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

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FOREWORD

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 *1st selector*). The selectors serve to advance the connection 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.

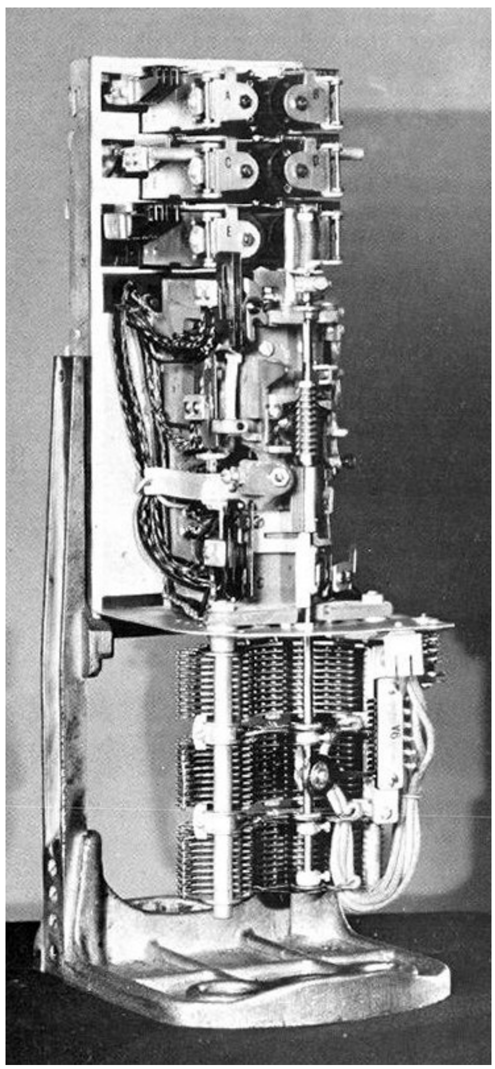

Figure 1. Typical line finder switch

2 THE SWITCH ITSELF

2.1 General

Figure 1 shows a typical "200-point" switch (in particular a line finder), 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" line finder bank assembly

But in a line finder, 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.

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

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 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).

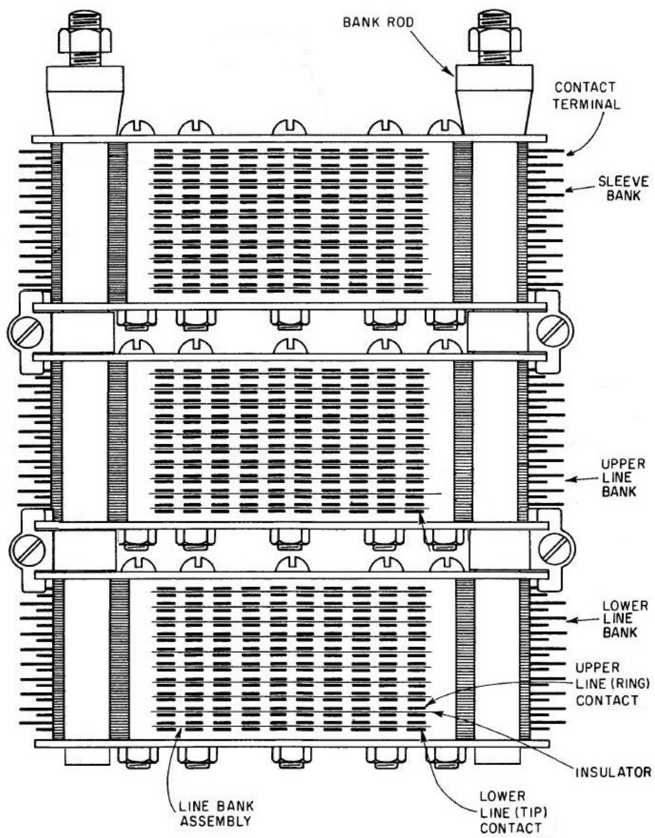

Figure 2. 200-point line finder bank assembly

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.

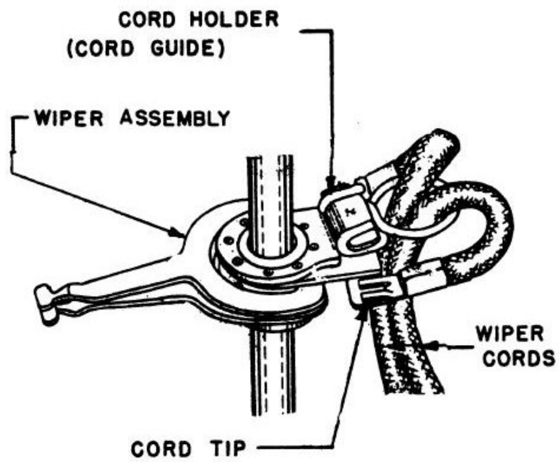

Figure 3. Two-contact wiper

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 slide onto terminal 1.

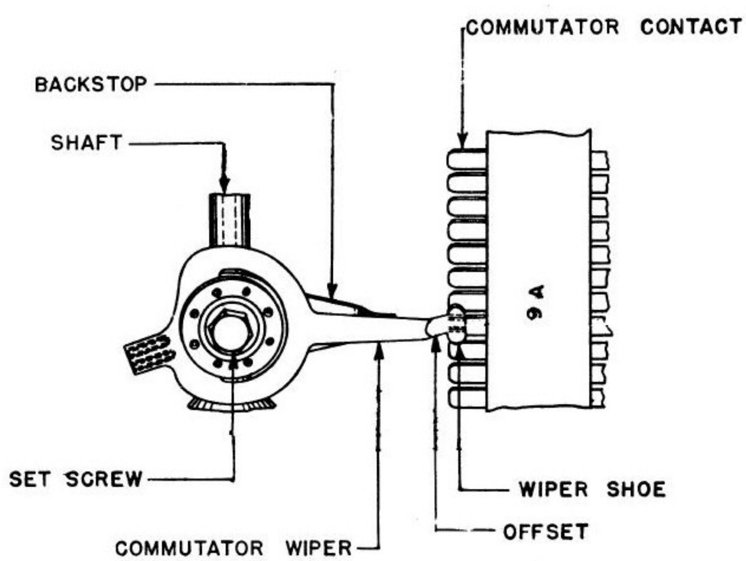

Figure 4. Line finder vertical commutator and its wiper

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). It us sometimes called the "switching fabric"

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 1st 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.

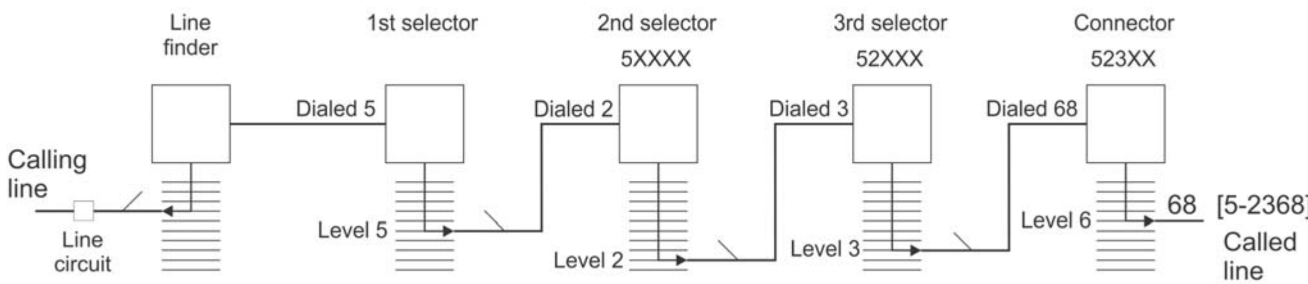

Figure 5. 5-digit switch train

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, goes 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 of interest.

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 circuit.

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 “FRONT END”

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,

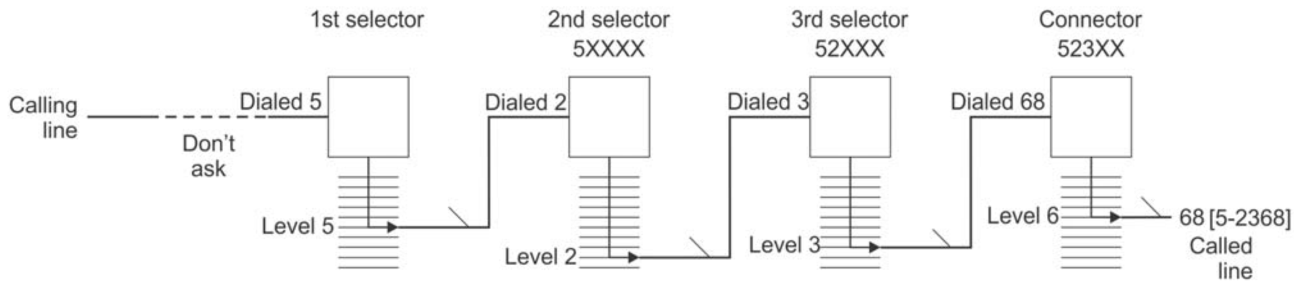

Figure 6. Switch train from the 1st selector

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 1st 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.

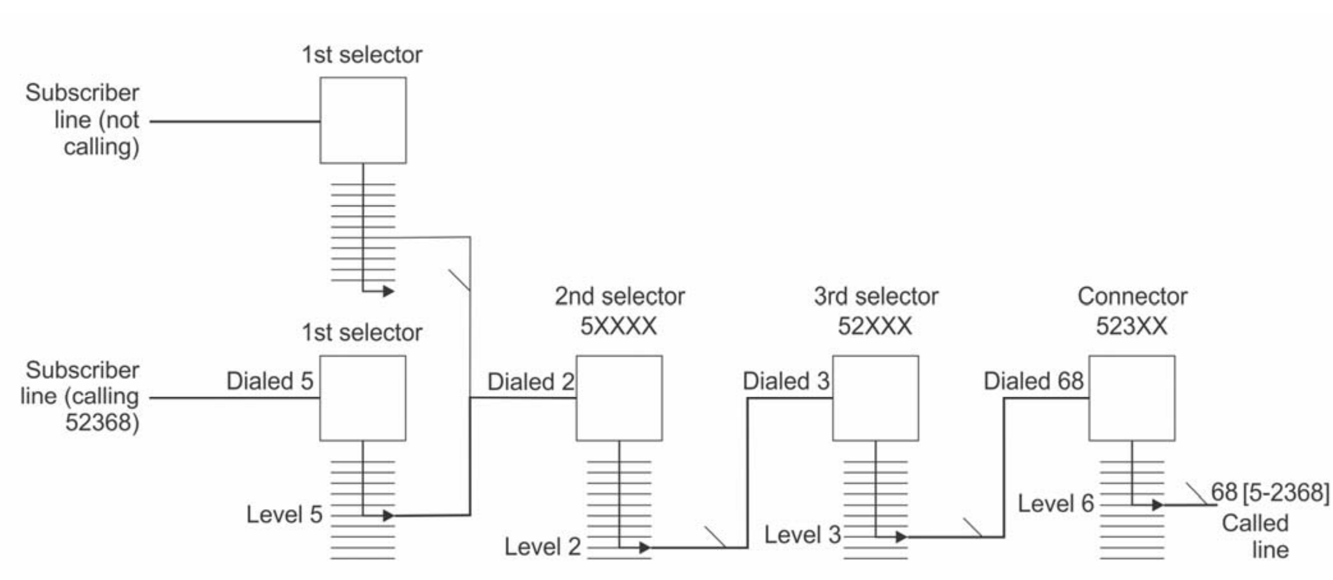

Figure 7. Switch train with individual 1st selectors

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 using this scheme and 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, rather than the *line finder* scheme to which this article is primarily devoted. Figure 8 shows this scheme, in our familiar context, in one common implementation.

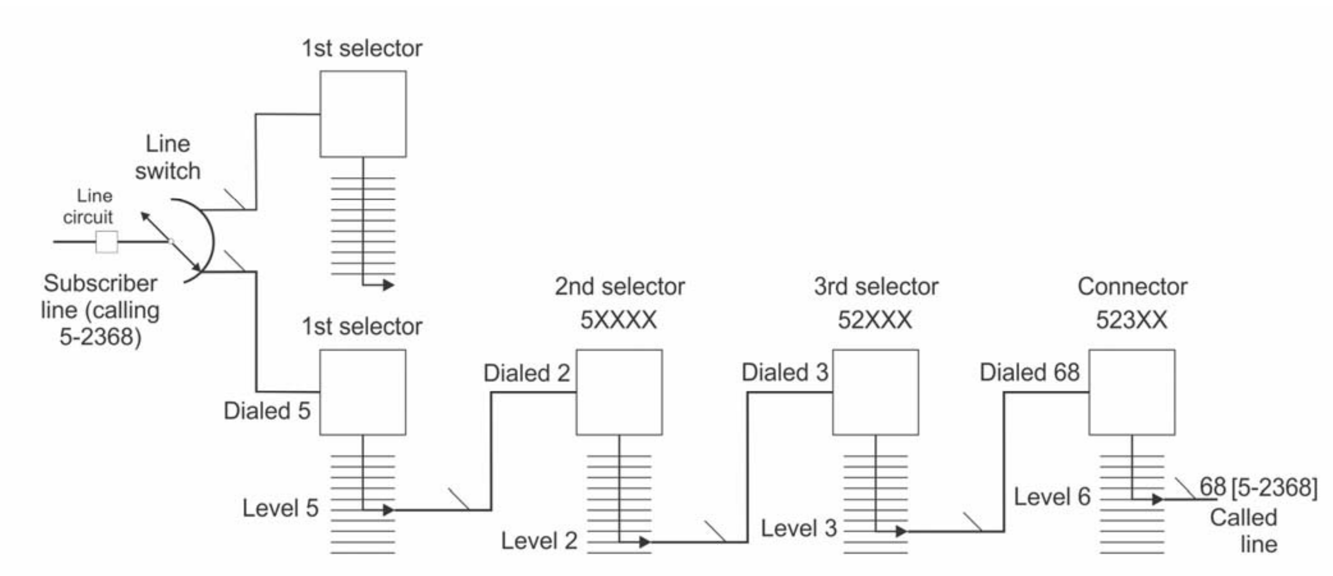

Figure 8. Switch train with line switches

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 *uniselector*[2]*s*, 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 Western Electric 200-type, or in a later design, 206-type, selector).

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[2] Although this terms is essentially never used in the Bell System

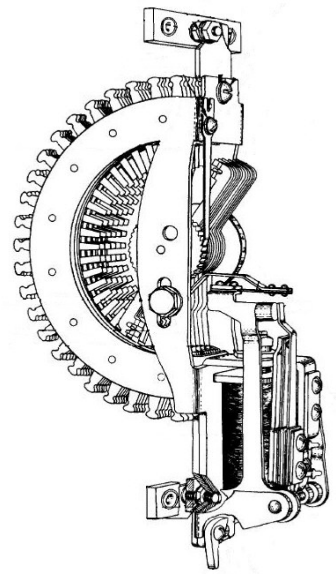

Figure 9. Uniselector

The terminals (it is typical for a Western Electric switch of this type to have 22 terminals, as in the one shown) covering a span of rotation of the switch of 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. A 23rd set of lugs on the bank connected to the feeder brushes, which made the "common" connection to the wipers.

We also see in Figure 8 for the first time a *line circuit*, a small collection of relays. Each line has one.

The up to 22 terminals 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 switch banks for other subscriber lines in a group 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 1st 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.

The further details of this and of the uniselector line switch scheme overall 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.

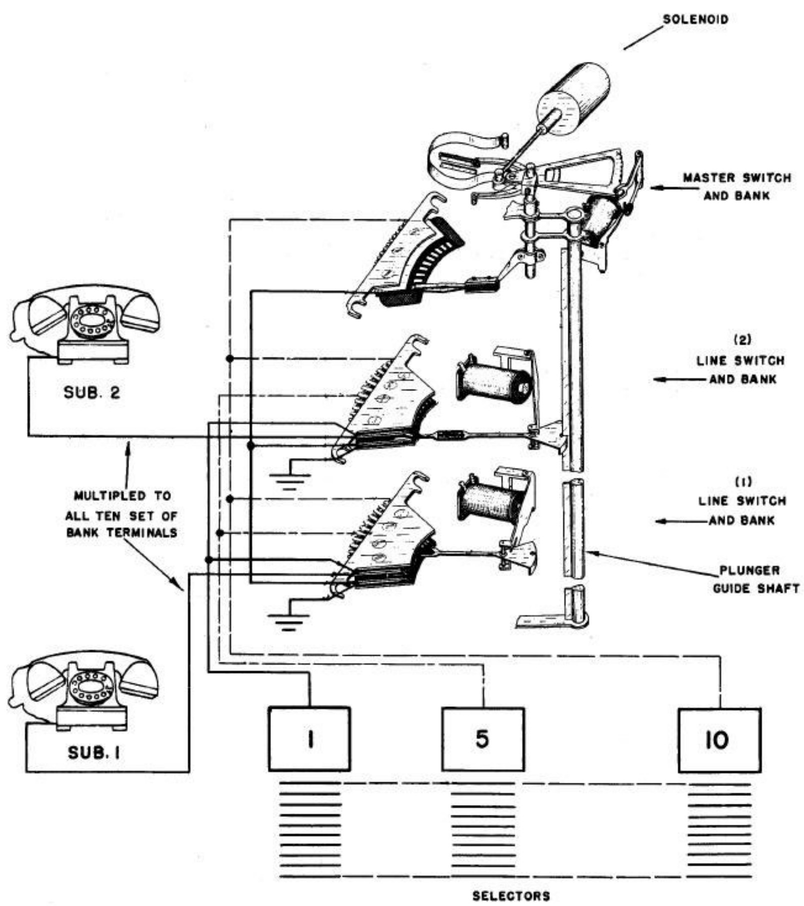

Figure 10. Plunger-type line switch

The connection between the line and the chosen 1st selector is not made with wipers touching contacts, but rather by a plunger on the unit for the line spreading a set of contact springs that close the path. There are 10 positions in the most common construction of this kind of unit. Thus every line in the group can be connected to any of 10 1st 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 idle lines 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 contact closes and 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”, detecting that the “current switch” for all the lines is now busy, then moves all the remaining plungers until they are positioned to connect their lines to a now 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[3]. 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.)

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[3] 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”.

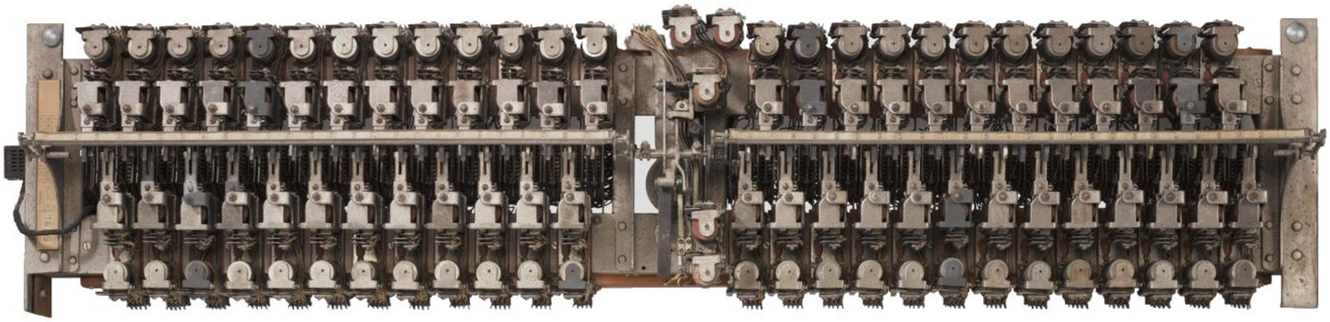

Figure 11. 50-line plunger line switch assembly

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, for an improvement in the efficiency of utilization of the line finders.

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.

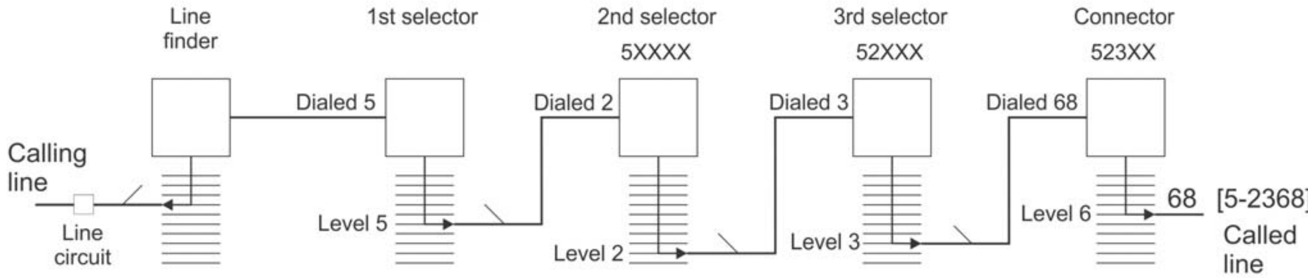

Figure 12. Switch train with line finders

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 already 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 used the line switch scheme, mainly using the plunger type line switch, Later the line finder scheme became the norm. But for Strowger systems in the U.K. for instance, the line switch scheme, with uniselectors, was the most common in larger central offices, over the entire era of the system.

5 CIRCUIT SCHEMATIC DRAWING CONVENTIONS

The circuit schematic drawings in this article utilize my adaptation of a system introduced in the Bell Telephone System in the late 1950s, called *detached contact schematic* notation.

In the prior drawing style (now called the *attached contact* style), the relay contacts were shown in a form evocative of actual physical contacts, with all the contacts on a certain relay adjacent on the drawing, much as they are in real life.

A major disadvantage of this system for circuits of any complexity was that the many circuit paths, often involving contacts on several relays, were a nightmare on the drawing. Following any particular circuit path was arduous.

Rather, in this newer system, simple (and easily drawn!) geometric symbols are used for the basic relay elements: the coil, which actuates the contacts, and the contacts themselves.

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 (they are “detached” from the symbol for the relay coil, thus the name of this style). 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).

Figure 13 shows the principles of the detached contact style.

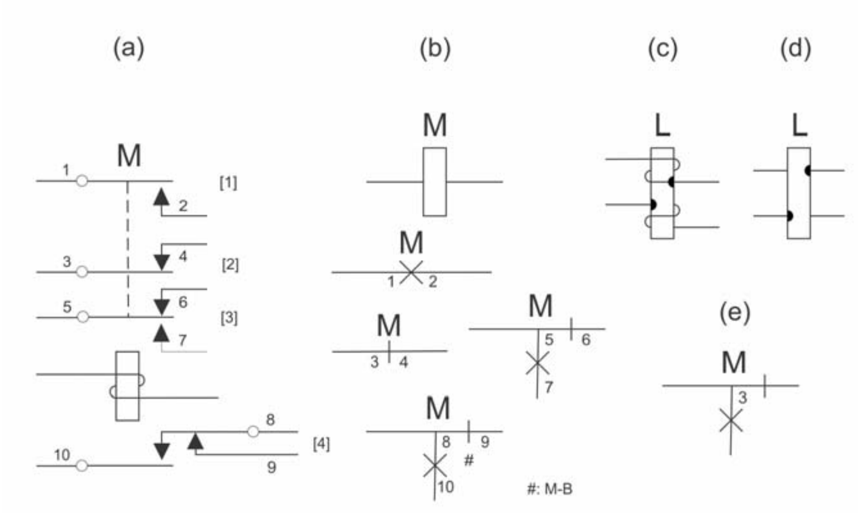

Figure 13. Detached contact schematic symbols—relays

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 "coil"). 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 one of 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 system. 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 coil (called here the relay "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 drawn un different places.)

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 the adaptation of the system I use, I use the symbol "#" to indicate that this is a "make-before-break" contact.

In some cases, there are two (in some 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, or opposing, magnetic fields (whichever we need for the intended circuit operation).

In panel (c) we see a two-winding relay coil shown under the attached contact system. In panel (d) we see that same coil under the detached contact system. In both cases, the little half-moon marks show "corresponding" ends of the two windings.

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 might be numbered 6-7-8, but as a contact is numbered 3.

5.1 References

5.1.1 *By spring or winding terminal*

In the detailed circuit description in Appendix A, the reference "A:1-2m" refers to, on relay A, contact spring pair 1-2, which is a *make* contact. The reference "D:3-4b" refers to, on relay D, contact spring pair 3-4, which is a *break* contact.

The reference "D:wT-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.

5.1.2 *By contact number or winding designation*

In some cases, I only used a single number to designate a contact, in which case a reference to a contact might be "L:1m", for the contact on L identified as number 1, which is a make contact.

Similarly, in some cases I will only identify the windings of a relay with multiple windings as "P" (primary), "S" (secondary, and (if applicable) "T" (tertiary).

In the circuit description, the primary winding of L would be spoken of as "L:wP". If L had only a single winding, that would be referred to just as "L:w".

6 THE CIRCUIT SCHEMATIC DRAWINGS

6.1 Introduction

Figure 22 (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 **Error! Reference source not found.** gives the notes for this drawing.

Figure 14 shows a typical line circuit that would be used with this kind of line finder. Figure **Error! Reference source not found.** shows a later variant. Figure 20 shows a lower-cost variant.

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.[4]

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.[5]

6.3 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

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 efficient use of the line finders, thus giving it a "line number".

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

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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, in which the relay designations came from their positions on the "chassis". Other systems, originally designed in the Bell System would typically use mnemonically-based relay designations, perhaps "ST" for the start relay rather than "A".

[5] 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.

That all having been said, next recall that in a connector, the first level is reached by dialing “1” as the tens digit, but the 10th level is reached by dialing “0”, 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, on level 1 (the first level) the first position 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

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.

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

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

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 (for “group”, but it actually relates to a subgroup) 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 line finder group ("first" according to the "batting order" established for the line finder group, starting with the preferred line finder for that line subgroup). 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 subgroup 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 operates the D relay, which halts the rotary stepping.

F also cuts the line tip and ring through to the mated 1st selector.

D advances the start lead to the next idle line finder in the start sequence for the group so it could respond to a subsequent service request.

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 which 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. the next part of the operation is as described above.

In either case, when the tip and ring are cut through to the mated 1st 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 rotation" to possibly be used for another service request.

9 The line circuit

9.1 Introduction

Each line is provided with a line circuit. Each line circuit comprises two relays, L (line) and CO (cutoff). We see it in a basic configuration in Figure 14.

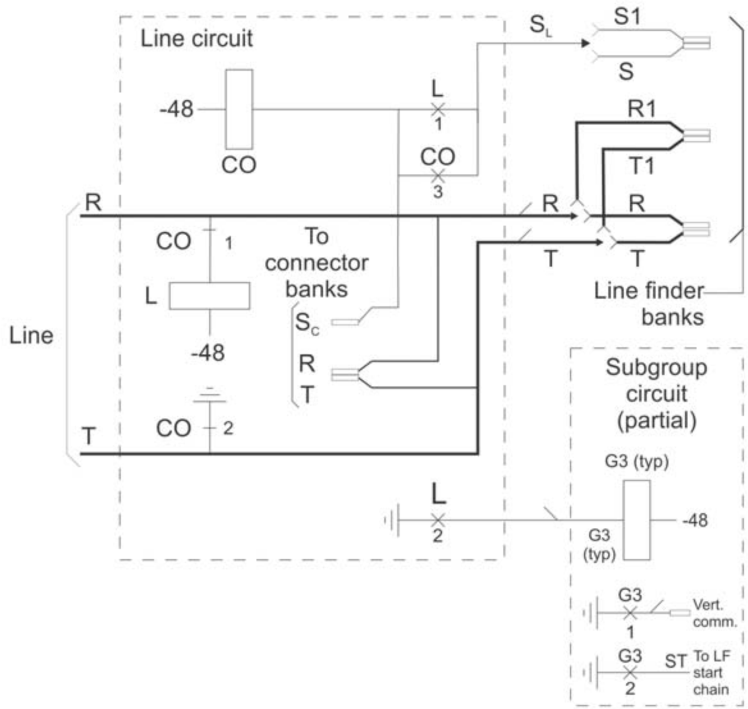

Figure 14. Line circuit (typical—unbalanced)

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 the winding of L and CO1B to the ring of the line, Ground is fed through CO2B 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.

9.2 A transmission issue

I interrupt the main story to note that with the line circuit as shown in Figure 14, with the line idle, we have the impedance of the winding of the L relay in the feed to the ring but no such in the feed to the tip. Hence 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 may 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 (idle), 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.

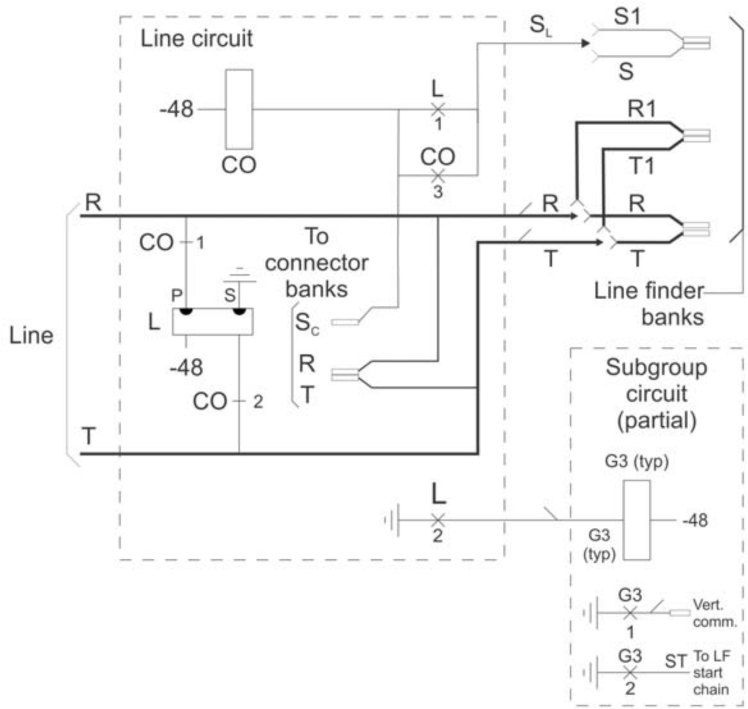

Figure 15. Line circuit (typical—balanced)

In later designs of most versions of the step by step system, this phenomenon was averted by using a two winding L relay (with one winding in the feed to each line conductor), as we see in Figure 15.

Oddly enough, in the panel dial, No. 1 crossbar, and No. 5 crossbar switching systems, over the lives of those systems, the standard line circuit used an unbalanced line relay, as seen for the step by step system in Figure 14. But the No. 1 ESS and 5ESS switching systems used an essentially balanced equivalent of the line relay. I do not know the rationale for this difference in approach.

9.3 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 formal 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!

10 THE SLIPPED MULTIPLE

10.1 Introduction

The description above perhaps 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 subgroup (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 16. For simplicity's sale, the figure assumes 100-point line finders, which can only access 100 lines. It assumes a group of 100 lines, which I have numbered 1-100, in 10 subgroups (1-10, 11-20, etc.) served by 10 line finders. This is not the actual numbering that would be used (see section 7.2), but I use it here for clarity.

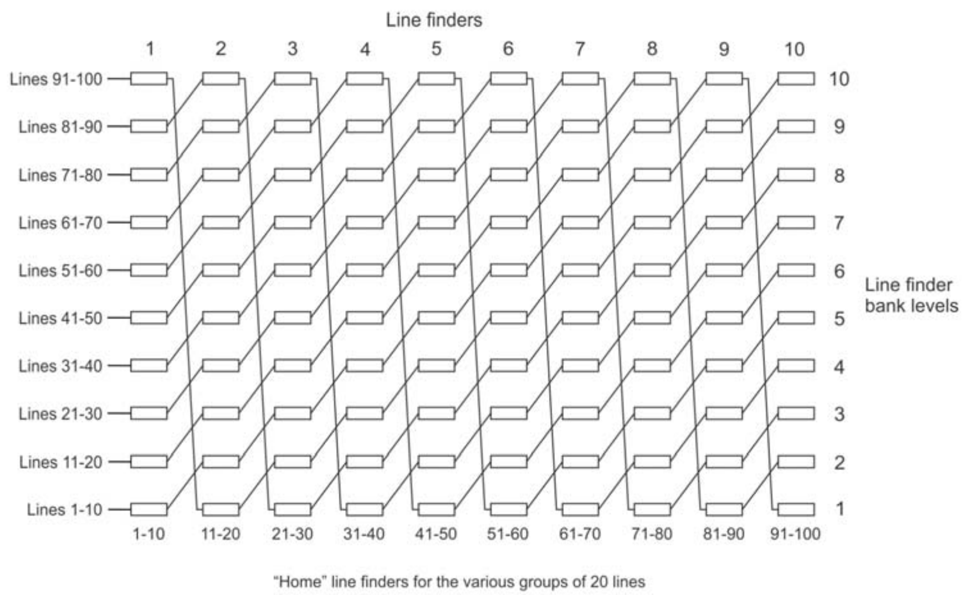

Figure 16. Line finder group with slipped multiple (principle)

Each line starting from the left represents the leads (T, R, and S) for the 10 lines in a subgroup (for example, lines 41-50). Each of the little rectangles represents the ten terminal positions on one level of one line finder.

A given line will always have the same rotary position, regardless of on which level it appears on any given line finder. Line 1 would always be on rotary position 1, etc.

We see that lines 1-10 appear on level 1 of line finder 1. The leads from one line finder bank to the next are "slipped" so lines 1-10 also appear on level 2 of line finder 2, level 3 of line finder 3, and so forth.

Lines 11-20 appear on level 1 of line finder 2, on level 2 of line finder 3, and so forth. On line finder 1, they appear on level 10 (this all works "modulo 10").

Lines 21-30 appear on level 1 of line finder 3, on level 2 of line finder 4, and so forth. (as for lines 11-20, the pattern "wraps around"

If a line in subgroup 1-10 comes off hook, line finder 1 is started to look for it if that line finder is not already busy on another connection. The line will be found on level 1 of line finder 1.

If however, line finder 1 is already in use, line finder 2 (if it is not already busy) will be started, and will find the line on its level 2). If, line finder 2 is already in use, line finder 3 (if it is not already busy) will be started, and will find the line on its level 3.

Now, if a line in subgroup 11-21 comes off hook, line finder 2 (if it is not already in use) is started, and finds the line on its level 1. The rest of the story is just as we saw for a line in subgroup 1-10.

Thus we see that the time to vertically hunt for the line requesting service is made a little as is possible considering the busy state of the line finders in the group.

Of course, the worst case would be if a line in subgroup 1-10 wanted service and all line finders except line finder 10 were in use. Then line finder 10 would be started and would find the line on its level 10.

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.

10.2 The start relay chain

Figure 17 shows (slightly simplified, and consistent with the conceits of Figure 16.) the circuit arrangements for starting the appropriate line finder in any situation

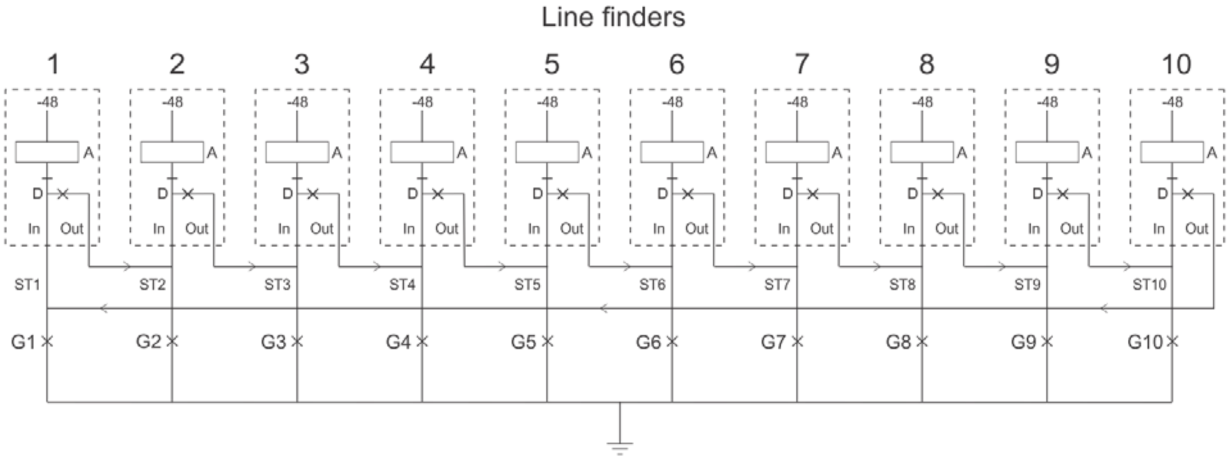

Figure 17. Line finder selection for slipped multiple operation (illustrative)

The L relay contacts of the line circuits for lines in subgroup 1 (1-10) 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 thus the ground from subgroup relay G3 will go there. 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 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.

10.3 In reality

In reality, the actual typical arrangements differ in several ways from that I showed, in a way intended to facilitate grasp of the principles, in Figures 16. and 17, as follows:

- The multiple “slip” is actually rather like the mirror image of what we saw in Figure 16.
- Accordingly, the start lead advance circuit is essentially the mirror image of what we saw in Figure 17.
- For ease in following the story, I showed the lines in subgroups identified as 1-10, 11-20, and so forth. In reality, so as to match the conventional way of thinking about the 100 positions of a step-by-step switch, which comes in turn from how they respond to various dialed digits, the lines here would be identified (by subgroup) as 11-10, 21-20, and so forth, through 01-00.
- Similarly, although I labeled the line finder levels as 1-10, in reality they would be designated 1-9 and then 0.
- In most step-by-step central office systems, the line finders are of the “100-point” variety, able to access 200 lines, 100 on each of two banks. The lines on the lower bank are identified as 11-10, 21-20, through 01-00; on the upper bank as 111-110, 121-120, through 101-100. But the “slip” plan for the upper bank lines is exactly the same as for the lower-bank lines.

All these realities (except for the start lead circuit) are reflected in Figure 18.

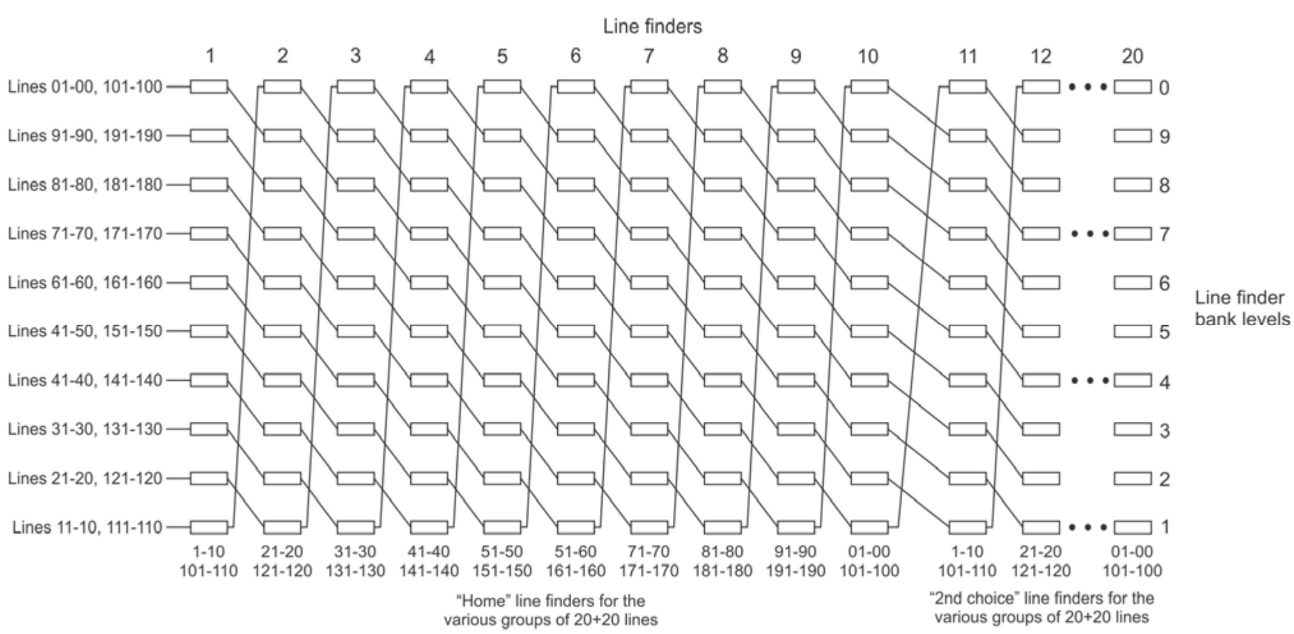

Figure 18. Line finder group with slipped multiple (typical)

As to the start lead, if line finder 1 is busy, the start lead from subgroup 1 (such as would come from lines 1-10 or 111-110) is diverted to line finder 11, on which those lines also appear on level 1. If that line finder is busy, the start lead is diverted to line finder 10, on which those lines appear on level 2. If that line finder is busy, the start lead is diverted to line finder 20, on which those lines also appear on level 1. And so forth.

On the shelf jack, into which a line finder switch is “plugged” when put in place, the contact springs for the in and out start leads are immediately adjacent. They are tensioned so that, with no switch in place, they touch. Thus if there is no switch in a certain shelf position (either because that position has not yet been equipped because not so many line finders are needed for the current traffic on that line group, or because an equipped switch has been removed, in anticipation of its being replaced as part of a maintenance operation), the start lead is sent on to the next switch in the “batting order”.

Figure 19 shows the start lead chain in a more realistic fashion.

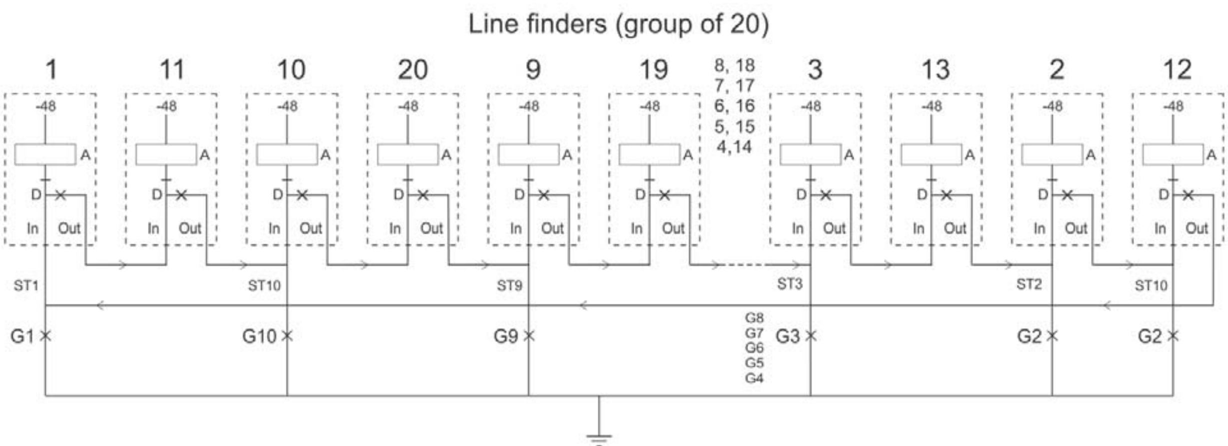

Figure 19. Line finder selection for slipped multiple operation (realistic)

The switch positions are equipped with switches, up to the number currently seen as needed for the expected traffic from that group of lines, in a certain sequence, thus (by line finder position number):

1, 6, 4, 9, 2, 7, 3, 6, 5, 10, 11, 16, 14, 19, 12, 17, 13, 18, 15, 20

The point is to optimize the overall average vertical hunting time given by the current complement of line finders. As more switches might be added to accommodate increases in traffic, they are placed in the subsequent positions of that list.

We note that all line finder positions 1-10 (the first half of the shelf) are equipped before equipping any in positions 11-20.

11 SINGLE RELAY LINE CIRCUIT

In some versions of the step-by-step system (especially in small unattended offices (community dial office, CDO). the line circuit uses a single relay, designated L, for both the line relay and cut off relay functions. It does this by way of what is called "two step" operation. Here, for a certain degree of energization of the coil winding(s), the relay operates thorough only part of its stroke, operating some contacts but not others. For a greater degree of energization, the relay operates through its entire stroke, operating all its contacts.

We see an illustrative version of this kind of line circuit in Figure 20. It is slightly simplified from the actual typical circuit in the interest of most clearly showing the principles involved.

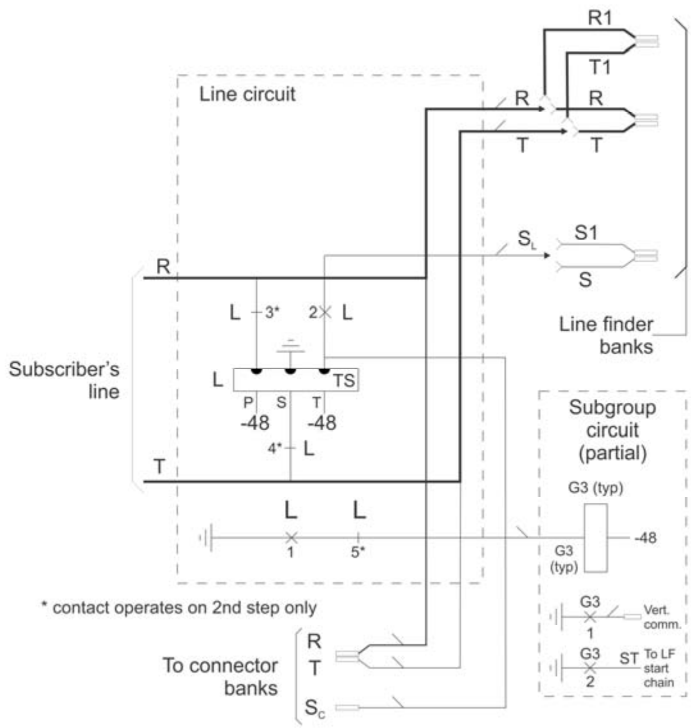

Figure 20. Single-relay line circuit (illustrative)

With the circuit idle, battery is fed to the subscriber line through the primary (P) and secondary (S) windings of the relay. The resistance of this path is such that, even if the subscriber line and the telephone set had zero resistance, the current through the relay windings would only be enough to operate the relay to its "first step". That closes contact L1, which starts a line finder, and L2, which applies battery from the tertiary winding (T) to the line finder sleeve, marking the line as requesting service.

When the line finder finds the line, and the loop bridge operates the A and then B relay in the associated 1st selector, the line finder grounds the line finder ground to the line circuit. This energizes the L relay tertiary winding. The current here is such that the relay will fully operate (to "step two"). This opens contacts L3 and L4, which disconnect the L relay P and S windings from the line conductors (just as the CO relay would in a conventional line circuit). Contact L5 opens the path from contact L1 that earlier started the line finder. With L fully operated, contact L remains closed, maintaining the path from the line finder sleeve (now grounded from the line finder) to the T winding of L, holding it fully operated. The connector sleeve is also now grounded, marking the line busy with respect to potential incoming calls.

If the line is connected to by a connector, as the terminating party on a call, the ground on the selector sleeve also energizes the L relay through its T winding, which will cause it to immediately fully operate. The result is that the L relay windings are disconnected from the line.

The line finder sleeve is not grounded, this being of no consequence (as any line finder browsing over this line's terminals would only be looking for battery as an indication that the line wanted service).

In later systems, this kind of line circuit was deprecated, as its proper operation depended on "finicky" adjustments of the L relay.

12 LOCKOUT FEATURE

As mentioned earlier, if a subscriber inadvertently takes his station off hook (causing the dreaded "permanent signal"), a line finder and associated 1st selector are put into play to serve the service request, but there is no dialing, and this bogus service request does not mature into a call (but holds out of use the linefinder and 1st selector). There is no point, when this situation is detected, in releasing the line finder-selector pair; the line is still off hook and the dilemma will be re-established.

The typical follow-on is that an alarm is brought in, and a switchman[6] will note what has happened and will take some action to del with it.

A similar phenomenon occurs when the calling party releases the call but the called party doe not go on hook. (Perhaps he thinks he has put the handset back in the cradle, but an inopportunely-placed book keeps the set off hook.) If the system uses calling party control, a line finder will be started (to no good end) for that line.

In the case of a small, unattended central office (such as a "community dial office", or CDO), there is no switchman on-site to deal with these situations. Accordingly, especially in such offices, special line circuits with the "lock out" feature are often provided. These have an additional relay, LO (lock out).

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[6] A gender-neutral job title.

If a 1st selector is seized but there is no dialing within a certain period, a timing circuit operates and causes the selector to unground the sleeve back to the associated line finder. The line finder in turn removes the ground on the sleeve back to the line circuit.

The ensuing sequence of events causes the LO relay to be momentarily energized, and it operates (and stays operated a brief while on its own accord, as it is slow release).

But L immediately operates because the line is off hook), and it holds LO operated. LO operated disables the contacts on the L relay that would start a line finder and mark this line for “finding”..

If and when the “permanent signal” is cleared by the subscriber putting the station back on hook, the L relay releases and that releases the LO relay. The outputs of the line relay are thus re-enabled, and if the line subsequently comes off hook (hopefully to place a real call), L operates and starts a line finder and marks this line for finding, and the call proceeds in the usual manner.

While a line is off hook in the “locked out” condition, a raucous tone signal (the “receiver off hook” tone, ROH) is placed on the line, hopefully to attract the subscriber to the off-hook telephone set, that he might put it on-hook.

13 ACKNOWLEDGEMENT

Thanks to Leonard Hicken for his information on the change of the step-by-step line circuit from unbalanced to balanced.

-#-

Appendix A
Detailed description of circuit operation

A.1 Introduction

In this appendix I will work from Figure 22, which is a detailed circuit schematic drawing of a typical 200-point general-purpose line finder (as most often discussed in the body of the article).

A.2 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.

A.3 The line circuit

The description assumes that the line circuit involved as that shown by Figure 14 in the body ff the article. It is shown here for convenience of reference.

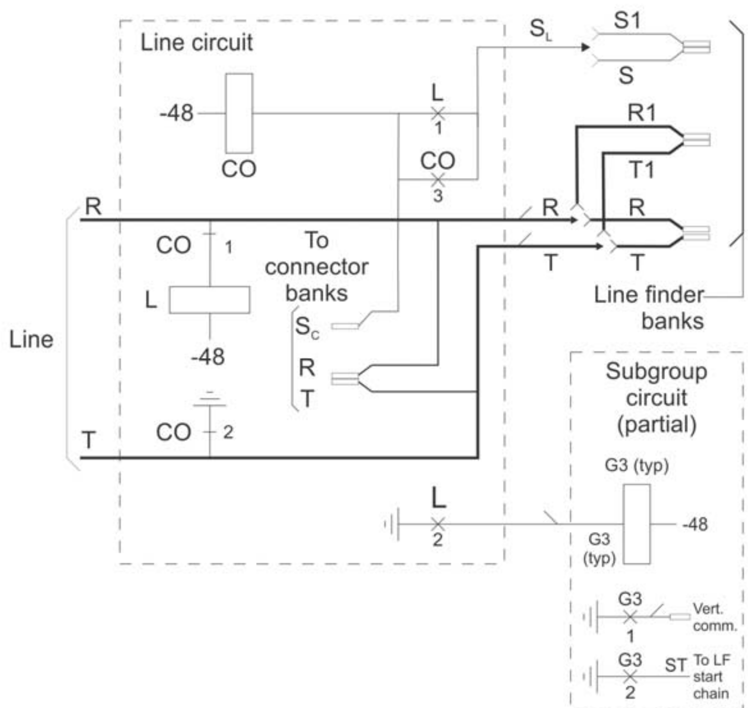

Figure 21. Line circuit (typical—unbalanced)

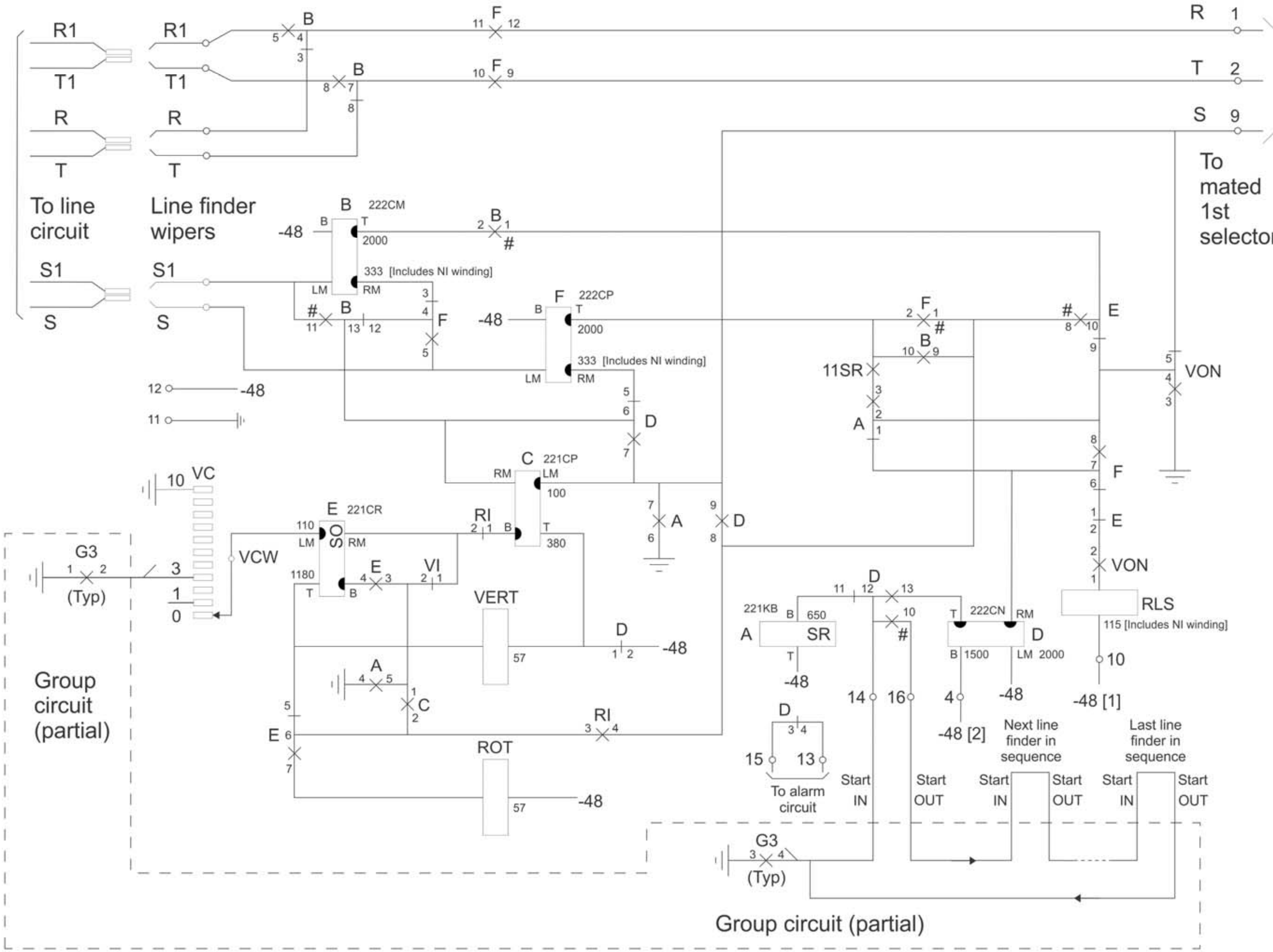

Figure 22. Illustrative line finder circuit (with line circuit and part of group circuit)

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.

Notes for Figure 22

A.4 Initial conditions

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

A.5 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 the applicable position on the top bank (the "sleeve bank"); the lines of the "upper bank" regiment have their sleeve leads on the upper contact of the applicable position on the upper bank.

A.6 Line idle

With the line idle, battery is placed on the ring lead by the path from battery through the winding of L and CO:1b (Figure 21) to the ring lead of the line. Ground is placed on the tip lead by the path from ground through CO:2b 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.

A.7 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 the winding of CO and L:1m 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 L:2m operates grounds the subgroup lead, G (here assumed to be ST3, for subgroup 3) which operates the G relay for the line's subgroup (here assumed to be G3, for subgroup 3).

Contact G:1-2m grounds the appropriate terminal on the vertical commutators on all line finders corresponding to the line's subgroup (in the example, subgroup 3).

Contact G:3-4m leads to the line finder start lead (ST) chain, where it will start the first available line finder in the sequence pertaining to lines in this subgroup.

A.8 Vertical stepping

Ground on the ST lead for this line finder, through D:12-11b and A:wB-T to ground operates A. The path from battery through A:4-5m, VI:2-1b (the vertical interrupter contact), RI:2-1b (on the rotary interrupter contact), C:wB-T, and D:1-2b to battery operates C.

The path from battery through A:4-5m, C:1-2m, E:6-5b, the winding of VERT (the vertical magnet), and D:1-2b to ground operates VERT.

When VERT operates, VI:2-1b opens and releases C. C:1-2m 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 E:wLM-RM, RI:2-1b, C:wB-T, and D:1-2b to battery energizes E. This also holds C, preventing the release of VERT and preventing any further vertical stepping.

A.9 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, E:6-5b opens, opening the path to VERT, and E:6-7m 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.

A.10 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 on the line finder bank.

When the switch reaches that terminal, the path from battery (through CO) on S through F:wLM-RM, D:5-6m, C:wRM-LM, and A:7-6b 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 F:1-2m, a preliminary spring pair, closes, and the path from battery through F:wB-T, F:2-1m, RI:4-3M, C:2-1, and A:5-4 to ground pulls F fully operated. Later, after ROT releases, the path F:wB-T, F:2-1m, D:8-9. and A:7-6b to ground holds F operated.

Then battery through D:wLM-RM, F:7-8m, and VON:4-3m to ground operates D. Relay A releases, but the hold for F now comes from the selector sleeve through D:9-8m and F:1-2m.

The path A:6-7m, D:7-6m, D:13-12b, F:4-5m puts a solid ground on the line's S lead. This operates CO and marks the line busy. That also short-circuits the holding winding of the C relay (C:wRM-LM). D:2-1b opens the path from battery to C:wTB. Relay C releases, de-energizing ROT, which releases.

CO operated, through CO:1-2b and CO:3-4b, 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 through to the 1st selector.

D operated (at D:12-11m) releases A. The start lead through D:12-13 to D:wT-B holds D operated. D:11-12m 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 until the end of the connection.

A.11 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 B:wLM-RM, F:3-4b, B:12-13b, C:wRM-LM, and A:7-6m 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 B:1-2m, a preliminary spring pair, closes, and the path from battery through B:wB-T, B:2-1m, E:10-8m, RI:4-3, C:2-1, and A:3-4 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, D:7-6m, D:13-12b, B:13-11m 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 (C:wRM-LM). C releases, de-energizing ROT, which releases.

F operated cuts the ring and tip through to the 1st selector.

D operated (at D:12-11m) releases A. The start lead through D:12-13m and D:wT-B holds D operated. D:11-12m 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.

A.12 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 VON:3-4m, A:2-1b, F:7-6b, E:1-2b, VON:2-1m, and the winding of RLS to battery operates RLS, and the switch mechanism releases.

When the shaft reaches the home position, both VON:3-4m and VON:2-1m 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 D:10-12-11) makes this switch again “take note of” the Start In lead, putting this line finder back “in the rotation” to possibly be used for another service request.

A.13 “First choice” line finder already in use.

Suppose that, when our line in subgroup 3 comes off-hook to request service, line finder 3 is already in use on another call. It that event, its D relay will be operated. Its contacts D:11-12-10 take the incoming start lead off its A relay and send it back out, where it goes to the incoming start lead of the next line finder in sequence. (Which line finder that is is a complicated, matter, of which we will learn in detail in section 10.2.)

As we can see, if that line finder is also busy, the start lead will be redirected by its D relay (operated) to the incoming start lead of the next line finder in sequence, and so forth.

A.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. Following the description in section A.13, we find that the start lead fails to find a home in any idle line finder, and thus forms a closed loop leading to no 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.

A.15 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 (no line requesting service being found on that level). The contact of 11SR (the "11th step rotary" contact) closes. The path from battery through F:wB-T, 11SR:m, A3-2m, and VON:4-3m to ground operates F. The path from battery though ROT, E:7-6m, RI:3-4n, F:1-2, 11SR:m, A:3-2m, and VON:4-3m to ground holds ROT operated, preventing any further rotary stepping.

The path from battery through D:wLM-RM, F:7-8m, and VON:4-3m 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 on the selector.

D operated (at D:12-11m) releases A. The start lead through D:12-13m and D:wT-B holds D operated. D:12-10m sends the start lead on toward the next idle line finder.

A released (at A:2-3m) releases F and ROT. The path from ground through VON:3-4m, A:2-1b, F:7-6b, E:1-2b, VON:2-1M, and the winding of RLS to battery operates RLS, and the switch mechanism releases.

When the shaft reaches the home position, both VON:3-4m and VON:2-1m 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 because all contacts D:3-4b, which are all wired in parallel, are open. The alarm circuit 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 is still somehow grounded.

After the problem has been resolved, the alarm circuit briefly opens the battery feed to SJ4 (shelf jack terminal 4) of all line finders (the feed to the holding winding of D) and thus clears all the “frustrated” line finders. The details of this all this are beyond the scope of this article.

An open sleeve of 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 if it comes off-hook, 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.

A.16 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 VON:3-4m, A:2-1b, F:7-6b, E:1-2b, VON:2-1b, and the winding of RLS to battery operates RLS, and the switch mechanism releases.

When the shaft reaches the home position, both VON:3-4m and VON:2-1m open, releasing RLS.

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