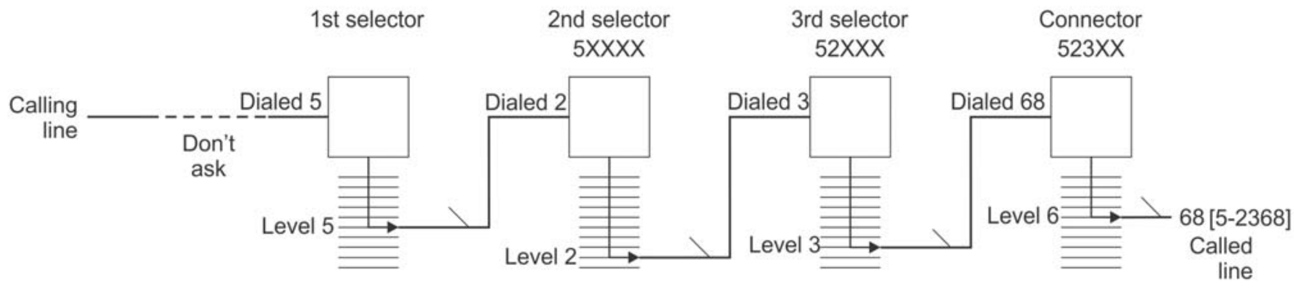

Figure 6. Switch train from the 1st selector

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.

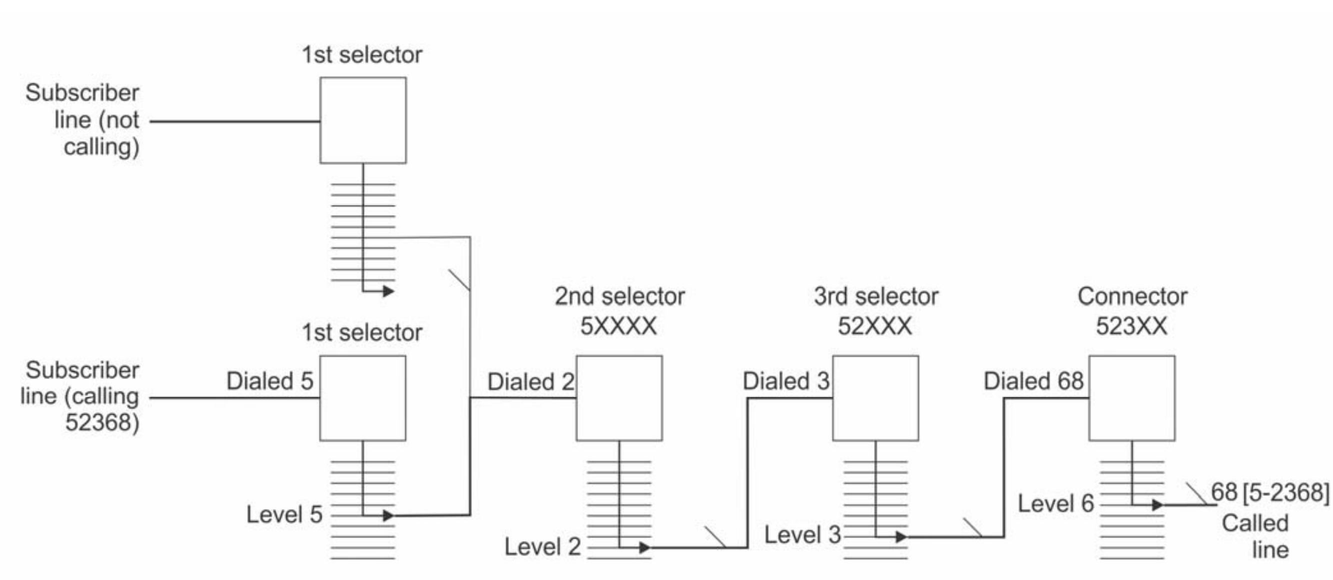

Figure 7. Switch train with individual 1st selectors

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.

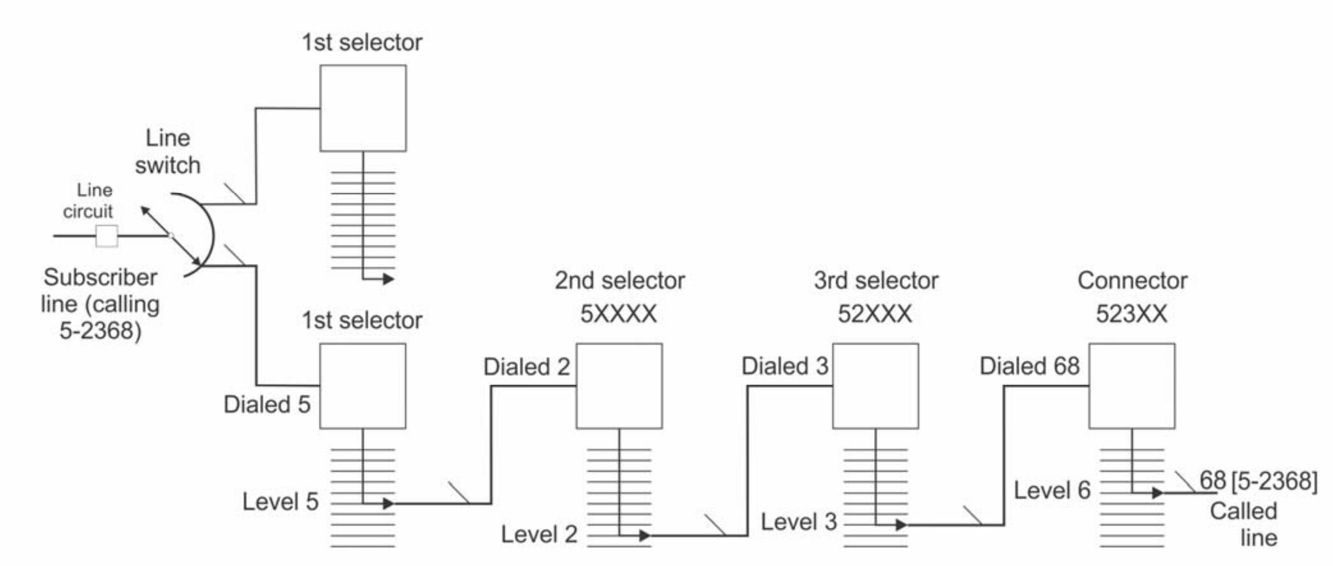

Figure 8. Switch train with line switches

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.)

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 releases; 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 (a 200-type, or in a later design, 206-type selector).

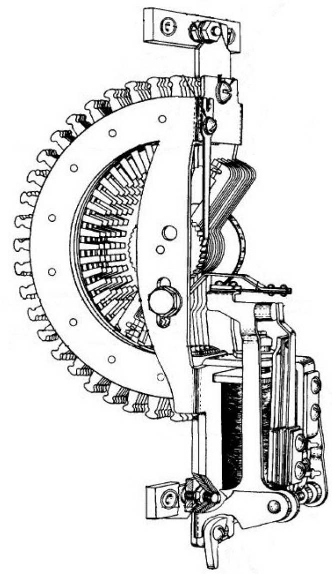

Figure 9. Uniselector

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°. 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 figure 8 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 lines 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 (just as with the line finder scheme). 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 in teh line circuit 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 stops its stepping, and another relay connects the line through to the line switch wipers and thus to the lucky 1st selector.

It is not ideal from a traffic efficiency standpoint that each line can only have access to a pool of up to 22 first selectors. Thus in some installations there is a second stage of line switch (“secondary line switches”), again implemented with uniselectors, allowing a larger group of lines access to a larger pool of 1st selectors.

Then further details of the uniselector line switch system 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 25 or 50 lines are consolidated into a single mechanical assembly, with a common drive element. We can see the principle in figure 10.

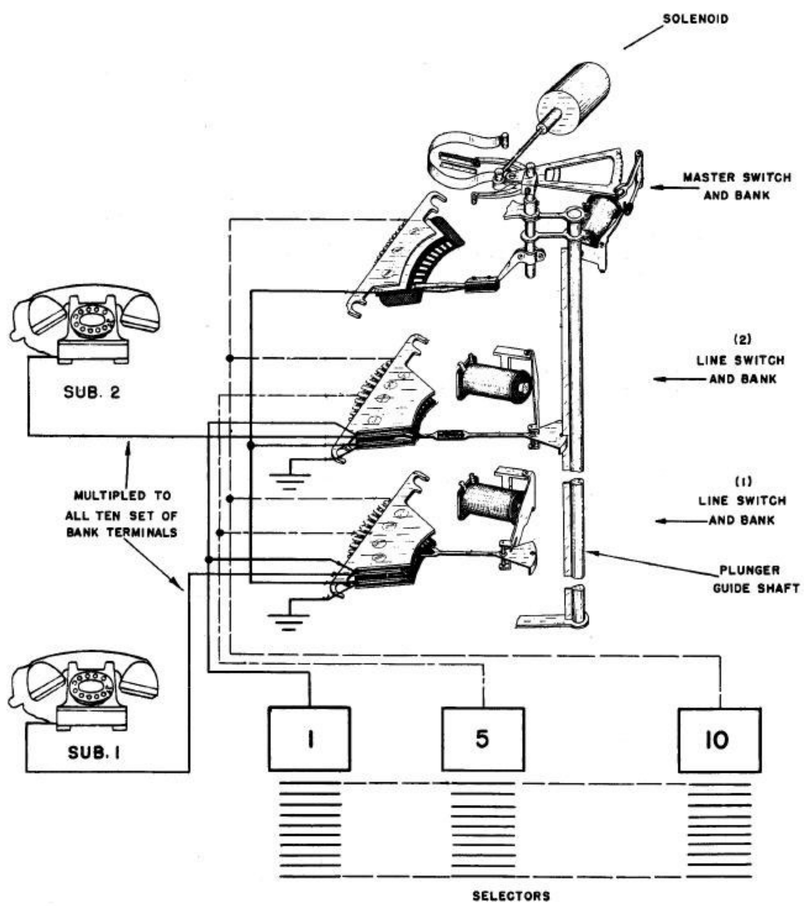

Figure 10. Plunger-type line switch

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. Every line in the group can be connected to any of 10 first selectors.

The assembly includes a common drive element (think “motor”) that, through a shaft with a fin, 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), 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 (the handset being lifted) 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]. Figure 11 shows a typical plunger switch assembly, this for 50 lines. The shaft is actually vertical; I have rotated the picture to save space. (This assembly is in fact from an office in New Zealand.)

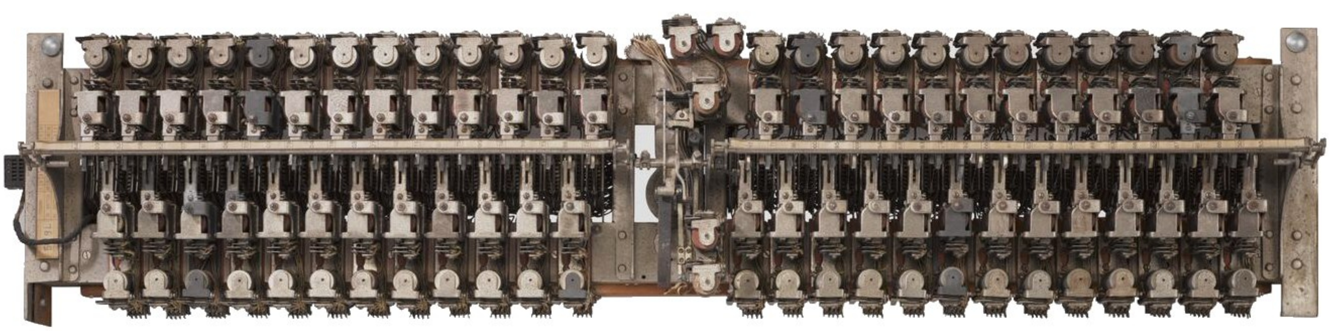

Figure 11. 50-line plunger line switch assembly

[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”.

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*. By means of a second armature on the plunger magnet, it also serves as the *cutoff relay*. In the center, there is the "master switch" and 5 magnets and relays for controlling it.

In an alternate configuration of this 50-line assembly, there would be two master switches, each associated with 25 line switches.

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.

As with the uniselector line switch configuration, it is very common to have a second stage of plunger type switches ("secondary line 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 the plunger type line switch configuration are beyond the scope of this article.

4.5 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.

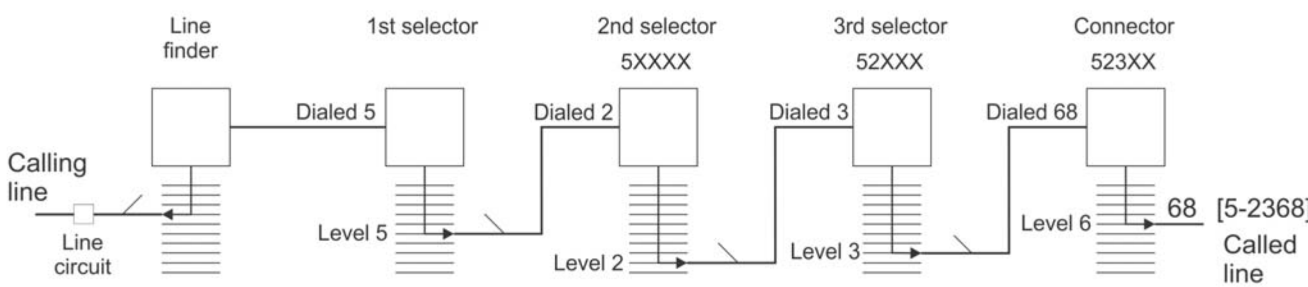

Figure 12. Switch train with line finders

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, at the system level, was discussed in detail in section 3 of this article.

4.6 Usage preferences

In the Bell Telephone System, during the early days of years of use of the step-by-step switching system, that system was used with the line switch configuration, mainly using the plunger type line switch, Later the line finder configuration became the norm. But for Strowger systems in the U.K. for instance, the line switch configuration, with uniselectors, was the most common, over the entire era of the system.

5 CIRCUIT SCHEMATIC DRAWING CONVENTIONS

The schematic drawing employs a system of notation introduced in the Bell Telephone System in the late 1950s, called *detached contact schematic* 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 “normally open” or “normally closed” contacts.

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, by the way, in real equipment would likely also 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.

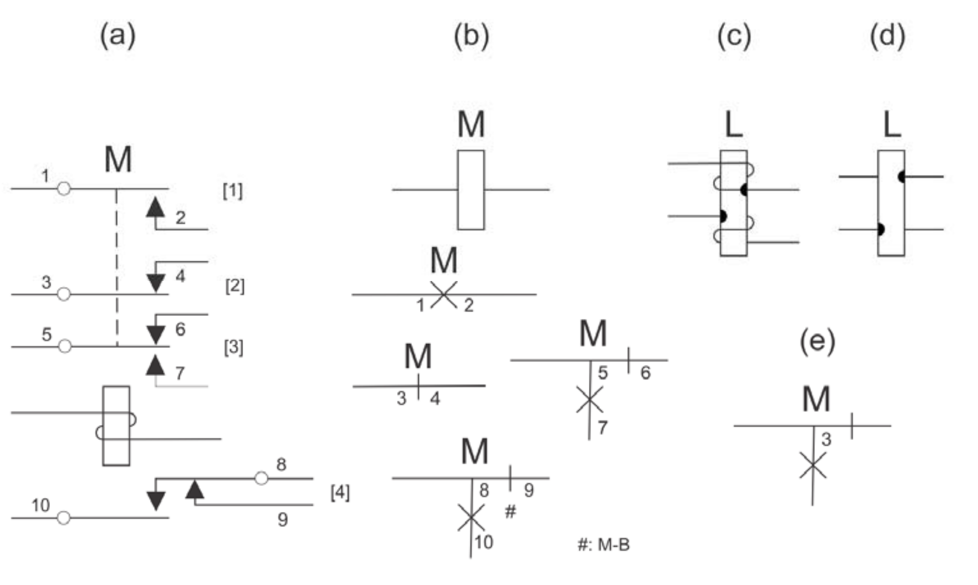

Figure 13. Detached contact schematic symbols—relays

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 contact “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 spring sets move together (toward the “core”). Of course, spring 10 on the spring set shown below the coil moves at the same time (toward the “core”), 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 electrical work a “form C” contact) is called a *transfer* contact; It implies a *break-before-make* operation (so there is never, even momentarily, a path from spring 6 to spring 7.

Spring set 8-9-10 is also called a *transfer* contact. It however implies a *make-before-break* operation. There is never, even momentarily, the loss of a path to both springs 9 and 10. This is often in fact spoken of in other electrical work as a “make before break”, or “form D”, contact. It is sometimes called a *continuity transfer* 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. (In larger drawings, they may well appear on separate sheets.)

We see that the core 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 circuit paths, the two parts may be separated.)

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

In formal Bell Telephone Laboratories drawings, that distinction was provided in tabular form in a separate “apparatus figure”. But in informal drawings, often some mark was applied, keyed to (or maybe just implying) a note that told that this was a “make-before-break” contact. 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 relative “polarity” of the windings, so the current through the two windings produces adding, not opposing, magnetic fields (or in some cases, produces opposing fields).

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.

6 THE CIRCUIT SCHEMATIC DRAWING

6.1 Introduction

Figure 17 (at the end of this article) is the circuit schematic drawing for an actual typical line finder switch. 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 a portion of the *group circuit*, which is responsible for “dispatching” the line finders (its other portions deal with many other functions not pertinent to the scope of this discussion). Figure 18 gives the notes for this drawing.

Figure 16 shows a typical line circuit that would be used with this kind of line finder.

6.2 Designations and notation

In the schematic drawing in this article, the relays in the line finder switch are identified with the designations (the letters A-F) used in the formal circuit schematic drawings.[3]

---

[3] Bell System step by step systems use this convention, inherited directly from the practice in systems made by Automatic Electric. Other systems, originally designed

The various coil winding terminals and contact springs of each relay are identified by under the numbering system that would be found on the formal circuit schematic drawings.[4]

6.3 References

In the detailed circuit description, the reference “A1-2M” refers to, on relay A, contact spring pair 1-2, which is a *make* contact. The reference “D3-4B” refers to, on relay D, contact spring pair 3-4, which is a *break* contact.

The reference “DwT-B” refers to, on relay D, the coil winding connected to terminals T and B.

In both cases, the order in which the springs or winding terminals are stated matches the direction of the path being described.

6.4 Relays and their functions

This section lists the relays in this switch with simplistic descriptions of their major functions.

A–Start

B–Calling line found in upper bank

C–Vertical/rotary step

D–Switch busy

E–Marked level found

F– Calling line found in upper bank; cut through

6.5 Simplifications

A 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. These do not influence the “logical” working of the circuit. Also eliminated (or in some cases simplified) are some circuit paths devoted to the monitoring of switch behavior by external circuitry.

---

in the Bell System would typically use mnemonically-based relay designations, perhaps “ST” for the start relay rather than “A”.

[4] This system is overly tedious for the purposes of this articles, but I do it this way to facilitate my maintaining in parallel a formal circuit schematic drawing and the drawing in this article, and a formal circuit description document and the circuit description in this article.

7 ON "LINE NUMBERS"

7.1 Introduction

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.

The "line numbers" of which I speak here are used to identify the line "positions" as they appear on the line finders.

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 position "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".

7.2 In a line finder

First note that in the line finders used in all but the smallest offices, 200 lines are served by a line finder group. The line finder has only 100 positions, but each position can access either of two lines, one said to be on the "lower bank" and the other said to be on the "upper bank." We will see more details of that shortly.

In actual practice, the lines that appear on a line finder are identified in terms of the positions they occupy, using the notation that would be used on a connector.

Thus, for the first subgroup of lines (10 "lower" lines plus 10 "upper" lines), the line numbers would be:

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 be:

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

This numbering plan of course differs from what we would expect from other parts of our experience (not in a step by step office).

So, in the descriptions to follow 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.

8 BASIC OPERATION

When the calling line comes off hook, the L (line) relay in its line circuit operates. One contact of the line relay operates a G (group) relay in the line finder group circuit. A second contact of the L relay connects the winding of the CO relay (which is fed from battery) to the sleeve contact of the line’s appearance on the line finder bank multiple.

One contact of the G relay grounds a terminal in the vertical commutator of all line finders in the group. A second contact of the G relay grounds the start lead of the first available line finder in the group. That operates the A (start) relay in that line finder.

The line finder begins to step in the vertical direction. The commutator wiper looks for ground on each commutator contact, At the level corresponding to the group in which the calling line resides, that contact is grounded, and the E relay operates.

That shifts the automatic stepping operation to the rotary direction, As the switch steps, the F and B relays look for battery on the sleeve terminals of the lower and upper bank, respectively. If the calling line is on a terminal in the lower bank, when the switch reaches that terminal the battery on the sleeve contact (from the winding of the CO relay in the line’s line circuit) operates the F relay. That halts the rotary stepping and cuts the line tip and ring through to the mated 1st selector.

That also operates the D relay, which advances the start lead to the next idle line finder in the group so that a subsequent service request will start that one.

If the calling line is in the upper bank, when the switch reaches that terminal the battery on the sleeve contact (from the winding of the CO relay in the line's line circuit) operates the B relay and halts rotary stepping. B switches the "from" part of the line finder's tip and ring circuit to the wipers of the upper bank. The B relay operated also operates the F relay. As before, that cuts the line tip and ring through to the mated 1st selector.

In either case, when the tip and ring are cut through to the mated first selector, that selector returns ground on the S (sleeve) lead. That holds the B (if applicable), F, and D relays in the line finder operated.

When the connection is ended, the selector removes ground from the sleeve lead. All relays release and the selector mechanism is released to normal. When the D relay releases, that puts this line finder back "in the running" to possibly be used for another service request.

9 DETAILED CIRCUIT DESCRIPTION

9.1 Initial conditions

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

9.2 Upper and lower bank lines

A fully-equipped line finder group serves 200 lines. The line finder has only 100 positions, but each position can access either of two lines, one said to be on the "lower bank" and the other said to be on the "upper bank."

In fact, as we saw in figure 2, the line finder bank assembly comprises three banks. The lines of the "lower bank" regiment have their ring and tip leads on the contacts of a certain position on the lower bank (sometimes called the "lower line bank); the lines of the "upper bank" regiment have their ring and tip leads on the contacts of a certain position on the middle bank (sometimes called the "upper line bank).

The lines of the "lower bank" regiment have their sleeve leads on the lower contact of a certain position on the top bank (the "sleeve bank"); the lines of the "upper bank" regiment have their sleeve leads on the upper contact of a certain position on the middle bank.

9.3 The line circuit

9.3.1 *Introduction*

Each line is provided with a line circuit. Each line circuit comprises two relays, L (line) and CO (cutoff). We see it in figure 16.

With the line idle (the station on hook ("hung up") and the line not involved in any connection) both these relays are released. Battery is fed through Lw and CO2-1B to the ring of the line, Ground is fed through CO4-3B to the tip of the line.

We will see later that the line circuits are organized in subgroups, each comprising 10 "lower bank" lines and 10 "upper bank" lines.

9.3.2 *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 actually connected 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.

9.4 Bank connections

We see 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), going 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). This may of course be on the "lower bank" or the "upper bank".

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”. We just have to keep track of where we are!

9.5 Line idle

With the line idle, battery is placed on the ring lead by the path from battery through Lw1-2 and CO2-1B to the ring, Ground is placed on the tip lead by the path from ground through CO4-3 to the tip. With the line idle (station on hook), there is no DC path from ring to tip, and thus there is no current in the line.

9.6 Start

When the station at a calling line comes off hook to request service, closing a DC path from tip to ring, the current that flows in the line operates the L relay. The path from battery through COw1-2 and L1-2 to the line finder sleeve lead for the line puts battery (through the winding of CO) on the sleeve terminal. The path from ground though L3-4M operates the G relay for the line’s subgroup (here assumed to be G3, for subgroup 3).

Contact G1-2M grounds the terminal on the vertical commutators on all line finders corresponding to the line’s subgroup (in the example, subgroup 3).

Contact G3-4M, through the chain of D relay contacts for the “earlier”, busy line finders, grounds the ST (Start) In lead to this line finder (ST3 in this example).

9.7 Vertical stepping

Ground, through D12-11B and AwB-T to ground operates A. The path from battery through A4-5M, VI2-1B (the vertical interrupter contact), RI2-1B (on the rotary interrupter contact), CwB-T, and D1-2B to battery operates C.

The path from battery through A4-5M, C1-2M, E6-5B, the winding of VERT (the vertical magnet), and D1-2B to ground operates VERT (the vertical magnet).

When VERT operates, VI2-1B opens and releases C. C1-2M opens and releases VERT. VI 2-1B closes, and re-operates C. The process repeats, stepping the switch in the vertical direction.

When the switch reaches the level for the calling line, where the commutator contact has been grounded by the G relay, the path from ground on VCW (the vertical commutator wiper) through EwLM-RM, RI2-1B, CwB-T, and D1-2B to battery energizes E. This also holds C, preventing the release of VERT and preventing any further vertical stepping.

9.8 Rotary stepping

E is slow operate, and there is a small delay before it operates. This is so that there is a short delay after the end of vertical stepping before rotary stepping commences. This is to allow vibration in the wiper cords to settle, to avoid tangling.

When E operates, E6-5B opens, opening the path to VERT, and E6-7M closes, completing a similar path to ROT (the rotary magnet). Now C and ROT operate alternately (just as described above for vertical stepping), stepping the switch in the rotary direction.

9.9 Finding the calling line–lower bank

Assume for now that the calling line appears on a terminal on the lower bank. Recall that the L relay in the line's line circuit has connected the winding of the CO relay in the line circuit, which runs from battery, to the S contact of the line's terminal.

When the switch reaches that terminal, the path from battery (through CO) on S through FwLM-RM, D5-6B, CwRM-LM, and A7-6B to ground energizes F. That path also holds C operated (which in turn holds ROT operated) to prevent any further rotary stepping.

Owing to the relatively high resistance of the CO relay in the line circuit, there may not be enough current to fully operate F (which has a serious contact load). But F1-2M, a preliminary spring pair, closes, and the path from battery through FwB-T, F2-1M, RI4-3M, C2-1, and A3-4 to ground pulls F fully operated.

Then battery through DwLM-RM, F7-8M, and VON4-3 to ground operates D.

Now the path from battery through FwB-T, F2-1M, D8-9M, A7-8M to ground holds F.

The path A6-7M, D7-6M, D13-12B, F4-5M puts a solid ground on the S lead. This operated CO and marks the line busy. That also short-circuits the holding winding of the C relay (CwRM-LM). D2-1 opens the path from battery to the CwTB. C releases, de-energizing ROT, which releases.

CO operated (through CO1-2B and CO3-4B) frees the line from the winding of the L relay on the ring and ground on the tip. The line circuit is now transparent to the line.

F operated cuts the ring and tip are cut through to the 1st selector, but since the wipers are not on any line terminal, there is no effect of this.

D operated (at D12-11M) releases A. The start lead through D12-13 and DwT-B holds D operated. D11-12M sends the start lead on toward the next idle line finder.

The combination of D operated and A released releases all relays other than F and D. Those two relays hold to the sleeve from the 1st selector.

9.10 Finding the calling line–upper bank

Assume for now that the calling line appears on a terminal on the upper bank. The L relay in the line's line circuit has connected the winding of the CO relay in the line circuit, which runs from battery, to the S1 contact of the line's terminal.

When the switch reaches that terminal, the path from battery (through CO) on S1, through BwLM-RM, F3-4B, B12-13B, CwRM-LM, and A7-6B to ground operates F. That path also holds C operated (which in turn holds ROT operated) to prevent any further rotary stepping.

Owing to the relatively high resistance of the CO relay in the line circuit, there may not be enough current to fully operate B (which has a serious contact load). But B1-2M, a preliminary spring pair, closes, and the path from battery through BwB-T, B2-1M, E10-8M, RI4-3, C2-1, and A3-4 to ground pulls B fully operated.

B operated switches the incoming ring and tip path from the lower bank wipers to the upper bank wipers.

The path from battery through FwB-T, B10-9, RI4-3, C2-1M, and A5-4M to ground operates F.

The path A6-7M, D7-6M, D13-12B, B13-11M puts a solid ground on the S1 lead, as before operating CO and marking the line busy (the details of which were covered above). That also short-circuits the holding winding of the C relay (CwRM-LM). C releases, de-energizing ROT, which releases.

F operated cuts the ring and tip are cut through to the 1st selector, but since the wipers are not on any line terminal, there is no effect of this.

D operated (at D12-11M) releases A. The start lead through D12-13 and DwT-B holds D operated. D11-12M sends the start lead on toward the next idle line finder.

The combination of D operated and A released releases all relays other than F and D. Those two relays hold to the sleeve from the 1st selector.

9.11 Release

When the call ends, ground will be removed from the sleeve coming back through the 1st selector. Relays B (if operated), F and D release. The path from ground through VON3-4, A2-1B, F7-6B, E1-2B, VON2-1M, and the winding of RLS to battery operates RLS, and the switch mechanism releases.

When the shaft reaches the home position, both VON3-4M and VON2-1M open, releasing RLS.

The release of A removes the ground from the sleeve (S or S1) of the calling line, restoring it to its normal idle condition.

The release of D (via D10-12-11) makes this switch again “take note of” the Start In lead, putting this line finder back “in the running” to possibly be used for another service request, and removing later line finders in the group from “the running”.

9.12 Line not found

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” in such a case, vertical commutator (VC) contact 10 has a “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.

In such a case, rotary stepping will continue until the switch reaches rotary position 11. The contact of 11SR (the “11th step rotary” contact) closes. The path from battery through FwB-T, 11SR, A3-2M, and VON4-3M to ground operates F. The path from battery though ROT, E7-6M, RI3-4M, F1-2M, 11SR, A3-2M, and VON4-3M to ground holds ROT operated, preventing any further rotary stepping.

The path from battery through DwLM-RM, F7-8M, and VON4-3M to ground operates D.

F operated cuts the ring and tip are cut through to the 1st selector, but since the wipers are not on any line terminal, there is no effect of this.

D operated (at D12-11M) releases A. The start lead through D12-13 and DwT-B holds D operated. D11-12M sends the start lead on toward the next idle line finder.

A released (at A2-3M) releases F and ROT. The path from ground through VON3-4, A2-1B, F7-6B, E1-2B, VON2-1M, and the winding of RLS to battery operates RLS, and the switch mechanism releases.

When the shaft reaches the home position, both VON3-4M and VON2-1M open, releasing RLS.

But D remains held to the start lead.

Shortly all line finders that were idle are in this futile situation. Once all line finders are "busy" (either on an actual connection or as a result of this futile attempt to find a calling line)

This is detected by an alarm circuit. It opens the path from the G relays to the start lead (so there will not be any "legitimate" ground on the start lead, and confirms that the start lead still grounded. After the problem has been resolved, the alarm circuit opens the battery feed to SJ4 (shelf jack terminal 4) of all line finders (the feed to the holding winding of D) and thus clear all the "frustrated" line finders. The details of this latter is beyond the scope of this article.

An open sleeve fro the line circuit of a calling line can likewise cause all currently idle line finders to, one at a time, try to find the line, to no avail.

Again, once all line finders are "busy" (either on an actual connection or as a result of this futile attempt to find a calling line), the alarm circuit is notified. We have not analyzed the details of what happens then.

9.13 Calling line abandons before cut through.

The L relay in the line circuit releases, releasing the G relay in the group circuit. G released takes ground off the start lead. This releases A. The path from ground through VON3-4, A2-1B, F7-6B, E1-2B, VON2-1M, and the winding of RLS to battery operates RLS, and the switch mechanism releases.

When the shaft reaches the home position, both VON3-4M and VON2-1M open, releasing RLS.

9.14 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 in subgroup 3. Subgroup relay G3 will operate, 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, assuming that the calling station is still off hook, 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.

10 THE SLIPPED MULTIPLE

The description above intimates that, when each line 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.

But there is a disadvantages to 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.

To avert this, 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.

I have numbered the lines in this story from 1 through 200, as discussed in section 7.

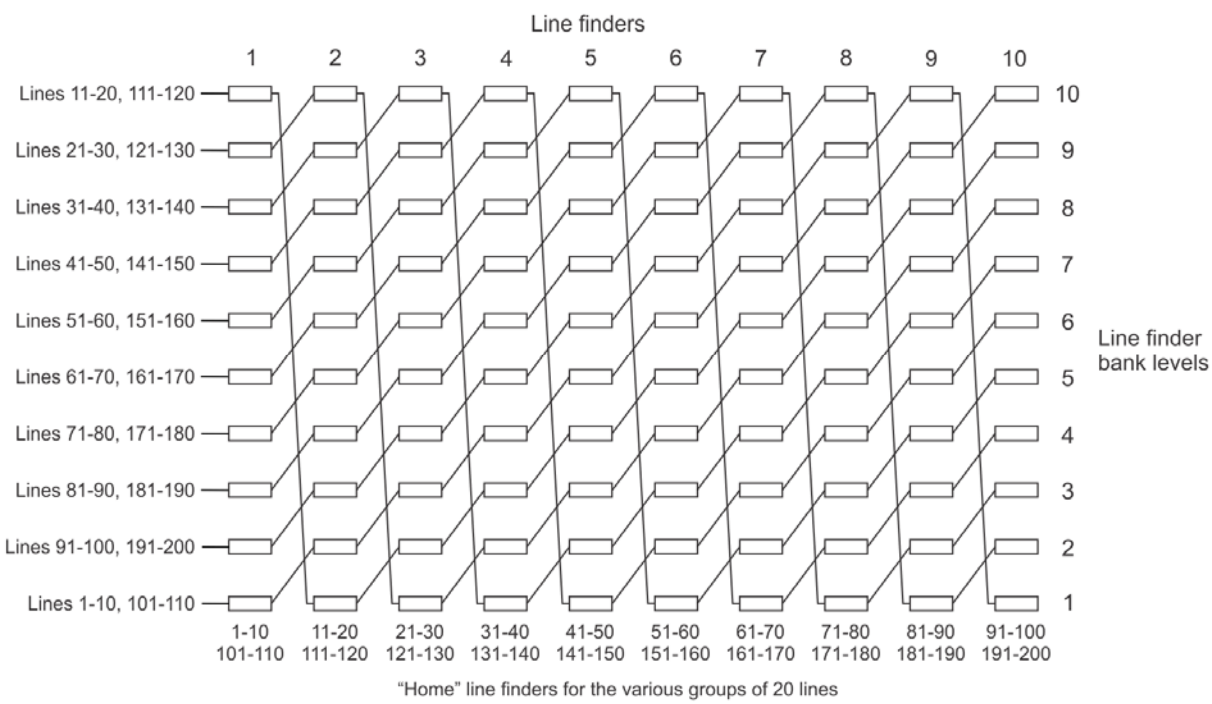

Figure 14. Line finder group with slipped multiple

Note that this is not the actual arrangement typically used, which follows exactly the same principle but "works in the opposite direction". I have used the arrangement here to most clearly illustrate the workings of the principle.

Each heavy line starting 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 terminal positions 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 "stepped" ("slipped") by one level. Of course, for the leads from the last subgroup of lines (21-20 and 111-120), they were on level 10 of the bank of line finder 1, so at line finder 2 they are shifted to the bottom level (this all works "modulo 10").

We already saw that not for every line would line finder 1 (if idle) be started. Rather, for each subgroup (20 lines), if a line one comes off-hook to request service, the line finder numbered the same as the line's subgroup (the subgroup's "home" line finder), if idle, will be started. And that is in fact the line finder on which, under the "slipped multiple" plan, the lines of that subgroup appear on the first level.

Thus in the happy situation where the "home" line finder is idle, then, for every line, the line finder it starts will only have to step once vertically to be able to access the line. For line 23, the "home" line finder would be line finder 3, and line 23 appears on its first level.

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

But suppose line 23 wants service and line finder 3 is busy on another call. Then line finder 4 (if it is not busy) gets the job. On it, line 23 appears on level 2, so two vertical steps will be required to find it. Not ideal in terms of time to find the line and wear on the switch, but not bad at all.

Figure 15 shows (slightly simplified) the circuit arrangements for doing this. Again note that this is reversed. left-to-right, from the actual arrangement most commonly used, another part of my scheme for greatest clarity of the principle.

The worst case would be if line 23 wanted service and all line finders were busy except number 2. On its banks, line 23 appears on the top level, and thus 10 vertical steps would be required to serve it. But that is perfectly all right—just a fraction of a second longer for the calling subscriber to get dial tone, just a miniscule greater wear on the switch. And this would only occur very rarely, at times of heavy calling.

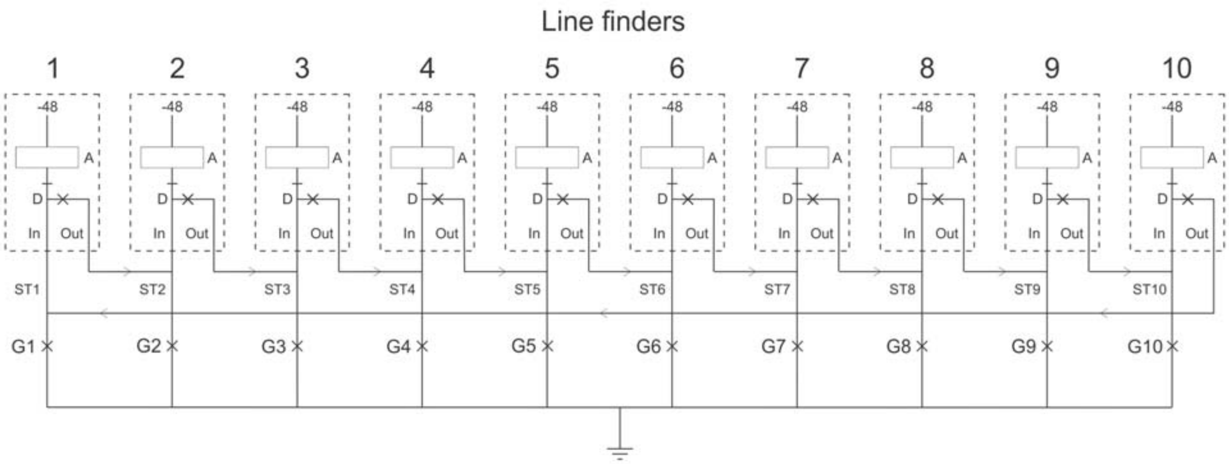

Figure 15. Line finder selection for slipped multiple operation

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.

Consider line 25 wanting service. Subgroup relay G3 will be operated. It applies ground to the ST In start lead of the home line finder for that subgroup, line finder 3 (ST3). If that line finder is idle, this ground will operate its the start relay, 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 and begin rotary stepping on that level, 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 and begin rotary stepping on that level, where it will indeed find the line.

11 ISSUE RECORD

Issue 6 (October 21, 2020) [this issue]: Substantial revision of the circuit schematic and circuit description. Revision of the presentation on the slipped multiple. Various editorial revisions.

Issue 5 (December 19, 2019): Updated discussion of detached contact schematic drawing system.

Issue 4 (October 21, 2020): Added further information on secondary line switches. Corrected error and added note on figure 17.

Issue 3 (June 20, 2018): 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.

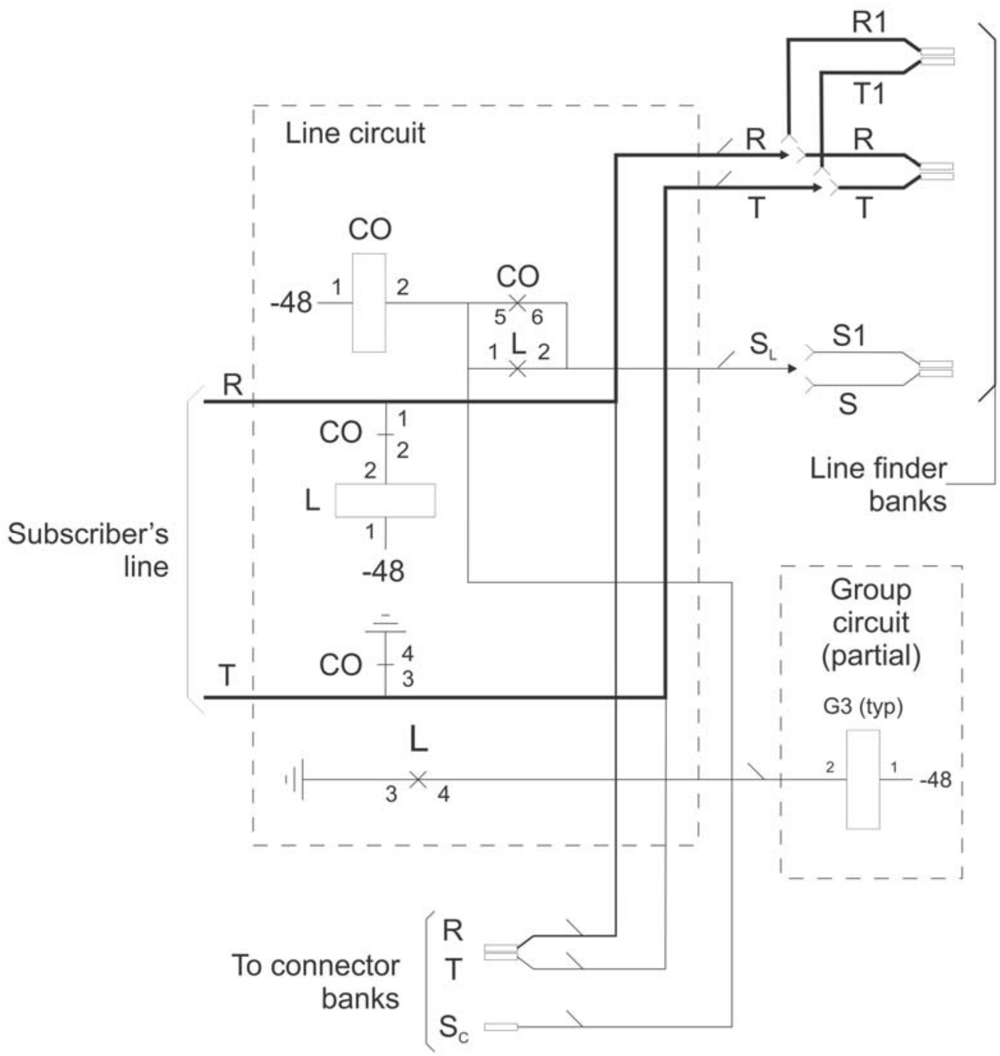

Figure 16. Line circuit (typical)

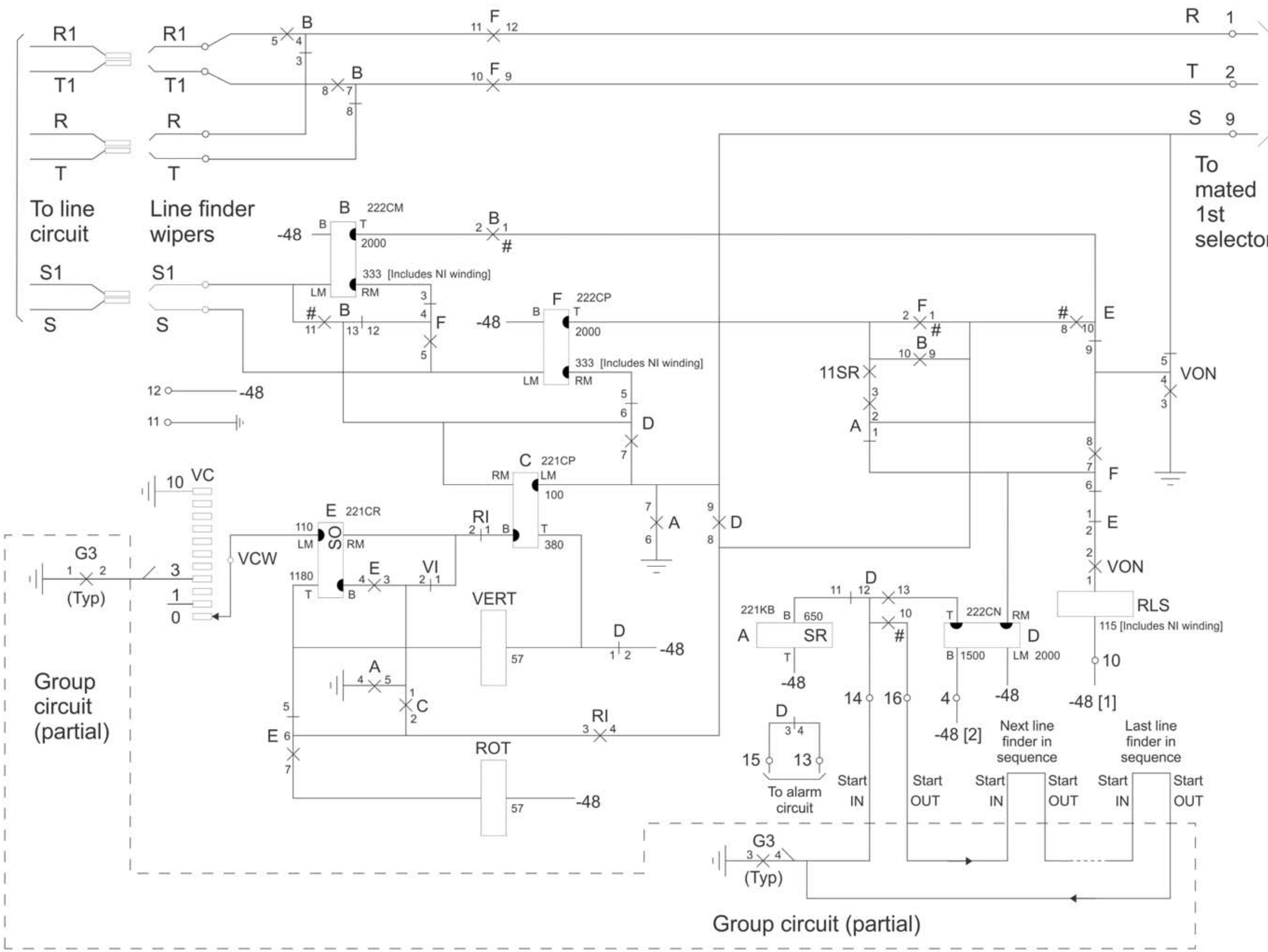

Figure 17. Illustrative line finder circuit (with line circuit and part of group circuit)

Relay functions (line finder)
A Start
B Line found in upper bank
C VERT/ROT step
D Switch busy
E Marked level found
F Line found in lower bank; cut through

Relay functions (line circuit)
L Line
CO Cutoff

Relay functions (group circuit)
G Subgroup

SO Slow operate
SR Slow release
VON Vertical off-normal
VI Vertical interrupter
RI Rotary interrupter
11SR 11th step rotary contacts
VC Vertical commutator
VCW Vertical commutator wiper

#: Make first spring or contact

Note [1]. Through common external relay that detects if any switch has not released properly

Note [2]. Through common external relay contacts to clear line finder after clearance of start lead malfunction.

Figure 18. Notes for figure 17

-#-