

The panel dial telephone switching system

Douglas A. Kerr

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ABSTRACT

In the 1910s, AT&T, the parent of the Bell Telephone System, anxious to reduce the stupendous labor costs of manual telephone switching (especially in large metropolitan areas), and realizing that the most prominent available switching system (the Strowger system) had serious limitations of its use in such areas, undertook the development from the ground up of a switching system based on many entirely new concepts.

This system, the *panel dial* switching system, came to be the mainstay of the Bell System's program of mechanizing telephone service in many of the largest cities in the U.S. In this article, we will learn of the evolution of this system, of the unique mechanisms around which it revolves, and of the implications of its basic operational principle, known as *common control*. Considerable detail in system operation is given, although not usually at the circuit level, except where necessary to illustrate an important concept.

1 HISTORICAL CONTEXT

1.1 The telephone industry in 1910

By 1910, the telephone industry in the United States was well on the way to its "classical" structure, which existed until about 1984. The Bell Telephone System, owned by American Telephone and Telegraph Company (AT&T), was becoming the major force in the industry, and provided local telephone service in most of the nation's largest cities (often after acquiring existing locally-owned telephone companies, sometime several competing ones in the same city, whose operations had to be harmonized and consolidated). In about 1907, AT&T adopted the slogan, "One Policy, One System, Universal Service".

Local telephone service at that time was mostly conducted by manual switching, in which human operators worked at switchboards (mostly of the cord type) to make the wanted connections between a calling subscriber and the desired destination telephone line. It is tempting to think of this system as "primitive", but it was far from that. The switchboards themselves, and the infrastructure within they operated, were very complex and represented a massive body of sophisticated design. This was supported by a very well worked out set of operating procedures and protocols.

1.2 The emergence of the Strowger system

But this scheme was nevertheless “manual”, and the labor costs of running it were stupendous. Not surprisingly, the matter of mechanization of telephone switching, so that a calling subscriber could somehow set up the wanted connection without human intervention, was a fertile field for inventors. Literally thousands of patents were issued for systems and for their various ingredients.

Of all the systems that were designed, many of which were actually implemented on a “spotty” basis, one eventually stood out as most widely used. This was the “Strowger” system, named after the Kansas City undertaker-turned-inventor who had originally invented the unique “two motion stepping switch” around which that system revolved.

This system was originally manufactured by a firm Strowger founded, which eventually morphed into the Automatic Electric Company of Chicago. It became, largely through its manufacture of the Strowger switching system, the second largest manufacturer of telephone equipment in the United States, after only Western Electric Company, the Bell System’s “in house” manufacturing and supply company.

1.3 What about the Bell System?

Many “progressive” telephone companies, outside the Bell System, adopted the Strowger system. Automatic Electric, of course, saw the Bell System as a potential giant market for the Strowger system, but their efforts to sell the system there were largely rebuffed.

AT&T was certainly eager to mechanize its local telephone service operations. But its eye was primarily on the systems in large metropolitan areas, where the potential cost saving was gigantic.

But AT&T’s Development and Research arm (later to become part of Bell Telephone Laboratories) had studied intensely the matter of telephone switching, and had concluded that the Strowger system (as it existed at the time) did not have the capabilities needed for optimal switching network performance in the context of a large metropolitan area.

Beyond that, the manufacture of the Strowger system involved, at its heart, one especially labor-intensive operation, about which I will speak further shortly.

1.4 The panel dial system

So AT&T decided to undertake the development of a wholly new switching system, which exploited a completely different new strategy of, operation, and used a startling new style of electromechanical

switch, whose manufacture averted entirely that very labor-intensive operation inherent in the Strowger system. This type of switch had its contact terminals embedded in large flat panels, from which the system got its name, the *panel dial system*.¹ It was a gigantic development effort at every level, but the result was a wondrous thing. The American Institute of Electrical Engineers (AIEE, one of the forerunners of today's IEEE) declared it to be (and I must paraphrase here) "the most complex system ever devised by man."

The initial "service" operation of the new system was made in 1904 in Newark, N.J. But this was not a fully "mechanized" system, rather, a calling subscriber, wanting to place a call, would lift the receiver and reach an operator, just as always in a manual switching system. The caller would give the wanted number to the operator, and if the call was to a number served by the new system, she would "key" the number into the system, causing it to complete the connection.

By doing this, the operation of the system mechanisms (which were entirely new and quite "radical" in their nature) could be proven in actual service, without having to go through the process of equipping all subscribers served by the trial central office with new telephone sets with dials. And there was still concern as to whether the average subscriber would "put up with" such a thing.

This approach also avoided the need to install various parts of the supporting infrastructure that would be needed in a "fully mechanized" installation. Thus the number of things that had to be simultaneously proven was slightly limited. But it was in any case a daunting project. It was however very successful.

The next "service" installation, on a fully mechanized basis (*e.g.*, dialing by the subscribers), was in Omaha, Nebraska. That city was large enough to provide a good test bed for the new system, but not so "frantic" as the cities that AT&T were actually most eager to mechanize, such as New York and Chicago. A similar installation was made in Seattle, Wash. And through these the system (in its form at the time) was "polished up".

Then came deployments in New York, Chicago, Boston, and Philadelphia, and then in other large metropolitan areas, to include Cleveland, the town in which I grew up.

¹ But in the vernacular, it was usually just called the "panel" system: "What kind of switching is in the Lakewood central office?". "Panel." And I will usually use that short form hereafter.

The last installation of a panel dial central office was for the Hyacinth 9 office in New York City in 1950. The last panel office operating in actual service, in Newark, New Jersey (how fitting), was decommissioned in 1983.

1.5 Closing out the story

Once the Bell System was well on the way toward mechanizing its large city systems, with the panel dial system, it turned its attention to the cities in the next tier of size. The panel system was "overkill" there.

So, in order to move on that, they began to buy Strowger systems from Automatic Electric (applying many of their own requirements and specifications²). Seeing that this was working out well, their next step was to arrange for a license from Automatic Electric under which they could manufacture Strowger systems themselves (that is, by Western Electric Company).

By the way, even when the equipment was purchased from Automatic Electric, the Bell System spoke of the system as the "step by step" system (often abbreviated as "SXS") rather than the "Strowger" system. And from here on, I will often refer to it as such.

2 SOME TECHNICAL BACKGROUND

2.1 Local battery and common battery operation

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

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

² Including the introduction of frames 11'-6" high, rather than the shorter frames then commonly used by the Strowger system. (The buildings would have 15' ceilings.) This made better use of the available building "cubic footage" and reduced the total length of inter-frame cabling.

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

2.2 Line and loop

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

Transmission of speech signals³ was on a balanced basis: identical AC signals (as would be measured with respect to ground), but with opposite polarity, appeared on the two conductors. Seen from conductor to conductor, the two signals added, and it was this net signal to which the telephone set responded.

When a DC voltage is applied to the line at the central office (as in *common battery* operation), in order to energize the transmitter (“microphone”) at the station, and to allow the central office to determine whether the station is “off hook” or not (see sections 2.1 and 2.5), the current flow is out one conductor and back through the other.

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

2.3 Tip, ring, and sleeve

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

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

Inside a switching system, the tip and ring leads are often accompanied by a third lead, called (by virtue of the same tradition) the *sleeve* conductor. It plays various control roles in the operation of the switching system.

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

³ Other than in the telephone system context we would probably say “audio” signals, but that term is not typically used in “traditional” telephone system discussions.

2.4 Battery

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

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

Most "mechanized" central office equipment operates from a nominal voltage of 48 V. For an esoteric but very important reason, this voltage is usually negative with respect to ground (-48 V).

2.5 Off hook and on hook

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

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

So, even today, the contact set operated in a modern telephone set when the handset is placed in the cradle is called the hookswitch⁴. And the state of the telephone set is spoken of as being *off hook* (when it is active) vs. *on hook* (when it is idle).

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

⁴ Curiously enough, the modern term is often "switchhook". I guess this is like the hair style feature made famous by General Burnside becoming called "sideburns".

2.6 Multi-party lines

In a multi-party line (often called by civilians a “party line”), two or more subscriber stations are connected to the central office over a single pair of conductors, a “cost sharing” measure. This is a gigantic topic overall, with many different schemes being used.

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

We may say that a panel switching system, fully “fleshed out”, can handle “up to 10,000 lines”, but what we really mean is “up to 10,000 numbers”.

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

2.7 Talking battery

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

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

2.8 The dial

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

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

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

3 SWITCHING APPROACHES

The step by step switching system (in its most commonly used form) is classified as a *direct progressive control* system.

Direct means that each switch is moved (in stepping switch fashion) directly by the individual pulses in a dialed digit or digits, each pulse moving the switch one "step".

Progressive means that the successive stages of the overall switching network⁵ are moved by successive digits of the dialed number, so the connection itself progresses "digit by digit".

This approach is contrasted with a *common control* switching system approach (as used in the panel system). In such a system, typically, the calling subscriber dials the entire wanted number into an equipment unit (a member of a pool of such, working on this "connection" just for as long as needed for it to complete its work). That unit, perhaps in concert with a "higher level" equipment unit, then some way sets the switches of the actual switching network to make the indicated connection.

4 THE PANEL SELECTOR

4.1 Terminology

In the step by step system, *selector* refers to a specific one of three distinct type of switches used in the switching network itself, the other two being the *line finder* and the *connector*. They all use essentially the same mechanism, but differ greatly in their roles in the network, in their circuitry, and in their operation.

In the panel dial system, *selector* is used to refer to all the switches used in the switching network proper (there again being various different types). The different types are distinguished by names such as "district selector", "office selector", and the like.

4.2 Construction concepts

In the step by step, system, the switching network is made of "two motion stepping switches". These can go to any of 100 positions by first stepping vertically to one of 10 "levels" of contacts and then by stepping in a rotary direction over the 10 sets of contacts in that level. The contacts are thus arrayed in a curved structure called a (*contact*) *bank*.

⁵ *Network* here is used in the sense of the structure in a switching system through which calls flow from one line to another across the system, and not in the sense of a number of interconnected switching systems..

Consider the type of switch used in the last stage of the network, the *connector*. Thus extends the connection to the actual called line, a given connector being able to reach any of 100 lines. But, for example, with regard to the lines whose numbers are 2300 through 2399, there will need to be more than one connector, as there of course might be the need to have, at any given time, more than one connection to a line in that range. There might well be as many as 20 connectors in the group that can access those lines. Each has a contact bank with 100 sets of contacts, three to each set (for the tip, ring, and sleeve leads of the line), a total of 300 connections to a single switch's bank.

Those contacts need to be connected in parallel over all 20 connectors in the shelf, a total of 6000 connections (made for many years by hand soldering) for just this one group at one stage of the network.⁶

This was a major source of labor cost in the manufacture of a Strowger system, and the switch design adopted for what became the panel dial system aimed to exterminate this almost entirely.

4.3 The basic concept

In the step by step system, the basic switch mechanism is a "two motion" switch. The contact "wiper" moves first vertically and then in a rotary direction to be able to reach any of 100 "terminals".

The panel dial selectors are "single motion": the contact wipers move, vertically only, over (typically) an array of 100 "terminals" arranged in a vertical column.

But the collection of 100 terminals over which the wiper set of one selector will run is not a separate module (like a step-by-step switch bank). Rather, the selector *bank* is a unitary assembly with 30 such columns of terminals on each face. The contact brushes of up to 60 separate selectors can run over the respective columns.

In figure 1, we see the construction of this bank, the "panel" from which the system takes its name. In the most widely used version, the bank is about 39 in. wide and 15 in. high.

At each terminal position in one selector's "column" there are three (in some cases four) individual contacts, positioned generally side-by-side but staggered vertically.

⁶ For historical reasons, this connecting of several collections of terminals in parallel is said to create a *multiple*. In the example, the whole thing (connector bank terminals and the paralleling wiring) is called the *connector multiple*.

At each terminal "level", all the *tip* contacts are tabs emerging from a single strip of brass running across the entire bank. All the *ring* contacts for that level are tabs on a second strip of brass, and all the *sleeve* contacts are tabs on a third strip of brass. All these brass strips are separated by thin strips of phenolic insulating material. On most selectors, the vertical spacing from one terminal to the next is 1/8". On line finder banks, with four contacts per terminal, the spacing is 1/6".

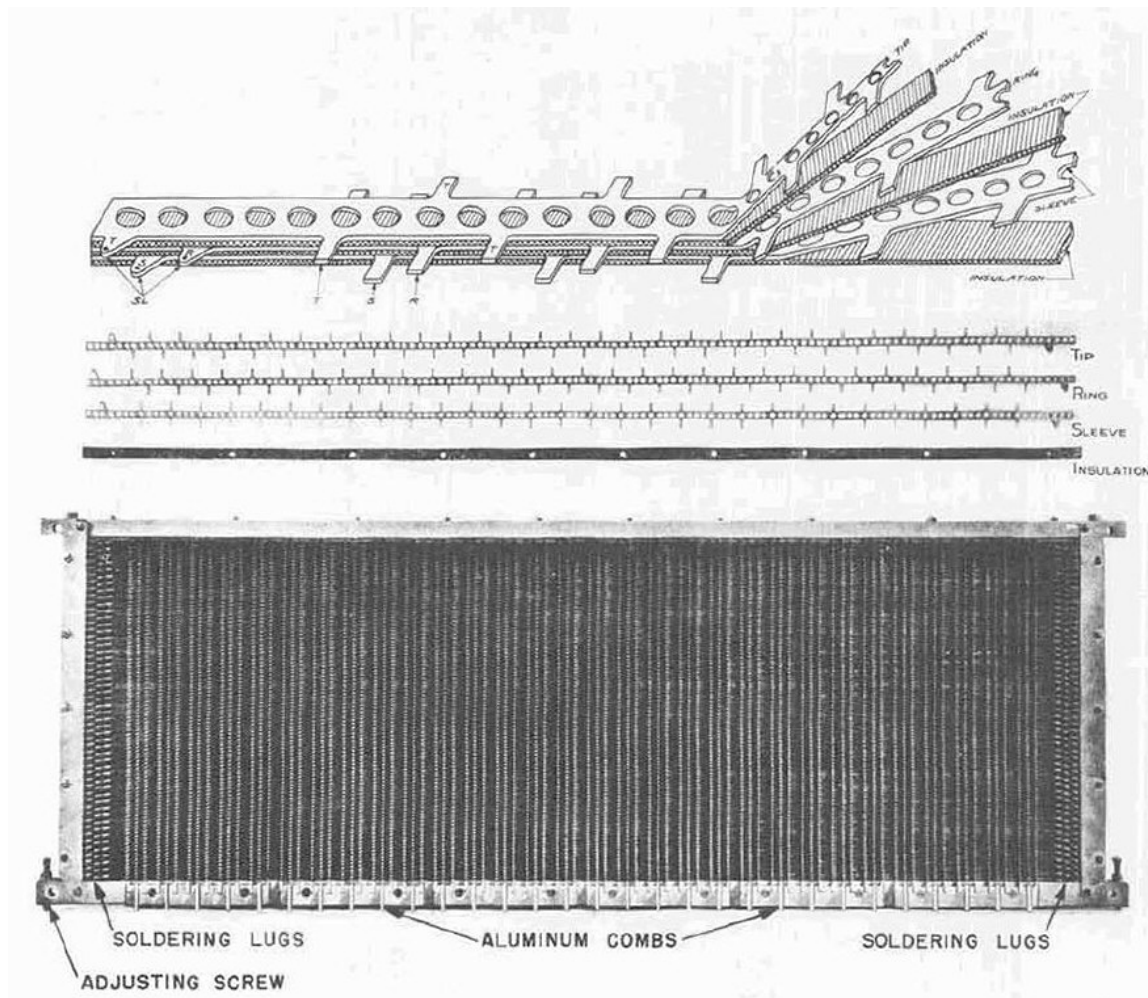


Figure 1. Typical panel bank

Thus, the collection of 100 sets of contacts for these up to 60 selectors are all inherently connected in parallel, as we normally need in the system, without the onerous running of 300 wires from bank to bank, as we have in the step by step system.

I note at this point that what I have spoken of earlier as contact "wipers" are actually called "brushes", and it is a *brush assembly* that runs over a selector's set of 100 terminals on each bank.

The brush assembly is mounted on a tubular *selector rod* (sometimes called an *elevator rod*). The aluminum "combs" seen on the figure

provide a guide for each rod to keep it aligned with its selector's column of 100 terminals on the bank.

At the top of the bank are two sets of all three (or four) types of contact strips, one on top of the other without any intervening insulation. The contact tabs on these serve as fat dummy terminals to guide the brushes if, because of some system malfunction, the selector rod should rise to put the brush assembly above the last level of actual contacts. (A mechanical stop prevents motion beyond that.)

In an actual typical selector frame, there are in fact five banks, each just as I have described, mounted one above the other, each with 100 "levels" of terminals. And each selector rod has on it five brush assemblies (sets of contact "wipers"), one running over each of these banks. Thus each selector can access any of 500 terminals.

Of course, we must "connect" into the circuit only one of those sets of brushes, the one for that bank in which the desired terminal exists.

Rather than doing this with, for example, a set of five relays, a more "mechanical" solution is used. In each brush assembly there is a cam operated by a lever that, in the normal position of the lever, holds the three (sometimes four) contact brush springs "spread" so that they will not actually touch any of the bank contacts. At the beginning of the upward motion of the selector rod, we "trip" the lever on only the brush assembly we want active. Thus the four other brushes just "go along for the ride". How the chosen brush assembly is tripped we will see in a little bit.

4.4 The commutator

One need here is for an electrical path from the contact brushes on the movable selector rod back to *terra firma*. This is done by a component called the *commutator*, which is mounted on the frame at the top just above (almost) each selector rod. We see an example in figure 2.

We can think of one aspect of this as being like a set of "slip rings", except of course they are straight. Each lead from the brush assemblies on a selector rod (all five assemblies in parallel) goes to a contact brush on a *commutator brush assembly* mounted at almost the very top of the selector rod. (Recall that the selector rod is in fact a tube, so those leads travel inside it, coming out at each brush assembly to connect to its brushes, and finally coming out its top and connecting to the commutator brushes.)

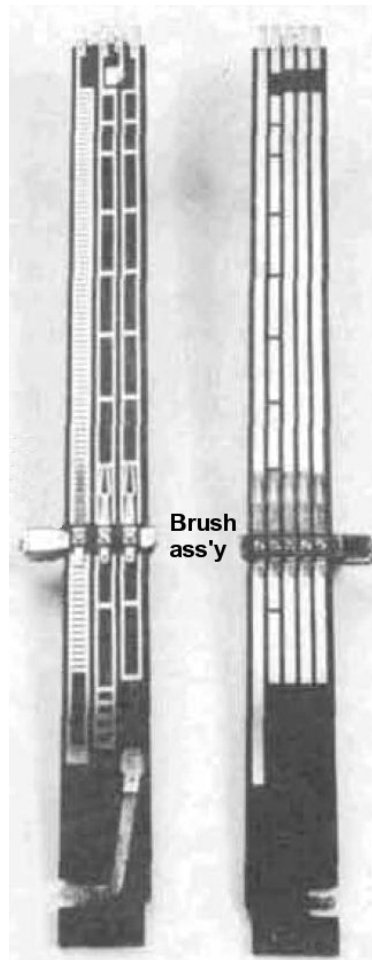


Figure 2. Commutator and commutator brush assembly

These brushes ride on conducting tracks in the commutator that run essentially the entire length of travel of the brush assembly. These carry the brush leads electrically to the selector circuit on "*terra firma*".

In the figure, the brush assembly is shown where it would be with the selector rod about 20% of its way "to the top".

But the commutator performs another kind of function. In addition to the tracks carrying the brush leads, there are other conductive tracks on the commutator that have various conducting patterns on them. Brushes on the commutator brush assembly, not connected to anything moving but just to each other, ride on these tracks.

The result is that electrical conductivity is provided between these tracks or not depending on the position of the selector rod and the patterns of the tracks. The roles these play in system operation will be discussed later. Yes, this is a "position encoder".

4.5 Driving the selector rods

In the step by step system, the switch wipers are moved by two stepping mechanisms. In either, an electromagnet is repeatedly energized and de-energized. On each stroke, a pawl moved by the magnet armature operates on a ratchet wheel or equivalent, moving it one "notch" for each stroke.

But in the panel dial system, the selector rods are driven smoothly up (and down!) by a motor drive. The principle is seen in figure 3.

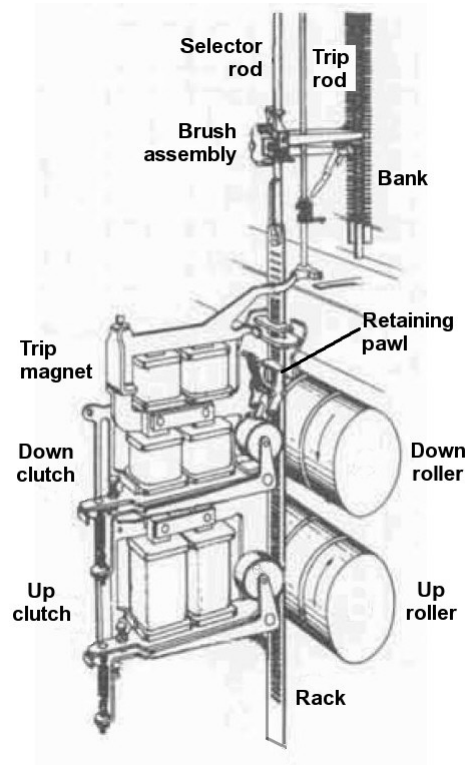


Figure 3. Selector drive system

The centerpiece of this system is a set of two metal rollers, with cork surfaces, extending across the full width of one face of the bank (another set on the opposite face), continuously driven (in opposite directions) by a small motor at the end of the frame. (The motor is quite extraordinary, but we will look into that later.) In most cases, the roller speed is about 64 RPM.

Each selector rod has at its bottom a flat strip of a spring brass alloy, called a *rack*. The normal position of the rack gives it a slight clearance from the two rollers. When the selector circuit wants the selector rod to move up, it operates the *up clutch magnet*, whose armature moves a small roller (not labeled—we might think of it as a "pinch roller"), which pushes the rack against the *up roller*. The friction with the moving surface of the roller pushes the rack up and it pushes the selector rod (the rack is stiff enough that it does not

“buckle” in the process). The rack has a slot through it corresponding to each position in which we might want the rod to stop (including, but not limited to, the 100 positions in which we might want the selector to end up).

There is a *retaining pawl* just above the up clutch mechanism. It engages these notches as the rack moves up. When the circuit realizes that the rod is at the desired position (how we will see shortly), the up clutch is released, and the rod slips back just a little (by gravity) until the pawl holds it in the exact position desired.

At the end of the connection, when the selector is to be restored to its home position, the selector circuit energizes the down clutch magnet, whose armature moves another roller, which presses the rack against the down roller. The armature also pulls the retaining pawl out of engagement with the rack.

The friction between the down roller and the rack does not in fact “pull the rack and rod down” (which would probably happen fine by gravity, albeit too abruptly) but in effect “lets it down”. When the rod is back in its home position, the down clutch magnet is released. How does the circuit know when the rod is in its home position? That’s one of the things it finds out from the track patterns on the commutator.

On the final frame (which makes the ultimate connection to the called line) there is a third drive roller, which advances the rod up at a slower speed than the regular drive roller (about 1/4 the “regular” speed). (We will see the need for this later). On that kind of clutch assembly, there is an additional electromagnet, with an associated “pinch roller”, for engaging the *slow up drive*.

4.6 Tripping the desired brush assembly

We heard before that at some point before the brushes actually get onto the live part of the bank we will “trip” one and only one brush assembly so its brushes will actually ride on the corresponding bank. Figure 4 shows part of how that is done.

In the figure we see a brush assembly from its right; the bank is to our right.

Recall that (in the type of selector we have been considering) there are five brush assemblies, one for each bank. Behind the selector rod (that is, between it and the bank) is a second rod, this one solid and not moving vertically. On it are five *trip finger assemblies*. With the selector rod “home”, these are all slightly above the respective brush assemblies, but by staggered amounts. That is, the one for brush 1 is 0.25” farther above its brush assembly than the one for brush 0, the one for brush 2 is 0.25” farther up yet, and so forth.

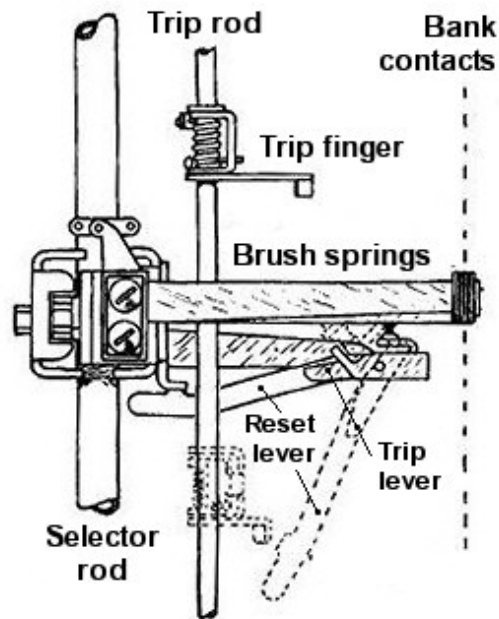


Figure 4. Brush trip mechanism

The idle rotational position of the trip rod is such that all the trip fingers are to the left of where they would strike the trip levers of the various brush assemblies. We can see that in figure 5, a top view of a brush holder, also showing a trip finger. The actual brush contact tips are to our right.

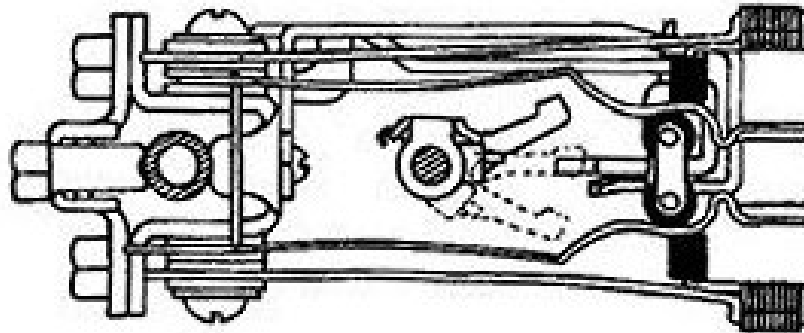


Figure 5. Brush assembly from the top showing trip finger

We see here the two insulating rollers on the trip lever that hold the brush sprigs apart (and away from the bank terminals) unless the trip lever is tripped. We see that the shape of the inner springs (then ones that are directly operated by the rollers), formed to provide a detent that holds the trip lever in its normal (up) position until it is pulled down by a trip finger.

The trip finger shown in solid lines shows the idle positions of all the trip fingers.

Suppose we are looking at brush 2, and that is the one we want to trip. We move the selector rod up to the place where trip finger 2 is adjacent to the trip lever on this brush assembly, and let the rod pause there for a moment.

Then, the trip magnet for the selector is operated. This rotates our selector's trip rod, swinging all the trip fingers clockwise so that they are now in the position shown by the lower dotted lines—except for the finger for "our" brush assembly. There, a tab on this trip finger strikes "our" trip lever, preventing any further rotation of this trip finger.

But each trip finger is connected to the trip rod by way of a small "carrier", with a spring to the trip finger. Thus the trip rod can make its full stroke, despite the fact that this one trip finger is prevented from going the whole way. For it, the spring just yields.

The "middle" dotted image shows the trip finger as it has engaged the trip lever on "our" brush assembly.

Now, the selector rod is sent up on its journey to the desired terminal. As it resumes its motion, for our brush assembly, the trip finger being engaged with the trip lever, it holds the trip lever in place (vertically), so as the brush assembly rises, the trip lever is shifted to the position we see dotted in the figure. This allows an insulating roller cam arrangement on the trip lever to let the brush fingers on this brush assembly drop toward each other, so they can ride on the bank contacts.

After the selector rod gets where it is going, the trip magnet is released so all the trip fingers go back to their "idle" positions.

When the selector rod is brought down at the end of the connection, the *reset lever* of the tripped brush assembly (actually a second "finger" of the trip lever) strikes a fixed horizontal rod that runs across the width of the bank, which resets the lever to its untripped position.

The brush contact tips themselves need to be narrow enough that they will not "bridge" contacts on two consecutive terminals as the selector moves, which could cause all sorts of mischief. But then the brush tips would be susceptible to dropping into the space between two consecutive contacts, which would be a disaster.

To avert this, the two outermost brush contact springs are embedded in "shoes" of insulating material. These extend above and below the actual contact-making tips of the contact fingers, thus giving them a larger vertical "footprint". This makes sure that as the selector moves upwards, the contact fingers always remain in mechanical contact with the bank terminals, having no chance to "drop between them",

while still not allowing any possibility that a contact tip could bridge two consecutive contacts.

In the earliest designs, these shoes were provided on all four contact fingers. It was later found tight using shoes on the outermost (tip and ring) contact fingers would suffice.

We see these shoes (from above) on figure 5.

I wrap this section up with a photo of some real brush assemblies, in place, in Figure 6.



Figure 6. Selector brush assemblies

These brush assemblies are of different vintages. An important distinction is between the older, grayish, corrosion resistant treatment (a "dull" form of galvanizing) and the newer, iridescent, "dichromate" corrosion resistant treatment. We also note the different type of insulation on the leads in the newer vs. older assemblies, so evidently it is the whole selector rod assemblies that have at some time been replaced.

We see just below each brush assembly, mounted to the aluminum "comb" at the bottom of the bank assembly, a metal guide plate for the selector shaft. These only appear on the next-to-bottom bank.

These are split so they can be removed easily when it is required to replace a selector rod (or a guide plate itself!).

As these are evidently not the bottom-most brushes, we can see that there is one set of leads from the brush springs that go up the selector rod tube to the next higher brush assembly and ultimately the commutator brush assembly, and another set of leads running down the tube to be brush assembly below.

We see that the clamp that holds the brush assembly to the selector rod is made so it can be easily removed to replace the brush assembly, which of course had to be done from time to time.

The "X" marking is most likely an indication to allow an "improved" part to be distinguished from an earlier one.

We can here slightly see that the bank's "glistening" appearance. This is from a petroleum jelly-like substance spread on the bank to prevent oxidation of the bank contacts (which are not made of, or even tipped with, any "precious metal", but are just made of brass or bronze). The subtle scent of this is an iconic artifact of a panel dial central office.

4.7 Tripping on a line finder frame

This figure is in fact of a line finder selector frame, where the tripping system is a bit different than I described above. In a line finder frame, as we will realize later, only one selector rod will be moved up at a time.

Here, there is not a trip rod behind each selector rod, with a finger at each bank. Rather, a horizontal trip rod runs across the width of each bank, at its bottom (and in a line finder frame there are 10 banks, and thus 10 wiper assemblies on each rod). It has a "window-shaped" trigger at the position of each selector rod. To trip the "bank 2" brush assembly on a selector about to be sent up, the bank 2 trip rod is rotated by a magnet. All 30 of its triggers engage the bank 2 trip levers of all selectors in the home position. But only selector rod will be sent up now, and so only its bank 2 brush assembly is tripped.

In this way, for 30 selectors, there are not needed 30 trip magnets but only 10.

5 THE SEQUENCE SWITCH

In any switching system, the various switching stages pass through a number of states as their work is accomplished. In a system such as step by step, the different states of a certain switch are "created" by the states of a number of relays, often operating in concert with contact mechanisms operated, for example, when the switch mechanism is no longer in its "home" position.

There are many circuit paths that differ from state to state, and these are created by complicated interconnection of contacts on the various relays. As a result, many of the relays must have quite a few contacts, which of course adds to their cost and the overall effort to keep them in proper adjustment over their lifetime.

In the panel system this situation would have become even more extreme, owing to the sophisticated ways in which the selectors function. So as to provide for a more cost-effective implementation, the different states of each selector are handled by a *sequence switch*. This switch can rotate to any of 18 positions, the rotation done by a clutch mechanism working from a continuously-rotating shaft driven by the same motor that drives the selector drive rollers.

Figure 7 shows the general construction of a sequence switch.

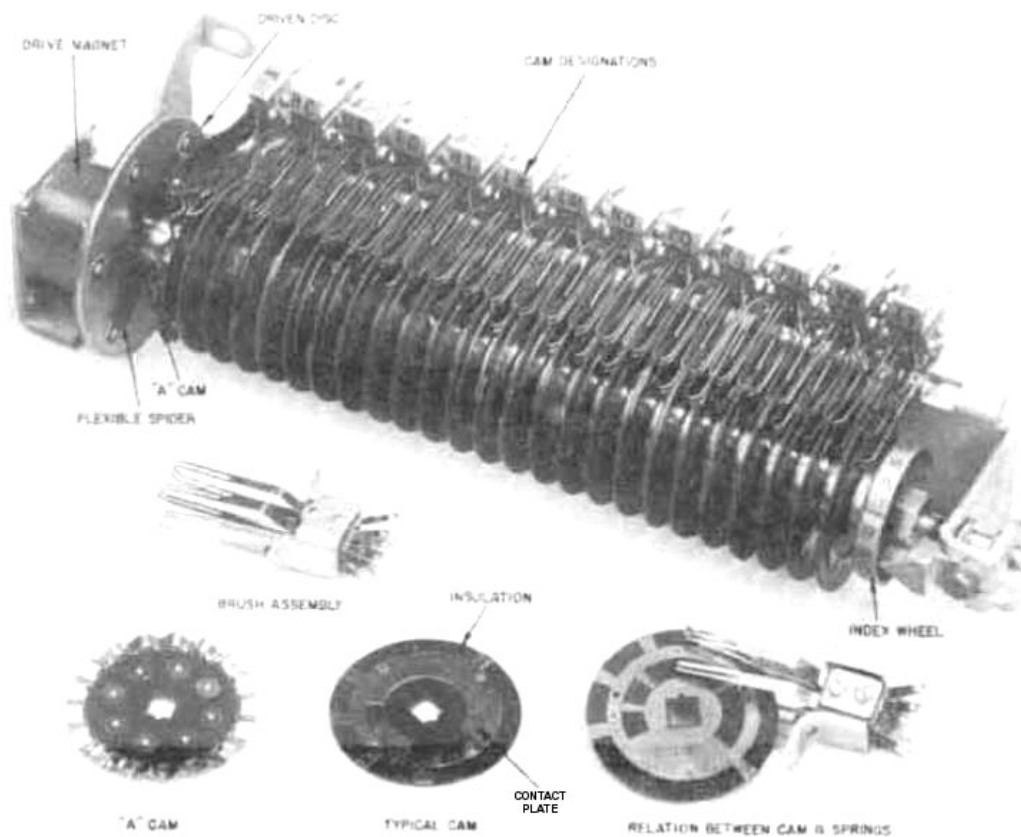


Figure 7. Sequence switch

It consists of a shaft on which are mounted up to 25 contact-making disks, called (inappropriately) "cams" (and this example has that many). The shaft is square, so as to provide a positive orientation for the cams, and one face has a rib that engages a mating notch on the cam to assure that it is assembled in the proper orientation.

A steel collar is placed between each pair of cams to provide for their proper spacing along the shaft, and the whole stack is clamped tightly by a hex nut at the right end of the shaft. Actually, the last item at

the right end of the stack is an aluminum drum (the *index wheel*) carrying the numbers 1-18, which (in connection with a fixed pointer) allows the current position of the switch to be easily determined.

On each face of each of the cams is an insulating disk on top of which is a phosphor bronze contact plate, which has various patterns cut into it to provide the proper circuit connections at each switch position.

For each cam there is a brush assembly, which carries four finger-like brushes (sometimes spoken of as *contact springs*), two of which ride on each side of the cam. The contact disks make connections among these brushes. In reality, the brush assembly carries those four brushes for two adjacent cams.

In almost every case, the contact plates on the two faces of the cam are interconnected (by way of rivets running through the cam assembly), in effect provide a "commutator" with four, rather than two, tracks (running under four brushes, two on each face).

In some cases it is desirable to connect together the contact plates on two adjacent cams. In this case, the contact plates extend inward to almost touch the shaft, and the inter-cam spacing collars make an electrical connection between the adjacent plates. (The collars do not touch the shaft, which is grounded, but rather have a clearance hole in the center to avert such contact.) When this is not desired, there is a clearance hole at the center of the plates so they will not touch the collar.

The cams are ordinarily designated by letters (usually consecutive, "A" through up to "Y"), and the brush assembly for each pair of cams has a little "flag" on which those letters can be marked.

The first cam (the "A" cam) is rather different from the others. Its base disk has a wavy exterior, and a spring-loaded roller runs against that wavy edge to provide a detent so that the switch, when its drive clutch is not engaged, will remain stably in one of the 18 legitimate positions. But so as not to waste the space this cam takes up, it in fact has an insulated contact plate on its leftmost face (which of course is why we speak of it as a "cam" and not as the "detent disk" or such!).

The A cam contacts are usually used in connection with the control of the drive clutch (about which more shortly). When the control circuit wants the switch to stop rotating, it de-energizes the drive magnet, but the switch might not yet be in exactly that position. But the pattern on the A cam keeps the clutch magnet energized until the switch is in an "real" position. Thus the electrical aspect of the A cam is sort of an electrical detent, collaborating with the mechanical detent

(also on the A cam) to assure that the switch, *restant*, is always at a "real" position.

Now for the drive clutch itself. Figure 8 shows several sequence switches *in situ*.

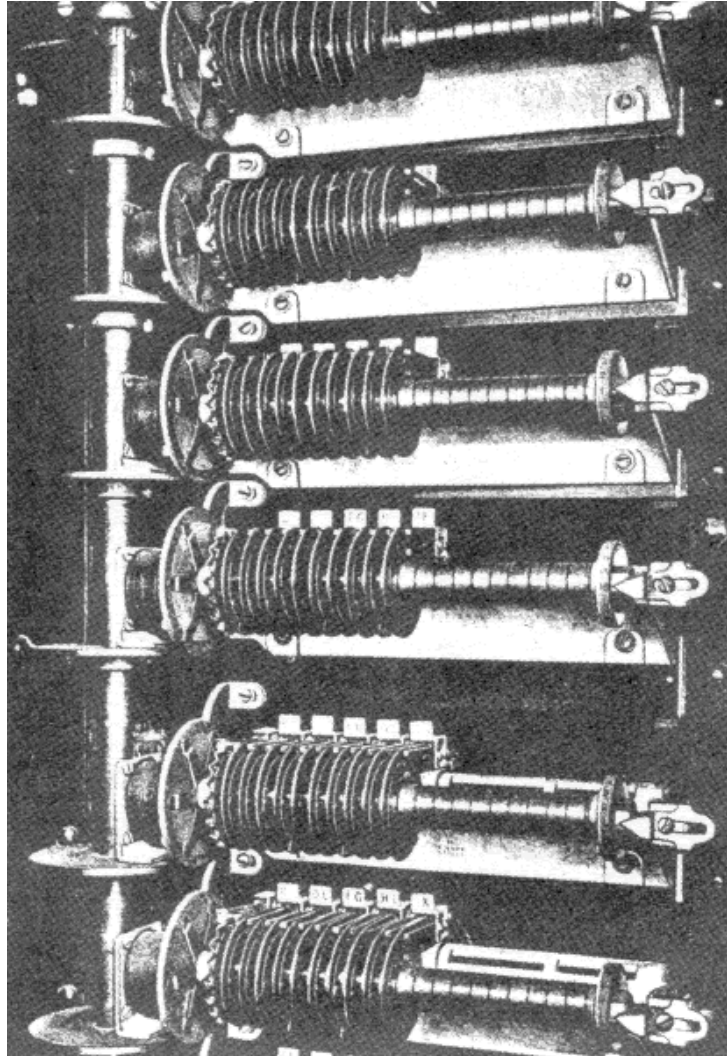


Figure 8. Sequence switches in place

First, we note that these switches have only 10 cams, far less than the maximum, but typical of the switches used on certain kinds of selectors. The remaining space on the shaft is taken up by dummy collars, thick enough to take up the space of a real cam plus the adjacent collar. They fit snugly on the shaft, there being no "non-contact" issue for them.

We see at the left end of the shaft the clutch disk, made of steel. It is mounted to the shaft by way of a spring bronze "spider" so that it can deflect slightly in the axial direction while still being coupled rotationally to the shaft.

Just to the left of the clutch disk we see a large magnet coil.

To the left of the switches we see a vertical shaft, which rotates continuously driven by the same motor that drives the selector drive rollers. At each switch position there is a steel drive disk. Under normal conditions, there is a small clearance between the clutch disk and the associated drive disk. But when the magnet coil is energized, the clutch disk is pulsed to the left, and the outermost portion of its face contacts the rim of the drive disk, so the switch shaft begins to rotate.

Typically, each time the switch is to advance (not necessarily to the next position), one of the cam contact patterns will be in the path to the clutch magnet, so that when the switch reaches that target position the circuit is broken, the clutch relaxes, and the switch stops (the dual detent action of the "A" cam making sure it settles into exactly that position).

Typically there is one sequence switch for each selector circuit.

In figure 9, we finally see an equipment frame, this one a typical district frame.

Recall that the normal arrangement is for there to be selectors operating on both faces of the banks, and so everything we see here is mirrored on the other side of the frame.

The selector portion proper is in the center. We see the banks (5 altogether), in this case equipped with the maximum possible number of selectors, 30 (on this side).

Notwithstanding the role of the sequence switches, there are still quite a number of relays in each selector's circuit. We see these on the right (those for each selector on one mounting strip, covered by a sheet metal cover).

These relay strips are in six groups of five, for the 30 selectors. Between each group is a strip that carries, for the five circuits, below, a couple of large components for each.

Just to the left of the relay plates are the 30 sequence switches, more or less aligned with the respective circuit strip (except for the disruption caused by the strip of components interposed between each five circuits. Thus the wiring from the sequence switch to the relays of the selector circuit (many leads) is fairly direct in each case. (We can in fact see this, for the "other side", just to the left of the set of banks (the back of the sequence switches and circuit relay plates on that side).

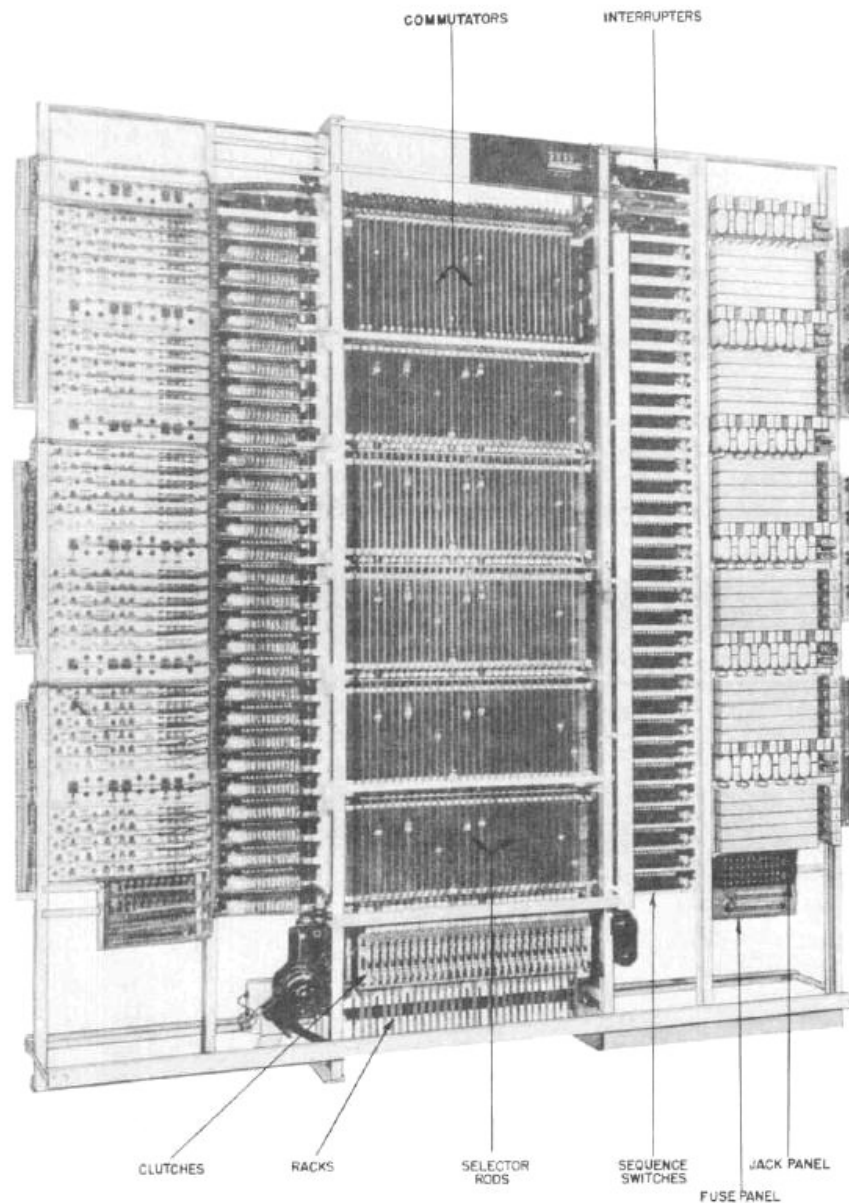


Figure 9. Typical district selector frame

Above the topmost sequence switch are a couple of *interrupters*. These are sets of contacts, operated by cams (or, more often, a crank, but still called a "cam") continuously driven from the vertical shaft that mainly drives the sequence switches, through individual small gearboxes to get the right operating periods. These generate trains of timing pulses (or contact closures) used for various purposes by the selector frame. For example, these might be used in recognizing when a selector has failed to complete some action in the expected time, without having to have an actual "timer" in each selector circuit.

Figure 10 shows a typical interrupter.

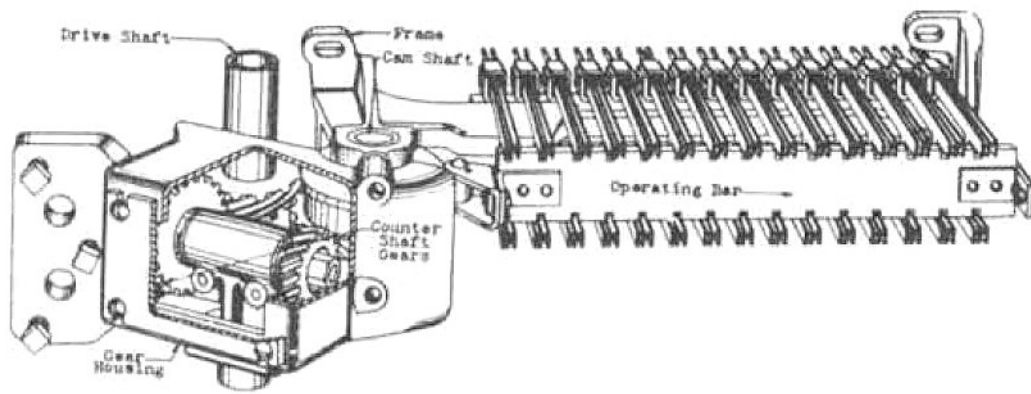


Figure 10. Typical interrupter

6 THE "STEPPING" ROTARY SELECTOR

A component that was widely used in at least three places in the earlier vintages of the panel system is the "stepping" rotary selector. Figure 11 shows one of these little beauties.

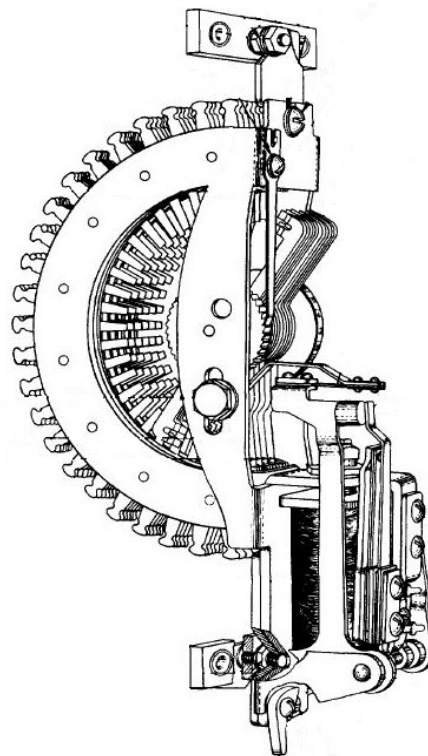


Figure 11. Rotary selector

Outside of the Bell System, this type of switch are often called *uniselectors*,⁷ They are *single-motion* stepping switches (that leading

⁷ Inside the Bell System, this type of switch is called a "200-type selector", the reason being that the original family of them all had apparatus codes ("model numbers") that started with 200 (such as 200AF). Ironically, at one point there was a significant mechanical design change to the basic mechanism of the family. The

to that name). That is, each time their electromagnet operates (and released; in the type 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. There is no motion in a second direction.

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. (In some switches there is a "home" position in which neither wiper arm is in contact with a terminal.)

These switches may be operated by operating the magnet the proper number of times to get to the desired position. However, by having the controlling circuit put in series with the magnet a normally closed contact operated by the magnet armature, the magnet will operate and release continuously (as fast as it can). Thus the switch may be made to autonomously "scan" over its terminals, perhaps some relay being operated when the "right one" is found. Among other things, this scheme can be used to return the switch to an arbitrary starting position when its work for one call or such is done.

We will hear later of the three major roles played by selectors of this kind in early panel systems.

7 THE "POWER" ROTARY SELECTOR

Also in the earlier vintages of the panel system we have what are often called "power" rotary selectors. Figure 12 shows a typical example (it is in fact a 1203-type selector).

You can see that it is many ways similar to the "stepping" rotary selector. In fact, the most common version has 22 positions, just like the stepping rotary selector ("200 type"). This type, however, has two banks, so that there are 12 sets of contacts (and 12 brushes).

But an alternate configuration uses brush assemblies with only single ended arms, with the arms staggered by 180° . So these have 44 positions, with 6 circuits.

new-design selectors all had apparatus codes starting with "206". Still, if asked about a circuit using one of the newer selectors, it would be commonly said, "Oh, it does that with a 200-type selector."

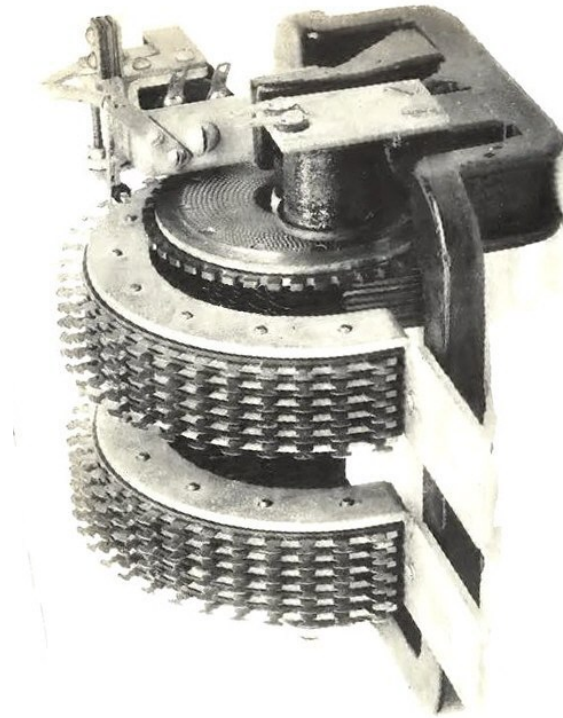


Figure 12. 1203-type "power" rotary selector

The 1203-type selector (as I will call it from here on) is driven from a continuously-turning shaft via a clutch system, very much like the way the sequence switch is driven. As on the sequence switch, there is a clutch disk, connected to the hub of the switch shaft by a spring spider, allowing the disk to be displaced axially while retaining its rotational connection to the shaft.

The switches are mounted adjacent to the continuously-rotating drive shaft, which has a drive disk at the position of each switch.

The photo is not ideal for understanding the orientation of the switch. The flat metal mounting bars we see would be downward in the switch's actual orientation; the switch axis is horizontal. The vertical driving shaft runs just beside the terminals of the small magnet we see. The drive disk in part falls into the "notch" in the switch frame we see on our side of that magnet.

In fact, the magnet I referred to just above is the "clutch" magnet. When it is energized, it pulls the clutch disk (up as it seem to us in the figure) into contact with the drive disk. In drawings and such it is called the *rotary magnet*.

A second magnet (seen on the far side), the *stop magnet*, when energized, moves a stop finger into a serrated disk with a tooth for every switch position (we see it in the figure).

To move the switch to a desired position (always marked in terms of some electrical condition on some terminal), the rotary magnet is energized and the switch shaft begins to rotate. When the marked position is attained (and some relay operates from the "marked" bank terminal, the stop magnet is energized and the rotary magnet is de-energized. The switch shaft stops rotating, "smartly", and at an exact position, owing to the operation of the stop finger.

We will hear later about some of the few uses of this kind of selector in the panel system, all, as I said, in earlier vintages.

8 THE MOTOR DRIVE SYSTEM

8.1 Introduction

The motor drive system is of course pivotal to panel system operation, and it has many unique features to attain reliable operation.

8.2 Split motor drive

In the cases of typical selector frames, the motor mounted on one frame drives only the drive rollers on one face, but also drives the rollers on that face of the adjacent frame (most often with the same type of selectors). In return, the motor in that second frame drives the other face of that frame, and as well the "other" face of the first frame.

Thus, if a motor should die (and this is detected by timing circuits running from a contact on one of the interrupters driven by the motor), a relay makes all the selectors on the disabled face of the frame appear to be busy, so they will not be chosen by a selector in the earlier stage. But all the selectors on the opposite face will still operate properly (thanks to the motor on the adjacent frame). Thus the loss of a motor causes a serious decline in capacity in one branch of the switching network, but not its complete disablement.

The motor rotation is carried from the motor's own frame to the adjacent frame with a shaft connected at both ends with simple limited-angle universal joints, so as to accommodate imperfect alignment of the two frames.

The motors are arranged so that they may be readily exchanged in case of trouble or for routine maintenance. The motor slides in place in the direction along its axis on a "gibway" type mount. A lever-operated clamp holds it in place. The motor has a plate on its shaft with two pins that engage holes in a mating disk on the bay's "transmission". But that disk is made of resilient material. The purpose is to avoid the noise—and more importantly, the wear on the mating parts—caused by vibration, given that the engagement is not "tight".

The electrical connections to the motor are made with plugs on cords (more on that later).

8.3 The duplex motor

Adding to system reliability is that the frame motors are of a special type, called a *duplex motor*, which normally runs from the commercial AC supply but, should that supply fail, begins automatically to operate from the central office -48 DC power system, which of course itself under such a situation operates from the storage battery.

The design of the duplex motor is very ingenious. (During the early years of the panel system a slightly different concept was used. I will describe the later one, used for the rest of the life of the system.) There are an AC motor and DC motor in the same housing. The AC motor uses classical induction motor design and construction (with a wrinkle I will discuss shortly). The DC motor is a shunt field type, and is of classical design (except for a wrinkle I will mention next).

When the field windings of the AC motor are energized (that is, while there is in fact AC supply voltage available), the field winding and stator pole pieces also serve as an AC electromagnet, the armature of which lifts the brushes of the DC motor off their commutator and operates a contact that opens the path to the shunt field of the DC motor. Thus the DC motor is completely de-energized.

If the AC supply should fail, this electromagnet armature releases, energizing the DC motor shunt field and dropping the brushes onto the commutator, thus putting the DC motor into operation.

Of course, when the AC power returns, the AC "electromagnet" takes the DC motor completely out of operation, as described at the outset.

The basic principle of operation of an AC induction motor results in the motor having zero torque at zero speed. Thus, a motor built only under that principle cannot "self start". Many schemes are used on actual AC motors so they will "self start". The most widely used ones are in fact a bit cumbersome. They involve an auxiliary capacitor (typically physically large), a separate field winding on the motor's stator, and a centrifugal switch that rearranges the circuit once the motor gets up to nearly running speed.

But the AC part of the duplex motor of the panel system doesn't need any special starting provisions. The reason is that when the AC motor comes into play, the motor is already turning at operating speed, by way of the DC motor.

But what about when the motor is first started (say, after exchanging one motor with another)? The motor unit has two separate cords for

the power to the AC and DC portions. Each has a plug on the end that is plugged into a receptacle (with the corresponding kind of voltage) on a junction box near the motor (the box includes the fuses for the motor). The two plugs are different, so they can't be plugged into the wrong receptacle.

So, having put the new motor physically in place, we first plug in the DC motor cord. The DC motor can of course start by itself. Then when it seems to be running all right, we plug in the cord for the AC motor. As described before, the electromagnet action of the AC motor then disables the DC motor and we are off and running on AC.

There is in fact a clever reminder of the proper procedure for connecting a new motor, The two power receptacles are mounted one above the other on the "junction box", the AC one topmost. There is a teardrop-shaped flap of thick fiber supported at its narrow end on a shoulder screw just above the AC receptacle. In its normal position it actually covers the AC receptacle. This reminds the switchman, connecting a newly-emplaced motor, not to plug into that receptacle first. He plugs in the DC cord to the bottom receptacle and then swings the flap aside and plugs in the AC cord.

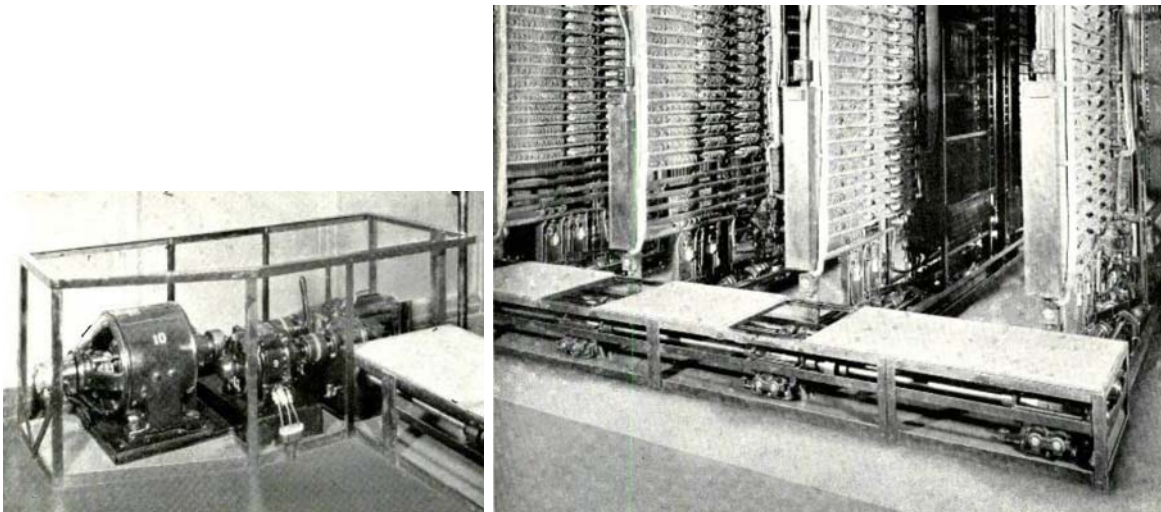


Figure 13. Common motor drive—Newark

8.4 In the earliest system

In the first "commercial" installation of the panel dial system, the "semi-mechanical" system installed in Newark, N.J. in 1915, there was not one motor per frame (co-shared between adjacent frames). Rather, larger motor pairs (AC+DC) drove quite a number of frames. The mechanical output from these motor pairs was distributed to their

“client” frames by way of shafts that ran across the floor in little “raceways”.⁸

Figure 13 shows this (fortunately) one-of-a kind arrangement.

But, by the time of the next installations, the much tidier system I earlier described came into use (although the duplex motors were of an earlier design than the one I described).

9 SWITCHING NETWORK ARCHITECTURE

Now that we are somewhat acquainted with the important players in the drama, it is time to look at the overall architecture of the switching network of a panel dial switching machine.

I note first that, over the early years of the evolution of the panel dial system, there were made some significant changes in system architecture, some of which affected the switching network itself. I will discuss this evolution later. For now, we will look at the architecture of the “matured” panel dial system (meaning as of about 1927).

I will also leave off for now a very important portion of the system, the common control arrangements, concentrating on only the switching network itself. We see this in overview in figure 14.

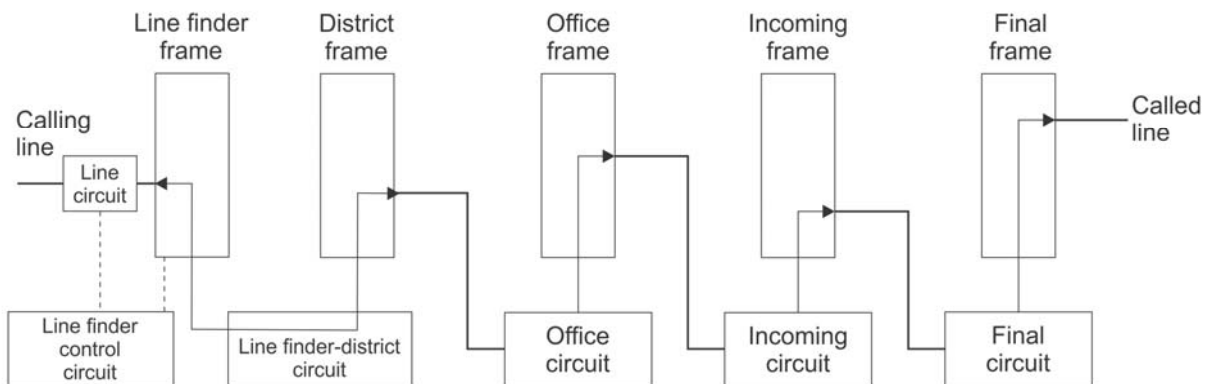


Figure 14. Panel dial switching network

We see that there are five stages in the complete path of a connection, involving five different types of selector (each in their own kind of frame). The names of some of the frames may seem a little odd, but the rationale for that will emerge shortly.

⁸ It is not true, as some wag (I wonder who) used to joke, that the earliest panel offices were driven by leather belts running from overhead shafts, nor that, even earlier, panel offices were driven by steam engines.

I make no attempt here to deal with such things as how do the individual banks on the selectors fit into the picture. That will emerge in due time.

The general scheme is fairly self apparent.

On any given frame, each selector consists of the selector proper (rod, brushes, etc.) plus circuitry comprising usually one sequence switch and one or two relays (this being indicated by the rectangles labeled, for example, "Office circuit").

In the system there are a large number of *line finder* selectors, each fairly permanently mated with a *district selector*. In fact, the circuitry of the line finder selectors is integrated into the circuitry of the mated district selector, resulting in the labeling we see of "line finder-district circuit". (Later, for conciseness, I may speak of this as just the "district circuit".)

When a subscriber lifts the handset to make a call, a relay in its line circuit operates, and the line finder control circuit assigns an idle line finder-district selector pair is assigned to the call. The line finder switch "finds" the calling line and when this is done the calling line is connected to the input of the mated district selector.

Now, the common control equipment comes in on the deal (we'll see how later), gives the caller dial tone, and accepts and records the entire dialed telephone number (which will usually comprise either 6 or 7 digits). That equipment then, in a way we will see shortly, causes the district selector, and then an appropriate office selector, and then an appropriate incoming selector, and then an appropriate final selector, to "pile on" to the connection, and then to make the final selector actually connect to the called line,

In this common control scheme, none of the selectors are directly controlled by dialed digits, but rather are set through the work of the common control facilities we don't see yet.

In the aptly-named *final* frame, there is a fixed relationship between the location of a line on the selector banks and the corresponding telephone number. Similarly, in the next-to-last stage, the *incoming* frame, there is a fixed relationship between the location of a certain final frame on the incoming selector banks and the telephone number.

But there is no fixed relationship between the dialed digits and the route from the district selector to an "appropriate" office selector, or from that office selector to an "appropriate" incoming selector. We will shortly get to appreciate how this does work.

9.1 About central offices and such

In the earliest small telephone systems, with a small manual switchboard, perhaps operated under a cooperative enterprise set up by the potential users in a small town, that small switchboard might have been located in the back room of the general store.

But as these systems grew, and substantial switchboards were needed to handle to traffic and number of lines, these came to be located in purpose-built (or repurposed) buildings, which came to be known as *central offices*.

And of course as a city really grew, it became most effective to establish more than one central office across the city, with the switchboards at the various central offices joined by *trunk circuits* (just "trunks" for short). For one thing, this minimized the total number of "conductor-miles" of telephone wires needed to connect all the subscribers in the city to a central office.

And so, to describe a wanted line to the operatr, one needed to give both the "name" of the central office that served it and its "station number". Perhaps the original central office came to be known as "Main" (how's that for original), while the newer one on the west side of the city was perhaps named "West" (or maybe "Lakeview", if that was what that neighborhood was generally called).

When mechanized service came along, with the subscribers using dials to "enter" the desired central telephone number, there needed to be a way to indicate the applicable central office. Perhaps five-digit numbers were used, with the first digit indicating the central office. Perhaps what, under manual switching, was known as the "Main" central office was now the "5" central office, and what was the "West" central office was now the "8" office.

Of course this greatly irritated the subscribers. If the lumber yard, for many years, had the number "West 1878", and was now 51878 (perhaps written as 5-1578, or even 51-578) subscribers would wonder how they would ever deal with that. Of course it was really pretty easy.

But the conversion to mechanized ("dial") operation in a city such as New York was another thing altogether. Among other things the introduction of dial central offices, to replace manual switchboards, had to be done progressively. And so there were created many clever, and complicated, provisions for handling a call from a subscriber now served by a panel office to one still served by a manual office, and vice versa.

And, as a matter of scale, there were literally hundreds of central offices in this service area. That meant for one thing that, to identify all these (and the new central offices that were coming on-stream at a prodigious rate), a 3-digit code was needed to identify the central office (leading to 7-digit telephone numbers. In cities such as Omaha, or Cleveland, with a more modest number of central offices, a 2-digit code was used to identify the central office (with 6-digit telephone numbers).

This raised the spectre of subscribers served by the new "dial" system all having to have large charts, which told what the "three digit central office code" would be for each central office in the city (in terms of its traditional name). It was clear to the AT&T executives that this would not be pretty.

An ingenious solution (now very familiar) was devised by W. G. Blauvelt, an engineer with AT&T. The telephone dial would have letters associated with the various digits, in the now-familiar way. Then (when 3 digit central office codes were used, as in the largest cities), to place a call to a number in the Madison central office, the user would dial the 3 digits next to which appeared the letters M, A, and D (6-2-3), and then the numerical part of the number. (In the medium sized cities, where only two digits were required to denote the central office, he would dial the 2 digits next to which appeared the letters M and A.)

For a set of reasons that I will dodge for the moment, no central office would be assigned a code starting with "1" or "0", so the letters were assigned on the dial starting on the digit "2", just as we see today, and only went on the digits through "9". The letter "Q" was not used, as it could easily be confused visually with "O", and the letter Z was not (at that time) included. So the remaining 24 letters fit nicely, 3 at a time, on the 8 digit positions 2-9.

Then, in the new telephone directories, the numbers were presented this way (I'll give examples for a city with 2-digit central office codes):

MA dison 2368

LA eview 7382

with a thin space after the two initial letters for clarity⁹. But in fact, especially for the longer names, the part after the three initial letters was usually abbreviated to save space in the directory layout, perhaps like this:

⁹ Although after a while that was given up, in the interest of saving space.

MA dsn 2368

LA kvw 7382

In any case, as I proceed, I will mostly speak in terms of a city with 3-digit central office codes (and thus 7-digit numbers). And, for conciseness, I will often mention central offices in terms of their numerical code (which is, of course, how the system sees it).

9.2 On the names of the frames

We are now ready to look into the rationale for the names of some of the frames (switching “stages”) in the panel dial system, and will learn a few other things in the process.

In figure 15, we see an expansion of what we saw in figure 14. (I have “de-cluttered” the area around the line finder and district selector – we know how that works.)

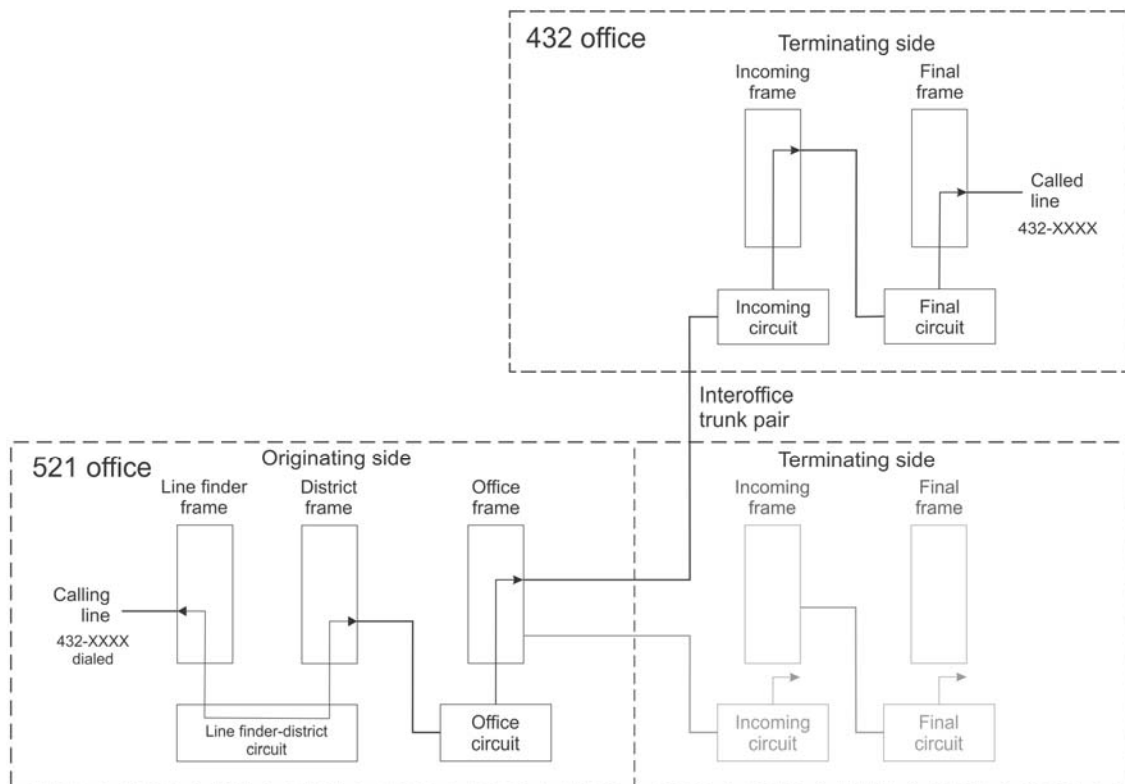


Figure 15. Switching network with distant central office

Here, we recognize that we are looking at the 521 central office, but we also see (part of) the 432 central office (in a separate building!).

We assume that a caller in the 521 office dials a 432 number. And so, the common control equipment would have (again in a way we have not yet seen) directed the district frame and then the office frame to make a connection to an interoffice trunk to the 432 office (this being carried over a cable pair). Nothing too surprising here. The common

control equipment in the 521 office would then continue to, over this trunk, direct the incoming frame at the 432 office and then the final frame there to complete the connection to the called 432 number.

Now, the moniker "incoming frame" makes sense: it's where a trunk from a distant originating office enters the switching network of the "destination" office, for completion of the call here..

And as well, "office frame" makes sense: it's where the connection is extended to a distant central office for completion of the call there.

It's just that in figure 14, where the "originating" and "terminating" offices are the same, we could not see that.

Now, what about "district"? Well, of course, the district frame takes us to an office frame from which a bunch of central offices can be reached. Does this mean that all the offices reachable from a particular office frame are all in a thing called a "district". No (although of course a bunch of central offices might indeed be in a telephone company administrative region called a "district"). "District" here is just a metaphor for "a certain collection of central offices"

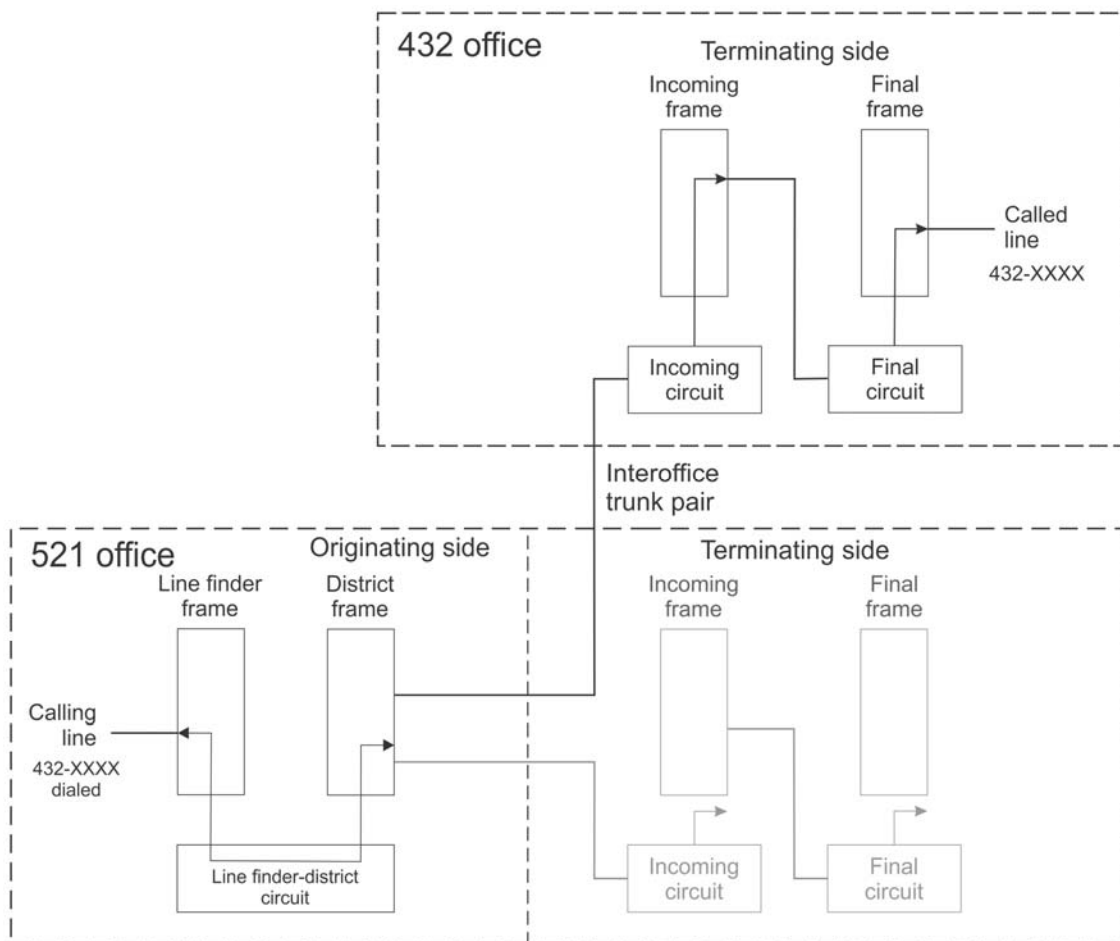


Figure 16. Shortened switching network

9.3 A shorter path

Figure 16 shows an alternate way to configure a panel dial office.

This might be done if the overall number of central offices in the city was modest. The office frame is omitted entirely, and the terminating offices (including the “local” one) are accessed directly from the district frame. This of course makes the moniker “district” seem especially odd!

9.4 Multi-unit central offices

With seven-digit telephone numbers, with the first three digits used to identify the serving central office, there are four digits left to identify the line within that central office, thus a maximum of 10,000 different numbers.

Suppose that the geographic region to be served by the Madison central office (623) has an increase in population or degree of “penetration” of telephone service, and so 10,000 numbers will soon be inadequate. An obvious step is to install another switching machine in the same building (perhaps expanding the building). But these lines cannot have “623” numbers—all those will soon be used up. So perhaps this new “central office” will have to be called “Worthington” (with central office code 967).

So now we have a terminology problem. Is this lovely Georgian style brick building at the corner of 8th Avenue and West 65th street a central office, or is it two central offices? After all, a central office is a “building”, right? But in this one we have two creatures with separate “central office codes” (and names), right?

The solution to this (and it is not really a complete solution) is to speak of the two creatures in that building as “units” of the panel dial switching system.

10 COMMON CONTROL—BASIC OPERATION

The workhorse of the common control aspect of the panel dial system is the *sender*. There may be well over 100 of these in the central office. A sender only is associated with a single connection for a fairly short while, thus exemplifying the common control concept.

When a call begins and a line finder has connected to the calling line, an idle sender is drawn from the “pool” and temporarily made part of the nascent connection. Its first job is to give dial tone to the calling subscriber, and then to receive and store the digits he dials (making, for the moment, the name “sender” seem a bit curious)

We see how that works in figure 17; this is a rather “fanciful” figure, intended to help grasp the important principles (especially given that the details of execution varied considerably over the maturation of the panel system). We’ll see some of the actual gory details later.

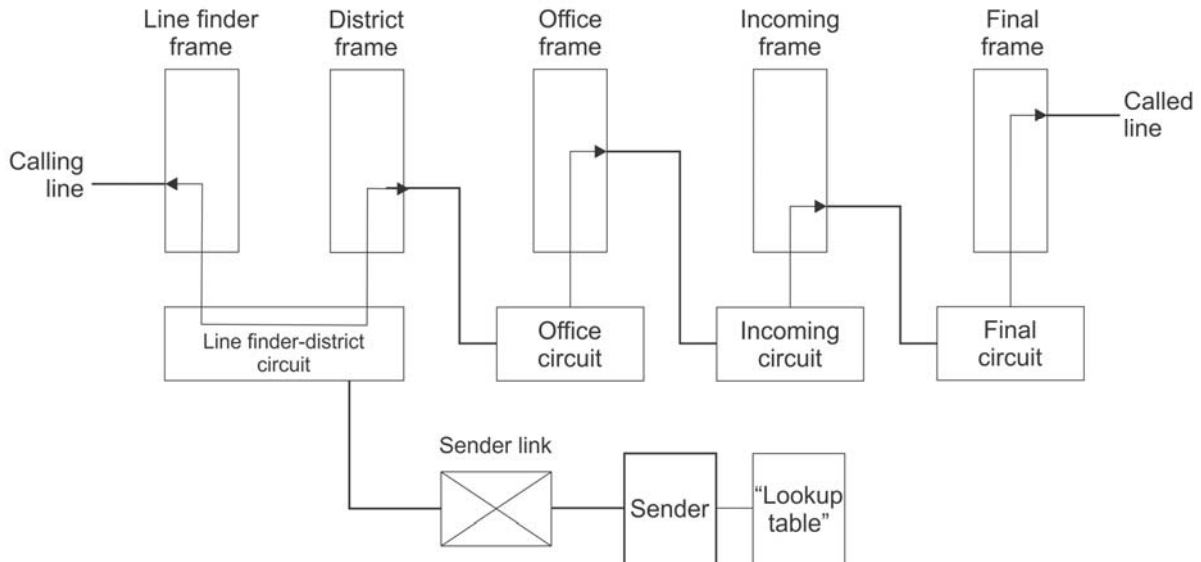


Figure 17. The sender

When a line requests service, as I briefly described earlier, an available line finder-office selector pair is assigned to the call, and the line finder connects to the line. Now, an available sender is drawn from the “pool” and is connected to the office selector circuit through a switching network I call here (generically) the *sender link*.

The state of the district circuit at this point in time is such that the path from the calling line is extended through the line finder-district circuit (from here on I will just call it the *district circuit*) to the sender, which returns dial tone to the calling line.

The calling subscriber dials the entire wanted number (either 6 or 7 digits, depending on the system, and the sender is of course set up for one or the other). The digits are received by the sender and stored on relays in the sender.

The sender then “looks up” the first 2 or 3 digits (the central office code) in what I call in this figure a *lookup table*. (Do not for the moment be concerned with how this is implemented; that is one of the grier details to which I earlier alluded.)

The “return” from the table is in terms of the numerical parameters of “setting” the district and office selectors to reach the central office indicated by that office code.

The sender, working back through the sender link to the district circuit, sends (aha!) over the nascent connection instructions for setting the district selector, and then, through the district selector, sets the office selector as needed, and then sets the incoming selector, and then sets the final selector.

By the way, the parameters for setting the incoming and final selectors are derived from the last four digits of the telephone number by a fixed algorithm, which is "hard wired" into the sender; no "table lookup" is needed for this.

Although we can truly say that the sender "sends forward" the instructions for setting the various switch stages (thus justifying its name), the numerical parameters of those settings are not in fact sent forward but rather rearward. This odd-sounding situation is inherent in the unique signaling system used, called *revertive pulsing* (which I will describe shortly).

In any case, as soon as the sender has "set" all the selectors in the connection, it is disconnected from this connection and is available to do the same thing for another call.

11 REVERTIVE PULSING

11.1 Introduction

The instructions for setting the various switching network stages are conveyed by the sender to the various stages, one stage at a time, using a signaling system called *revertive pulsing*. This concept was first widely used in the panel system (which is wholly dependent on it), although it had been used in some earlier systems.

The concept can best be explained with a parable. Alice wants to direct Bob to climb up a ladder to a certain point, 4 rungs up from the ground, where she knows he will have to be to do something she wants done (perhaps put in a nail on which to hang a picture).

She says "start". Bob starts climbing, and each time he gets to a new rung he says "mark". After Alice has heard "mark" four times, she says "stop". Bob stops, and is on rung 4, just as desired.

So the actual numeric parameter of Bob's climb, "4", is conveyed in the **reverse** direction (by four consecutive cries of "mark"). His utterances have "reverted" to the "commanding" end of the communication channel.

11.2 The fundamental circuit

Fundamental circuit refers to a two-wire path (tip and ring) that starts at the sender, passes through the sender link to the district circuit,

and from there grows forward, one stage at a time, as each switch in the train is set. It is over this circuit, out to the switch to which it has so far been "assembled", over which the sender sets that switch.

After all switches have been set, the part of it from the district circuit forward metamorphoses into the actual "connection".

11.3 Principle of operation

Now let's see, in figure 18, how this really happens, electromechanically.

On the left toward the top we see the line finder-district selector circuit. On the lower left we see the sender, attached (for the duration of its work) to the line finder-district selector circuit through the link circuit. On the right we see the incoming selector being controlled. The fundamental circuit has earlier been extended to it through a district selector and an office selector (both having already been "set" as required, using the very scheme we are about to see for the incoming selector).

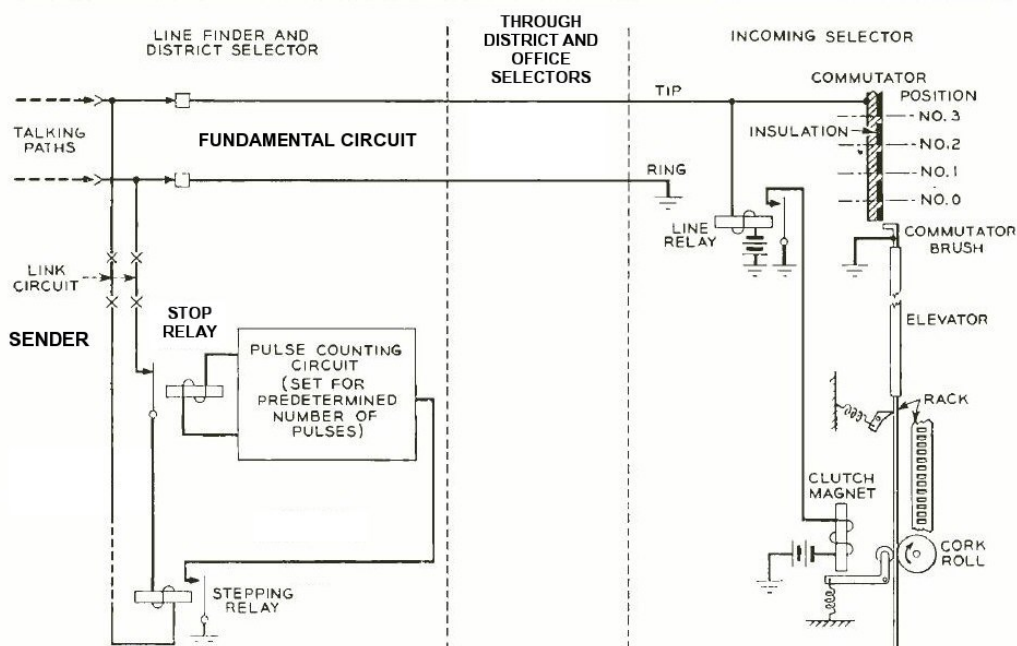


Figure 18. Revertive pulsing

We will assume that we are in the first stage of control of the incoming selector, needing to move it to one of five "preliminary" positions so that the proper brush can be setup to be tripped.

The incoming selector, when idle, maintains ground on its incoming ring conductor and battery through the winding of its line relay on the tip.

When the connection has been made through the district and office selectors to this incoming selector, there is continuity from tip to ring in the sender (through the coil of the stepping relay in the sender).

The current that flows operates the stepping relay in the sender and the line relay in the incoming selector. At the sender, this tells the sender circuitry that indeed it is now connected to a selector (which it presumes to be an incoming selector, owing to where the sender is in its overall scenario). At the incoming selector, the operated line relay operates the up clutch magnet, and the selector rod begins to rise.

As it does, a grounded brush on the commutator wiper assembly travels over a region of the commutator in which there are periodic narrow contacts, separated by insulating regions. When the selector rod reaches its first step position (called "position 0") the wiper makes contact with the first of these conducting places on the commutator, which grounds the tip conductor of the fundamental circuit.

That causes no change at the incoming selector end; the line relay remains operated (in fact, the current through it increases). But to the sender, the fundamental circuit is "short circuited", and current flow through the stepping relay ceases. That causes the counting circuit (composed of a bunch of relays) to say, in effect, "that's one". Then the brush moves off the first conducting place, the ground on the tip is removed, and there is again current through the fundamental circuit to the stepping relay (and the counting circuit says, in effect, "and-a").

This process repeats until the counting circuit says, when the count reaches the target location of the distant selector, "that's it", which it does by operating the stop relay. This opens the fundamental circuit at the sender

Now, when the brush moves beyond this conducting place, removing the ground from the tip, there is now no alternate path through the sender, and so the line relay at the incoming selector releases, releasing the up clutch magnet, and stopping the motion of the selector. The selector drive rack settles back on the retaining pawl, and this stage of the movement of the selector rod is done.

We will see a little later what is the overall sequence of "instructions" issued by the sender in this way to set all the selectors in the connection path.

11.4 Pulse rate

The rate of the pulses in one revertive pulsing train varies with the specific "setting" command that is being conveyed. The fastest rate

(which occurs for the various “brush” selections) is about 30 pulses per second.

12 CONNECTING THE SENDER

12.1 Introduction

Three distinct schemes were used during the first few years of the panel dial system for connecting an available sender into the connection. One survived for the remainder of the life of the system.

12.2 The sender selector

In the earliest form of the panel system, each line finder-district circuit had a sender selector circuit, which revolved (!) around a rotary selector (stepping style—“200-type”). When the line finder-district selector circuit had been called into service to serve a line requesting service, that selector “scanned” a group of not more than 22 senders, and when it found an idle one, grabbed it and brought it into the story. We see this in very symbolic form in figure 19.

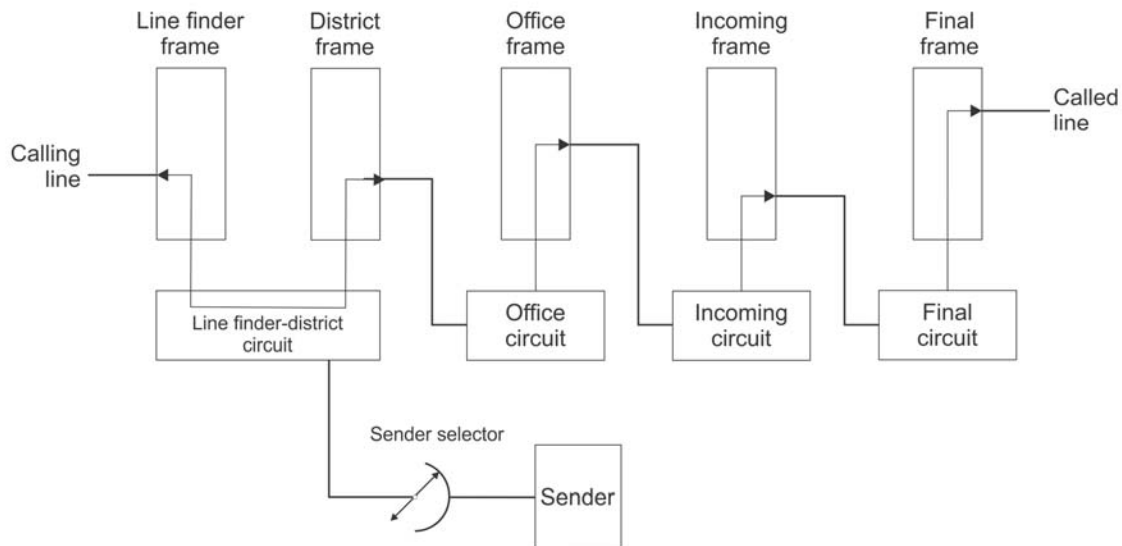


Figure 19. Sender selector

The fact that any given line finder-district selector could only choose from among a fixed group of 22 senders (of the hundreds typically existing in the central office) was not at all good from a statistical utilization standpoint.

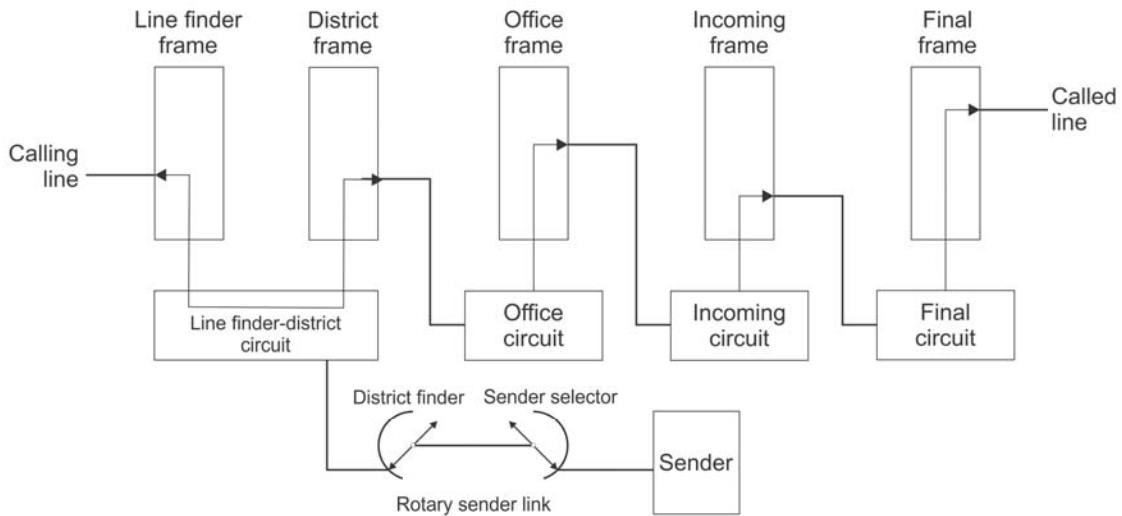


Figure 20. Rotary sender link

12.3 The rotary sender link

In the next iteration of this matter (see figure 20), there were a group of *sender links*. These each had a 1203-type power rotary selector on one end (which could connect to up to 44 line finder-district selector circuits), and another such selector on the other end (which could connect to up to 44 senders). By the use of clever schemes as to how the “candidates” for each of the ends of each sender link were arranged (a matter that is beyond the scope of this article), there was much more flexibility of utilization of the senders.

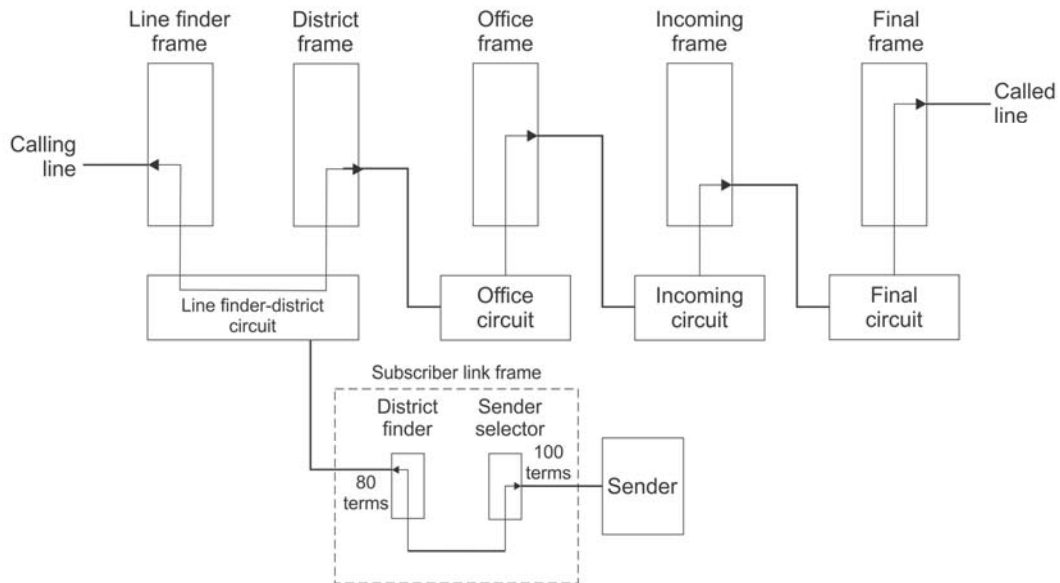


Figure 21. Panel sender link

12.4 The panel sender link

Basically the final stage of development in this area was a scheme that was architecturally similar to the rotary sender link but which used instead special kinds of panel selectors at each end of each link. Figure 21 shows this in highly symbolic form.

The basic concept is straightforward. The details are gravely tedious, and I will not penetrate this matter any deeper here.

13 SENDER DIGIT REGISTRATION

In the earliest panel offices, the senders used a set of rotary selectors (yes, 200-type) to count the pulses of the dialed digits and store the digits. There was one of these selectors for each expected digit, and one more to “steer” the incoming digit trains to the digit register selectors in order.

But in 1928, in conjunction with a major system redesign (the adoption of the “decoder” approach to translation, of which we will learn more shortly), the sender design was changed to do all this with relays.

14 TRANSLATION OF THE OFFICE CODE

14.1 Introduction

As I mentioned above, for each valid office code that might be received, the sender must learn the needed settings of the district selector (and office selector, if used) to direct the connection to a trunk to the proper office. This is conceptually what we would call today a *table lookup* process. In the discussion of telephone switching systems, it is spoken of as translation, and the concept is considered one of the pivotal developments in that field.

Two general architectural concepts of performing translation were used over the early period of evolution of the panel system.

14.2 The “translator” system

When the office codes are two digits (where there can only be at most perhaps 88 different “code points”), the “lookup table” is part of the sender itself (one in each sender). The concept is shown in highly symbolic form in figure 22. The table lookup part of the sender is spoken of as a *translator*.

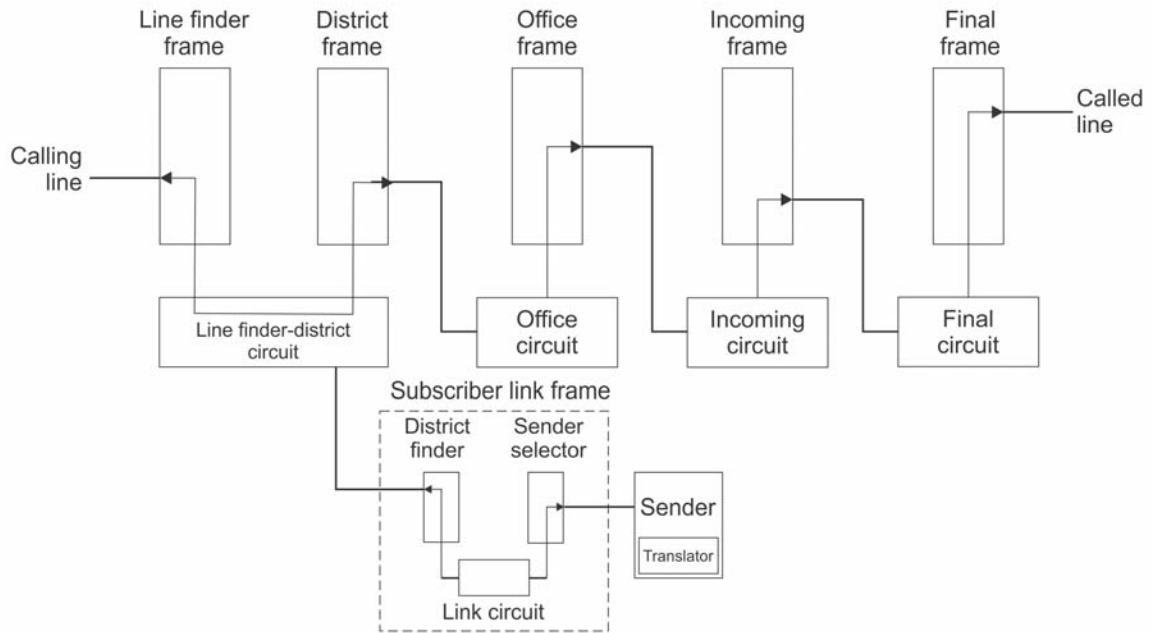


Figure 22. Translator-type sender for 2-digit office codes

The translator in this arrangement utilizes a number of 1203-type power rotary selectors. They are set to arbitrary positions from the office code as stored in the two 200-type selectors that received those dialed digits, based on cross-connections made on a terminal strip. The result would be for each of as many as 44 combinations of the digits of the office code (there are 64 valid office code possibilities altogether) these selectors would be set to specific (arbitrary) positions. Each corresponds to a destination central office.

For each of those positions, the terminals on those 1203-type selectors are connected by jumpers on a second terminal field to "return" the numerical selector setting information to reach that central office, which is used by the sender when doing those settings.

In offices using three-digit office codes (so there are a large number of "code points"), the translator is much more complicated, and is actually in a separate equipment unit, but still each sender has its own. We see the concept in figure 23.

This translator uses a panel selector, rather than a 1203-type selector, to do the translation. The scheme is complex, and I won't describe it here.

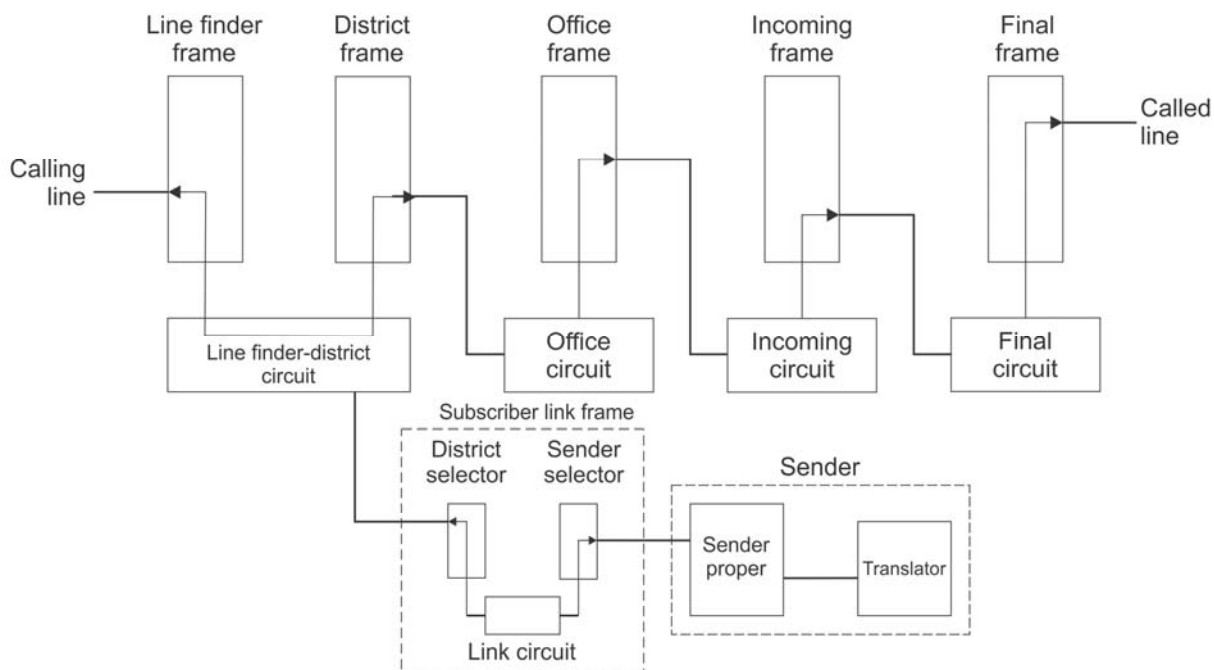


Figure 23. Translator-type sender for 3-digit office codes

But even in the simpler case of the 2-digit office code office, the translator arrangement made the sender rather complicated. Worse yet, whenever a change had to be made in the “routing” for the various office codes (perhaps a new central office code has been put into service), the “lookup table” has to be updated in every sender—that is, in its translator (and there may be well over a hundred of them).

14.3 The decoder system

14.3.1 Introduction

In the next, and very important, stage of evolution (ca. 1928), the “lookup table” function was separated from the individual senders and placed in new, more centralized unit, called a *decoder*. It uses only relays, rather than any type of moving selector, to do the translation. The decoder takes such a short time to “return” the selector setting information for a central office code (2-digit or 3-digit) that only a few of them can do all the work for an entire central office (it is not unusual for there to be only three of them, and six was the maximum that could be supported).

Once a sender has received the digits of the office code (it need not wait to receive all the digits; the last four digits translate to setting instructions for the incoming and final selectors via a fixed algorithm, hard-wired into the sender), it must “connect to” an idle decoder to get the translation done. This connection is made through a little

switching network called the *decoder connector*. In figure 24 we see this arrangement.

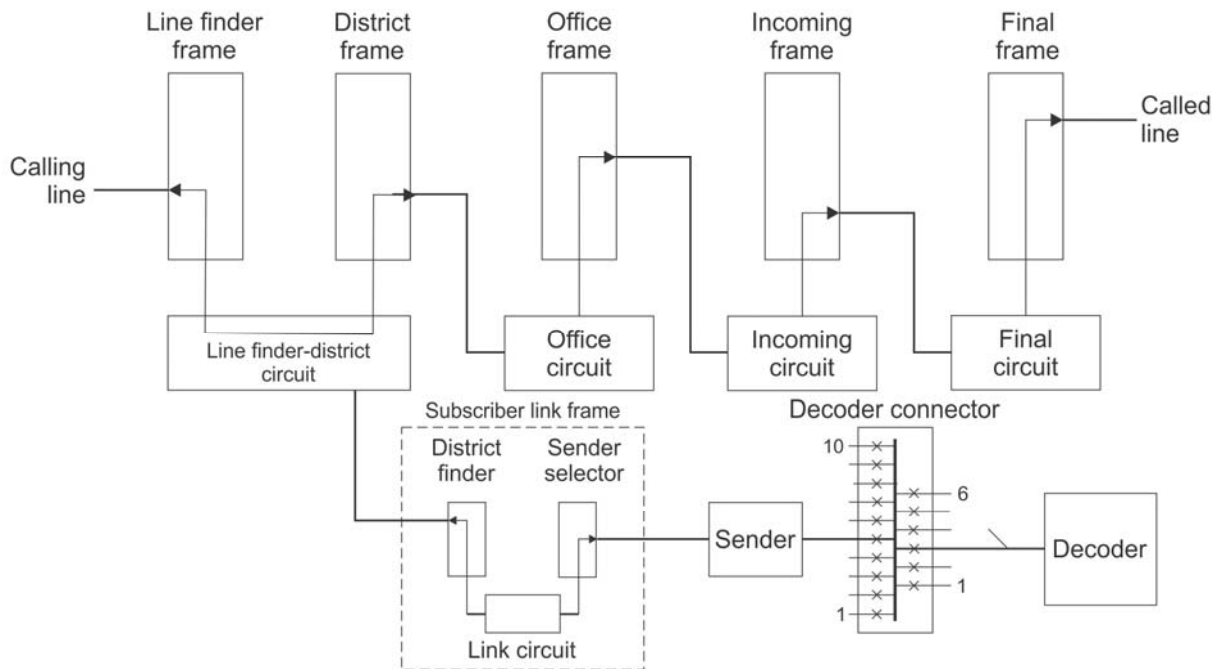


Figure 24. Sender-decoder system

There is one of these for each 10 senders. It comprises a multi-contact relay for each sender plus a multi-contact relay for each decoder. Thus, at any instant, any one selector in the group of 10 can be connected to any of the decoders (that is not at the moment engaged, of course). The actual "work time" of a decoder is only about 300 ms, so the small complement of decoders can handle the rate of call arrival even in the busiest time of day. But of course any given sender might have to wait a little bit before it can be given the service of a decoder.

There is in fact elaborate circuitry devoted to the "assignment" of decoders to the senders requesting the service of same. It operates the sender connectors.

So that the inputs to the decoder and the returns from it can be conveyed on a "parallel" basis, there are 50 leads in the path through the sender connector.

14.3.2 *Translating the office code*

In the decoder, through a "tree" operating on the first 2 digits (or 3, depending on the numbering plan in use) that were dialed (passed by the sender to the decoder through leads in the decoder connector) a *code point* terminal on a cross-connecting field is grounded. For all

valid code points, the code point terminal is cross-connected to a *route relay*.

Several contacts on the route relay are cross-connected (on a separate part of the cross-connecting field) to relays in the decoder that will, for the moment, carry the selection parameters (district brush, district group, etc.) that will be needed to set the selectors appropriately for the "destination" ordained by the dialed office code digits that led to the operation of that route relay.

These relays ground leads indicating those parameters through the decoder connector back to the sender, where they are captured by relays there. The decoder has done its job, and it is released to make it available for use by another sender on another call.

Because this was a major change in system architecture and operation (with many ramifications throughout the system), it is common to identify the "vintage" of a panel office based on whether it had the "sender-translator or "sender-decoder" arrangement. We might think that for short, these would have been spoken of as the "translator" and "decoder" versions, and that was sometimes done. But, inexplicably, they were often spoken of as the "sender" (older) and "decoder" (newer) versions

15 SELECTION AND HUNTING

15.1 Background

The basic job of the various selector stages (other than the final selector) is to advance the connection to a path connected to a selector in the next stage in the "branch" that "heads toward" the desired destination line. In some cases, that path goes to a selector in another central office, in which case that path is understandably called a *trunk*. But in fact in every case that path from a selector is called a *trunk*, because of the commonality of handling.

Invariably, there are more than one trunk going from a given frame to a destination on a selector in the following stage; several trunks (perhaps even a hundred or so) may be required to handle all the possible simultaneous connections needed to traverse that "path". So we may speak of a *group* of trunks leading from some frame of interest to selectors on a certain frame in the next stage. All these trunks are interchangeable. That is, for a connection needing to be extended to a selector on a certain frame, one trunk in the group is as good as an other.

In light of this, the process of extending the connection consists of alternations of the two processes *selection* and *hunting*. *Selection* zeros in on a group of trunks all leading to the proper frame of the

next stage (proper in the sense that it is part of the “route” to our ultimate destination). *Hunting* is the process by which a specific one of those trunks (of course, one that is not already busy) is chosen to be the next link in our connection.

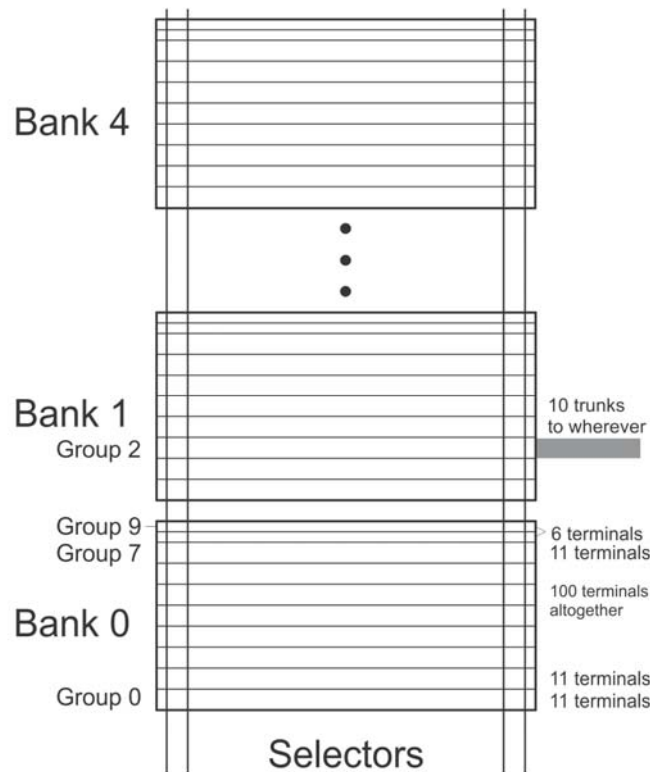


Figure 25. District and office banks

15.2 At the district and office stages

15.2.1 Organization of the banks

In a *district* or *office* frame, there are five banks, each with 100 “levels” of terminals. We see their organization in figure 25.

As we progress vertically in a bank, these 100 terminals are divided into 8 groups of 11 terminals each and then 2 groups of 6 terminals each. On a given bank, each of these 10 groups comprise terminals that can be used for a number of trunks¹⁰ to a certain destination—a *group* of trunks. The last terminal of each group is a “dummy” whose purpose we will learn of shortly. Thus the first 8 groups can contain terminals for up to 10 trunks each, and the last 2 groups can contain terminals for up to 5 trunks each.

¹⁰ “Trunks” here does not refer solely to trunks to a certain central office, but includes sets of “channels” leading to a certain frame in the next stage of the network.

In the picture, I show, for example, that on bank 1, group 2, all 10 of the available terminals are used for trunks in a group to some particular frame in the next stage.

15.2.2 *Selection and hunting*

Indeed suppose that the connection being set up requires (as indicated by the return from the decoder) the connection to be extended to a trunk in a group whose trunks are all on terminals in group 3 in bank 1. To achieve this, the sender will:

- Arrange for the bank 1 brush to be tripped on our selector, so that terminals on bank 1 will be accessed.
- Move the selector to the first terminal of group 2 and stop the selector motion. The selector brush is now on the terminal for the first trunk in the group of interest.

We note that for each trunk, the sleeve lead is grounded if and only if the trunk is busy (already engaged as part of another connection).

For this first trunk in the group, the office selector circuit tests to find if that trunk is busy, by testing the sleeve lead to see if it is grounded. If it isn't, that trunk is not busy. In that case, the selector remains halted at that position, and the selector circuit advances its state to extend the fundamental circuit over that trunk to the associated selector in the next stage.

If the first trunk in the group is busy, and so its sleeve is grounded, the selector resumes its upward movement, testing the sleeve of each terminal until it finds one that is not grounded. When it finds one, the selector halts, and the fundamental circuit is extended over that trunk.

15.2.3 *Overflow*

Suppose that all of the trunks in the chosen group to office selectors are busy? How do we prevent the selector from just continuing to move, now examining (inappropriately) trunks in the next group (which of course are not at all appropriate to the path the system is trying to set up).

In a larger group (11 terminals) the first 10 may go to trunks and for the moment we will assume that all 10 terminals in fact go to trunks. The 11th is a "dummy terminal", and it does not have ever have ground on the sleeve, so the district selector will definitely stop there. The selector recognizes (by a contact on one of the commutator tracks) that this is an "overflow" position. An electrical signal is sent back over the fundamental circuit to the sender, which advises the district circuit to return fast busy ("call cannot be completed") to the caller.

15.2.4 *Lesser numbers of trunks*

What if there are not needed the possible 10 (or 5) trunks in the group? For all remaining terminals (up to but not including the overflow terminal), the sleeve is statically grounded. Thus, if the selector gets that far, it will continue up to the overflow terminal, with the result described above.

15.2.5 *Consolidating groups*

Suppose we want to have 30 trunks to a certain "destination". We can consolidate three of the 11-terminal groups. To do so, on the overflow terminal at the end of each of the first two groups, we statically ground the sleeve. Thus, if the selector does not find a non-busy terminal in the first group, and continues to the overflow terminal, that will seem busy as well, and the selector will proceed on, now considering the terminals in the next of the consolidated groups.

15.2.6 *The bigger picture*

In figure 26 we see a certain district frame and two office frames at the 521 central office.

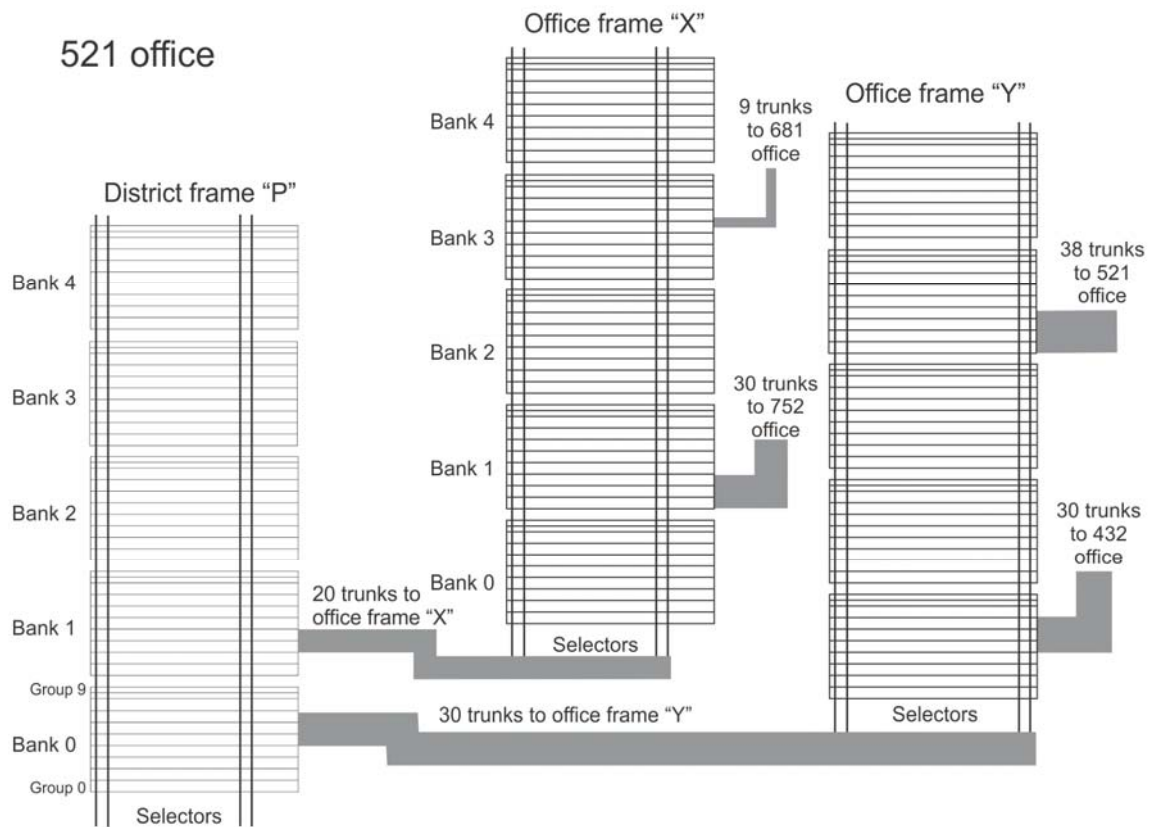


Figure 26. District and office stages

The figure should be fairly self-explanatory. We see two groups of trunks from our office selector "P", one to selectors on office frame "X" and one to selectors on office frame "Y". Both are large enough

that 2 or 3 basic groups on the district banks involved have been "consolidated".

On these two office frames we see trunks to incoming selectors at several central offices (including the "local" central office, 521).

In some cases, depending on the number of central offices in play and the projected traffic to each, trunk groups to the incoming selectors at some central offices (including the "local" one) may come from the district frame. In some situations, no office frames are installed at all.

Any time that no office selector is part of the path implicated by the central office code, the translator or decoder returns an indication ("skip office") that no office selections should be made.

15.3 Selection at the incoming and final stages

Figure 27 shows a typical incoming frame and two final frames.

Here, the organization of the banks differs from that on the district and office frames, and is wholly in terms of telephone numbers.

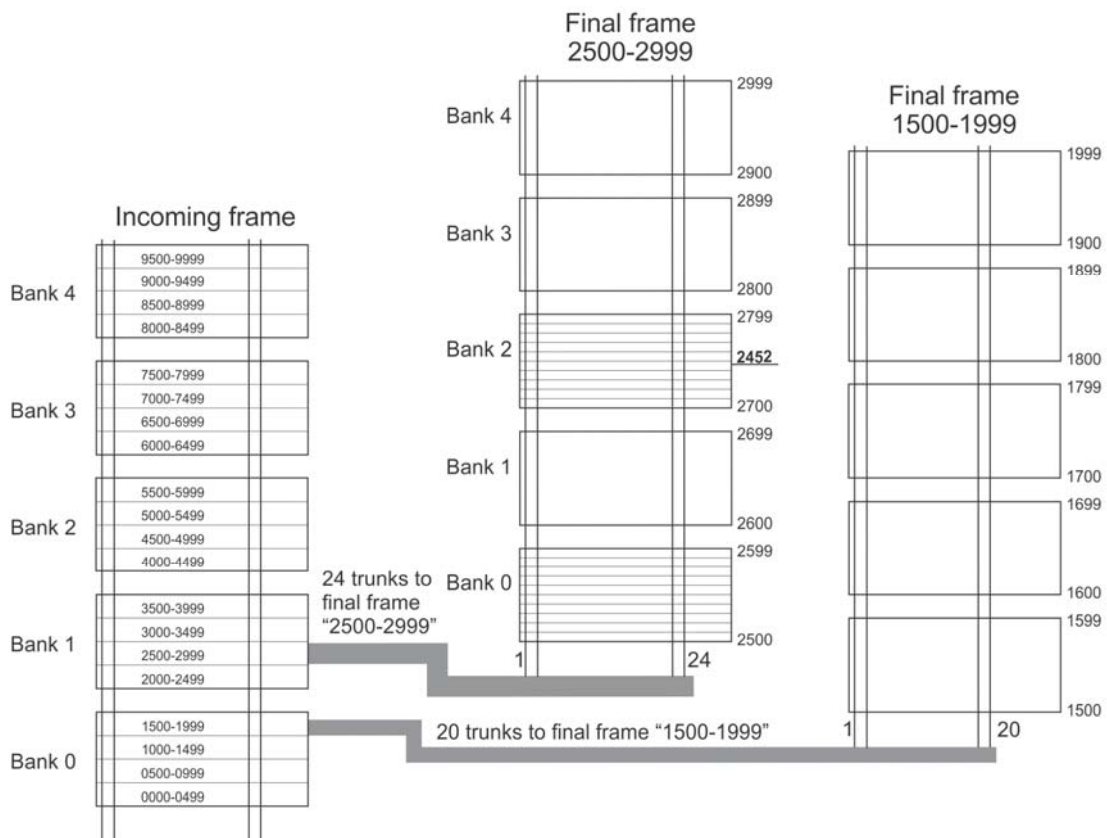


Figure 27. Incoming and final stages

On the incoming frame, each bank is divided into four groups, each with 25 terminals, 24 of which can carry trunks to final selectors and the last one of which is the "overflow" terminal.

But the 20 groups we have altogether (on the five banks) are immutably committed to final selectors on frames each reaching specific groups of 500 consecutive telephone numbers. The groups on the incoming banks are each marked on the figure with the number range of the final frame to which all trunks from that group go. So, bank 1, group 1 (not marked as such on this figure) has trunks to selectors on a final frame serving numbers in the range 2500-2999.

Because this "mapping" is invariant, the sender does not need to consult a translator or decoder to learn how to set the incoming and final switches to reach a certain line number. The "translation" (from the last four digits dialed) is fixed and "hard wired" into the sender proper.

That having been said, the sender sets the incoming selector just as we saw earlier for the district and office selector, and after the incoming group is set, the incoming frame "trunks hunts" just as we saw before to find an idle selector on the appropriate final frame.

But at the final frame, things are a bit different. For one thing, each of its five banks is divided into 10, rather than 4 groups, each having 10 terminals. Those 10 terminals correspond to 10 consecutive line numbers, nnn0 through nnn9.

When the sender is setting the final frame, it sets the brush (to select the bank) and the group just as before, the selector now resting on the step before terminal nnn0.¹¹ But this time there is no trunk hunting (there being no further stage).¹² By the way, this "group" setting is actually called "final tens"

Now there is one more setting command, to move the selector to the exact terminal in that group of 10. This works just as any other revertive command, except that during its execution, the "slow up" clutch of the final selector is engaged (else the revertive pulses, one per "level", would be too closely spaced for reliable transmission to the sender and counting there). This setting is called "final units"

¹¹ Why not **on** that terminal? Because in the next step, the revertive pulsing system demands that there be some movement of the selector, so if it is in fact terminal nnn0 that is wanted, the selector must be allowed to make one "step" to reach it.

¹² But see also section 24.

Suppose the caller had dialed xxx-2542. The "hard-wired" algorithm in the sender proper causes the sender to set the incoming selector to bank 1, group 1, where appear all the trunks go to final selectors on the final frame that accesses line numbers 2500-2599.

If in fact all the trunks are busy (an "overflow" at the final frame), as was done at the office selector, an electrical signal is sent back over the fundamental circuit to the sender, which advises the district circuit to return fast busy to the caller. But we will assume no such bad luck.

That algorithm then tells the sender to set the final selector to bank 2, group 4 (which group corresponds to line numbers 2450-2459). Then the "final units" setting moves the selector to the terminal for line number 2452.

16 COMPLETING THE CALL

Now lets look at actually completing the call.

As soon as the final selector is done being set, it advises the incoming selector (by some playing around with the ring lead). The incoming selector "takes a beat" and then connects to the tip and ring going forward to the final selector, and applies ringing to that circuit through a *ring trip relay*, which will detect when the called subscriber answers.

And at about this same time, the final selector looks at the voltage on the line sleeve lead to see if the line is busy. If not, the final selector connects the tip and ring coming forward from the incoming selector to the tip and ring of the called line, and so the line is actually being rung. When the subscriber answers, the ring trip relay operates, causes the ringing signal to be removed, and the incoming selector sets up its part of the talking circuit.

If the final selector finds that the line is busy, it applies a contact closure to the ring coming forward from the incoming selector that causes the ring trip relay in the incoming circuit to operate, again causing the ringing signal to be removed, and the incoming selector to set up its part of the talking circuit. Of course there is no called subscriber to "talk to". But in the final selector, busy tone is applied to the circuit. This goes back though the connection to the calling subscriber, who hears it.

17 THE TALKING CIRCUIT

First recall that during the entire time the calling subscriber is dialing, talking battery is supplied by the sender (its "dial pulse receiving" side), to which the line is connected during this phase of the call. Only

after the connection is wholly set up is the calling line connected to the path through the switching network.

In the completed connection, the talking circuit is in two parts. Talking battery is fed to the calling line by the district selector circuit, through the windings of a repeat coil¹³, the other side of which connects to the "connection going forward".

The rest of the talking circuit is in the incoming circuit. It supplies talking battery to the called line (reaching it through the path established by the final selector) through the windings of a repeat coil. The other side of the repeat coil connects to the circuit "coming forward" from the office selector (perhaps over a trunk pair, if the call originated in another office).

Battery is also sent back by the incoming circuit over the trunk to the district circuit. By controlling the polarity of that battery, the incoming circuit conveys to the district circuit the *supervisory state* of the called line (not answered yet, answered, hung up), needed by the district circuit for various call management purposes.

18 RELEASE OF THE CONNECTION

18.1 Calling party hangs up first

In the panel system, on a completed connection, if the calling subscriber hangs up, the supervisory relay in the talking circuit of the district selector releases. This opens the DC continuity of the path forward, and the rearward battery feed relay in the incoming selector releases.

The final selector (which is just a "conduit" from the incoming selector to the called line) is being "held" by the incoming selector circuit (which is, after all, "holding the baby" at this point) by way of a ground put on the sleeve lead toward the final selector by the incoming selector.

The incoming selector has learned of the "hanging up" of the calling subscriber by the loss of current in the arriving connection. It gets ready to release (meaning, among other things, to run its selector rod back to the home position), but first it takes ground off the sleeve going forward, so as to "dismiss" the final selector.

Let us assume that the called subscriber didn't get around to hanging up yet.

¹³ A high-quality transmission transformer (its full name is "repeating coil").

So what does the final selector do? We might think that it would open the paths to its brushes and run its selector rod down, so as to be ready for the ext call that reaches it. But if it did that, it would remove ground¹⁴ from the sleeve of the line circuit.

The CO relay in the line circuit would release, but since the line was still off-hook, the L relay in the line's line circuit would operate, and put into train a series of events that would result in this subscriber line being connected, through a line finder, to a line finder-district selector circuit, and through that and the sender link system to a sender, which would give the line dial tone.

Well, most likely this subscriber wasn't interested in making another call just now—he had just not yet hung up. So he would hang up, and the sender and the line finder-district selector team all abort. So we have, to no benefit, exercised many pieces of equipment, and in fact occupied them for a short while, taking away from the overall capacity of the office to handle calls.

To avert this, in reality, when the final selector finds itself dismissed (by the removal of ground on the sleeve lead from the incoming selector), it takes over the care of the called line. It provides talking battery to the called line (to which it is still connected) through a relay that it earlier used for something else. So long as that relay remains operated, nothing happens. But when the called subscriber does hang up, that relay releases, and now the final selector disconnects the paths to its brushes and runs its selector rod down.

Now, while this final selector is baby-sitting the called line, is the selector marked as "busy" so an incoming selector will choose it for a new call. No. The potential capacity of final selectors is so important that the system can't have one tied up indefinitely baby-sitting a line when the final selector is needed to do "real work". So this final selector (by way of the voltage on its sleeve lead) appears "idle" to incoming selectors.

So if this final selector is chosen by an incoming selector to complete a new call (and it learns of this when the incoming selector grounds the sleeve lead into the final selector), the final selector "turns loose" of the former called line, runs its selector rod down to home, and then tells the incoming selector that it is in fact ready to complete a new call. The incoming selector passes that back to the sender, so the sender will now command the final selector to go to the proper terminal for this new call.

¹⁴ Or battery, if it the system was of the GCO persuasion (see section 21)..

What about our hapless former called party, still dawdling with his line off-hook? Well, as I described before, in this situation, he in fact will start a new connection, sender and all, and will get dial tone.

18.2 Called party hangs up first

Suppose the called party hangs up first, and the calling party dawdles for a while.

When the called party hangs up, the supervisory relay in the cognizant incoming selector releases. The incoming selector, by changing the polarity of the battery fed "upstream", advises the district selector of this. The district circuit releases the connection forward so the office selector (if one is in the picture), incoming selector, and final selector restore to normal.

If shortly the calling subscriber hangs up, the supervisory relay in the district circuit releases. This causes the district circuit to "turn loose of" the calling line and return the district and line finder selectors to normal.

But if the calling subscriber has not hung up for a preset period of time, the district circuit "turns loose of" the calling line anyway and, as before, restores the district and line finder selectors to normal.

The cutoff relay in the calling subscriber's line circuit releases and reconnects the line relay which, since the line is still off hook, operates, causing a line finder to connect to the line, just as for a "real" subsequent call. When no digits have been dialed into the sender for a predetermined period of time, the sender goes to a decoder (I'll assume the decoder architecture here) with a special indication (that "no" central office code has been dialed). The decoder returns the parameters needed for the sender to set the district selector (and perhaps the office selector) to extend the call to a special "baby setting" circuit. This may give the calling line a tone signal (or in more modern times a recorded announcement) indicating (or saying), "If you wish to place a call . . .".¹⁵

If after a while the line still does not hang up, the circuit will apply bursts of a very loud and raucous tone. The hope is that if this incident came from the calling subscriber accidentally not hanging up and walking away from the phone, this noise will summon him back to the scene of the unfinished business. (The same scenario would occur

¹⁵ At one time in this situation the call would have been routed to the "dial service assistance" operator (the one you get if you dial "0"), who would have managed this scenario..

if no call had been made in the first place but the cat had knocked the handset out of its cradle.)

19 ABOUT THE LINE FINDER, OR MAYBE NOT

19.1 Introduction

In this section, we will look a little more thoroughly into the panel system line finder. As we first saw in figure 14, in the system configuration we see there, it is the line finder that allows a calling line to become connected to a district selector, from which the forward journey of the connection progresses. Briefly, the way this works is that when a line requests service by going off-hook, its line circuit advises some common circuitry of the line's wish, and the result is that an idle line finder-district selector team is tapped for this job, and that line finder finds the line.

But first I must digress and point out that in the first generation of the panel system, the *line finder* approach to this task was not used. Rather, a scheme working in rather the opposite direction, called the *line switch* approach, is used. I won't spend a lot of time on it since it moved fairly quickly into the dustbin of history, but for completeness I thought I would give a brief description. The concept is shown in figure 28.

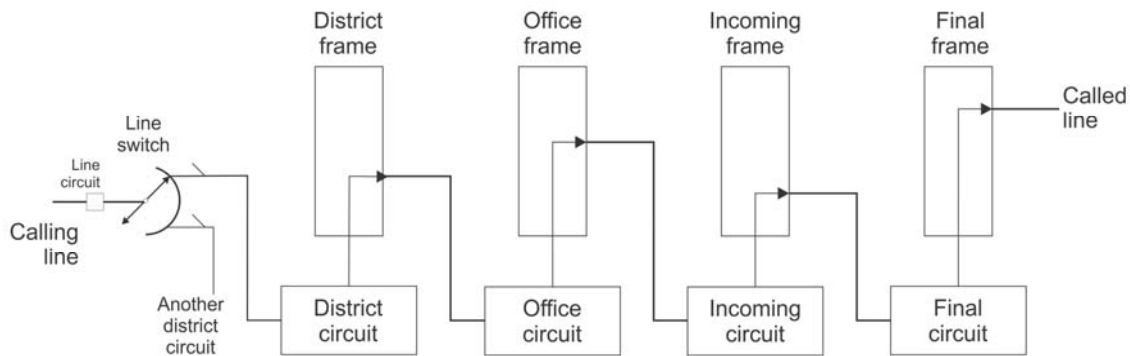


Figure 28. Panel switch train with line switch

Here, each line is equipped with a line switch, and when the line wants to place a call, the line switch hunts over perhaps 20 district selectors and, when it finds one, connects to it.

The line switch proper is a stepping rotary selector such as we see in figure 11 and as is described in section 6. There are also a couple of relays associated with its operation in the line circuit, beyond the familiar line (L) and cutoff (CO) relays. Of course all this is a substantial cost for each line. Further, the rotary selector cannot hunt over a group of line finders larger than 22, which is not desirable from a usage efficiency standpoint.

I won't speak much more about the line switch arrangement.

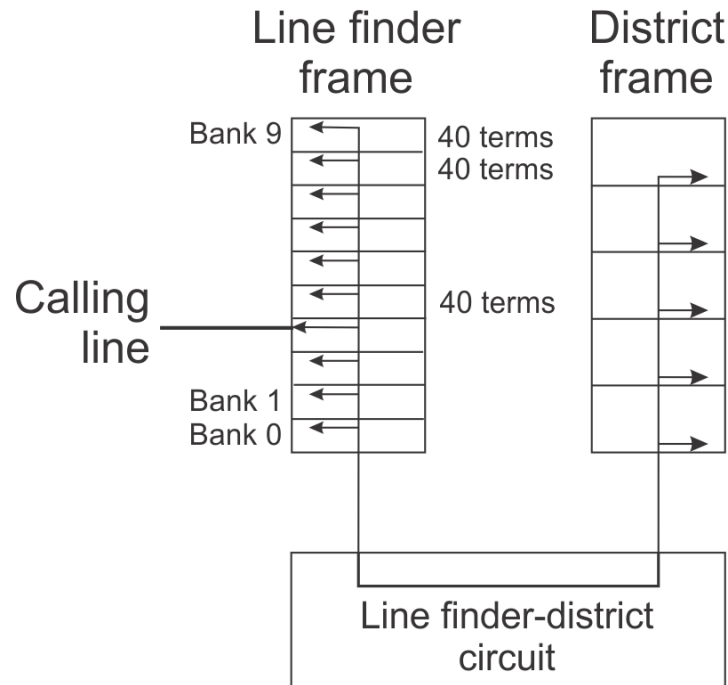


Figure 29. Line finder

19.2 The line finder

The line finder approach (in the basic implementation of the form used for most of the life of the panel system) allows up to 60 district selectors to be available to up to about 400 lines. I will use figure 29 to show just how this works.

19.3 The line finder bank

We note that while all the other frames have 5 banks, with 100 terminals on each, in the line finder frame we have 10 banks, with 40 terminals on each (a total of 400 terminals, accessing up to 400 lines). The reason for the use of such "small" banks is that the line finder selector will potentially have to search the entire vertical span of a bank to find the line that is asking to be served. By limiting the height of the bank to 40 positions, the maximum travel time is less than if the bank had its normal height of 100 terminals.

We might assume that the line finder banks, while less high than the other selector banks, were nevertheless integrated across a width that could support up to 60 selectors (on each side).

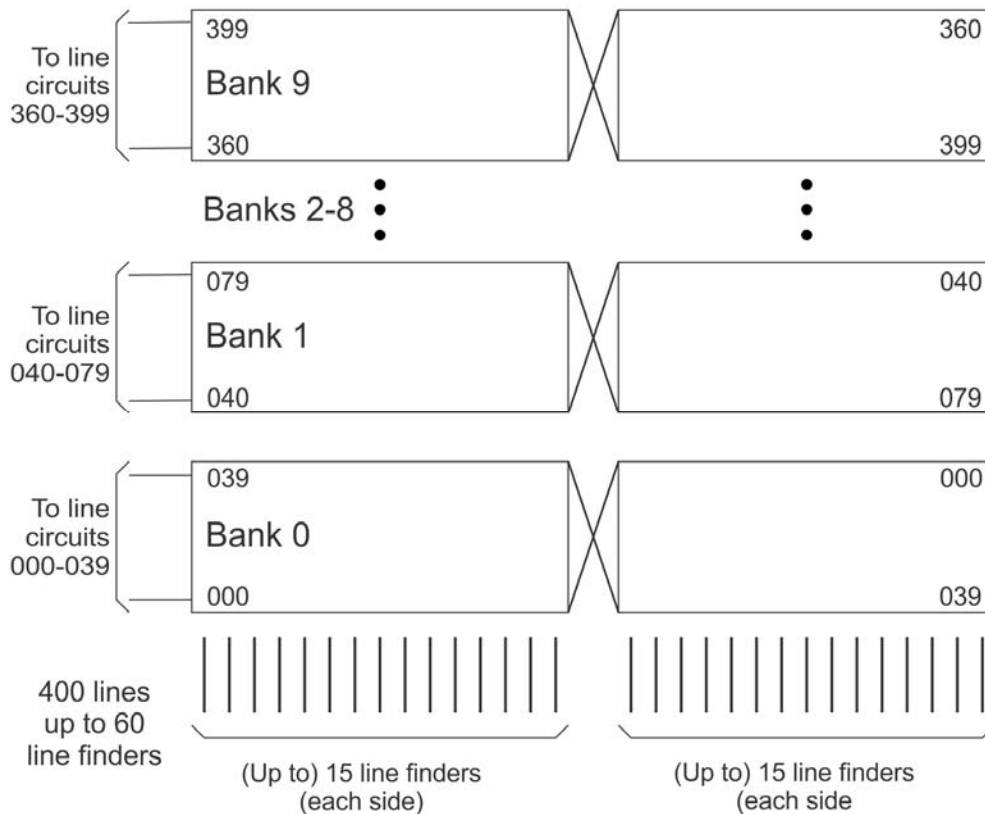


Figure 30. Line finder banks (60 line finder arrangement)

But that is not quite so. As we see in figure 30, each “bank” is in fact made up of two sections, each wide enough to support up to 30 selectors. The contact strips from the left section are carried across to the contact strips of the right section by wiring, but reversed. That is, the line that is connected, in the left section, to terminal 0, is connected in the right section to terminal 39; the line that is, on the left section, connected to terminal 39, is connected in the right section to terminal 0.

Then, when a line requests service, the line finder control system will, if possible, start a line finder in the half of the frame where that line appears in the lower half of the bank. Thus, if we think in terms of a time where there is a modest level of calling, the average time for a line finder to find a line requesting service is less than with a “straight across” bank.

This arrangement is a classic example of what is called a “reversed multiple”.

Of course, the solder lugs and wiring required to make this reversal create a “dead zone” on which no selectors can run (two selector spots are lost). But the bank overall is made wider than the banks on other switches (by 2 selector spacings), so there is still room for 30 selectors on each side (60 altogether).

Now suppose that the projected traffic from a group of 400 lines does not require that there be 60 line finder selectors to serve them, perhaps only 45. Well, we just only install 45 selectors on the frame.

But now suppose that for a certain class of line, the projected traffic from 400 lines suggests we have only 20 line finders. Installing only 20 line finders on a frame with a capacity of 60 does not make effective use of the frame.

So in such a situation, a different bank arrangement is used. The bank contact strips are split at a point halfway across their width, but there is no interconnection by wiring. Thus we now in effect have split the line finder frame into two independent "subframes". Each of those can accommodate 400 lines, thus the whole frame can accommodate 800 lines. No selector positions are lost at the location of this split. So at this point, it would seem that the whole frame could accommodate 32 line finders on a side (16 on each half).

But each of the bank halves is split at **its** center, with the two sides connected by wiring, in the "reversed" pattern we learned of above. And of course, two selector positions are lost where that happens. Thus, in each "subframe" we can have up to 14 line finders on each side, or 28 altogether.

The arrangement is shown in figure 31.

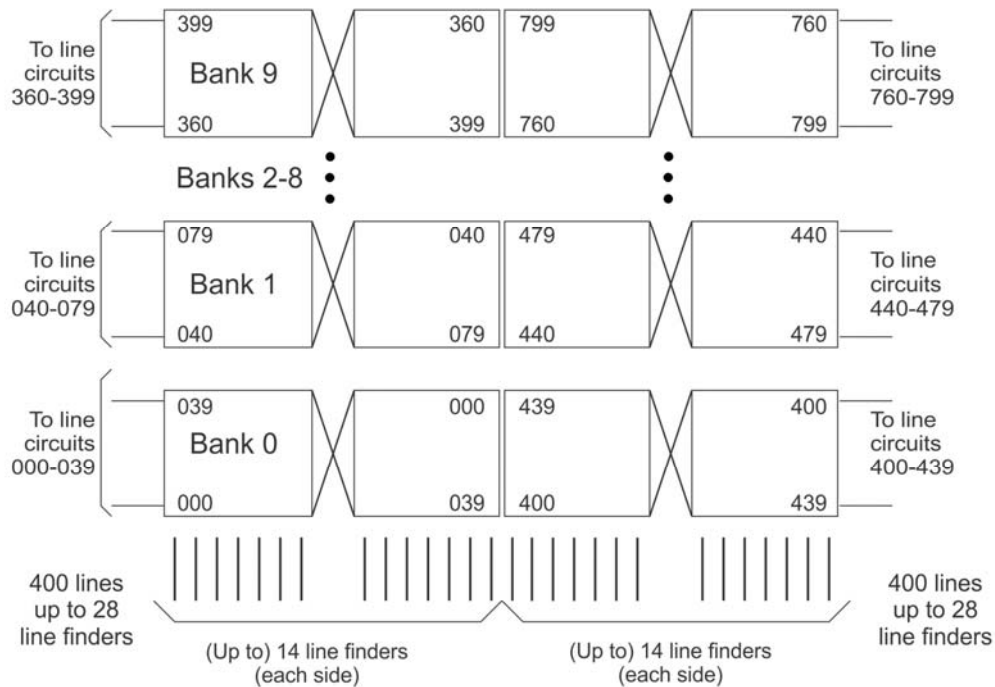


Figure 31. Line finder banks (28 line finder arrangement)

Overall we in effect have two independent line finder subframes, each accommodating 400 lines, which can be served by up to 28 line

finders. Of course, in this arrangement there must now be 800 line circuits on the frame rather than 400. This leads to a different frame configuration, with a somewhat wider frame.

Other arrangements, involving using 2 or 4 adjacent frames as the fundamental module, and dividing the banks in various ways, can lead to situations in which a group of 400 lines can be served by up to 40 line finders or 80 line finders. Considering all these possibilities, we can have 400 lines served by up to 28, 40, 60, or 80 line finders. The office may have sets of line finder frames set up in several of these ways, in order to best accommodate classes of lines with different traffic expectations.

I will remind us that we earlier learned that the brush trip arrangements on the line finder frame are different than on the other frames. This is described in section 4.7. When a bank is truly split (as we see in figure 31) the two "subframes" are wholly independent. The trip rods then are in two parts, one extending over each half of the bank, each having its own operating magnet at its "outboard" end.

19.4 The 300 point line finder

The first line finder system used in the panel system (introduced in 1920) had 15 banks, each with 20 terminals (allowing access to a total of 300 lines). The object was that the line finder would never have to hunt over more than 20 terminals to find the line requesting service (not over 10 in most cases since a reversed multiple was used.)

But mechanical problems with this made caused this "300 point" line finder to be supplanted in 1924 by the "400 point" line finder we discussed at some length above, and which was used over the rest of the life of the panel system.

As to why these were called "300 point" and "400 point" line finders rather than "300 line" and "400 line", it is probably because of the "switch" rather than "system" outlook on the hardware.

20 SETTING THE SELECTORS

By now this is a bit of an anti-climax. We already saw in section 11.3 how the sender sends a "setting" command to a selector via revertive pulsing. But here I want to summarize the entire "syntax".

First recall that after the central office code has been dialed, the sender (via its own translator or a common decoder, depending on vintage) knows how it must set the district selector and (if there is one in the "route"), the office selector. (In fact, the return from the

translation included information on whether there is an office selector in the route or not.)

As soon as the sender has this information (whether or not the calling subscriber has yet dialed the rest of the number), the sender begins its dialog with the great beyond, setting the district and (if applicable) office selectors. There are pros and cons of its working that way:

- Assuming that the calling subscriber doesn't "dawdle" after dialing the central office code, this speeds up the overall setting up of the connection. This is desirable from the calling subscriber's viewpoint, and as well shortens the time that the sender spends on this call.
- If the calling subscriber in fact dawdles after dialing the central office code ("Let's see, the lumber yard is MULberry—something. Just what is the rest of it?"), then this *modus operandi* ties up the district (and maybe office) selector for longer than is "attractive". The sender however, is a little impatient about this, and if the subscriber dawdles too much between any part of dialing the number, the sender routes the connection to a special district or office terminal that returns "fast busy" to the subscriber so the sender can disengage from this call and go back to the "sender pool" to be available for assignment to a new call.

In any case, here is the sequence of "switch setting" orders in a full-blown connection (including an office selector). I will start each item with the formal name of that "command" and its customary abbreviation.

- District Brush (DB). This can have one of 5 choices (said to be "brush 0-4"). This determines the bank on the district selector on which a trunk to the proper part of the next stage will be found.
- District Group (DB). This can have one of 10 choices (said to be "group 0-9"). This determines the group of 10 or 5 consecutive terminals on the chosen selector bank to the bottom of which the selector will be set. The selector will then hunt over all of those terminals looking for an idle trunk to an office selector on the proper district will be found. But in fact the selector may be able to hunt over the more than the terminals in that group if two or more groups have been consolidated.
- Office Brush (OB). The story here is identical to that for District Brush, except of course it is the office selector that is being directed.

- Office Group (OB). The story here is identical to that for District Group, except of course it is the office selector that is being directed.
- Incoming Brush (IB). The story here is identical to that for Distinct Brush, except of course it is the incoming selector that is being directed.
- Incoming Group (OG). The story here is identical to that for Distinct Group, except of course it is the incoming selector that is being directed.

The result of all the above is that the connection has been extended to a final selector in the group serving the 500 consecutive numbers in which the called number is included. The setting of the incoming brush and group is based in a fixed way on the thousands and hundreds digits of the dialed number.

- Final Brush (FB). This can have one of 5 choices (said to be "brush 0-4"). This determines the bank on the final selector on which the "target" terminal will be found. This bank of course serves 100 consecutive numbers. This is based in a fixed way on the hundreds digit of the dialed number.
- Final Tens (FT). This can have one of 10 values. This determines the group of 10 consecutive terminals on the chosen selector bank just underneath which the selector will be set (corresponding to the group of 10 consecutive numbers in which the called number is included). This is based in a fixed way on the tens digit of the dialed number. There is no hunting, as there would be in earlier stages; the final selector just sits there, awaiting the last order¹⁶.
- Final Units (FU). This can have one of 10 values. This determines the terminal (in the already-committed group of 10) that corresponds to the called number. This is based in a fixed way on the units digit of the dialed number. The final selector moves at a slower than usual speed (so that the revertive pulses, now coming at one for every 1/6" increment of selector movement, will not be too fast for successful transmission over the fundamental circuit and counting in the sender.

After this, the last switch setting command, the final selector tests the line at that terminal for busy, and so forth. The sender is done. It tells the line finder-district circuit that it should go into the

¹⁶ An exception to this is covered in section 24.

“connection completed” state, and the sender disengages from this connection.

21 GCO vs. BCO

21.1 Introduction

In 1929 there was a major overhaul to the innards of the panel dial system; however, no substantial architectural or conceptual change was involved.

One change that was very “visible”, and thus noteworthy, was a change in the way, electrically, that the cutoff (CO) relay in the subscriber line circuit was operated.

21.2 The line circuit

As we saw earlier, in the panel dial system the interface between a subscriber line and the switching network proper is the *line circuit*. Its main job is to detect when a subscriber has taken his line off-hook to place a call, and put into motion the steps that will cause the switching system to connect to that line so as to serve it.

In figure 32 we see (in slightly simplified form) the line circuit used in the panel system..

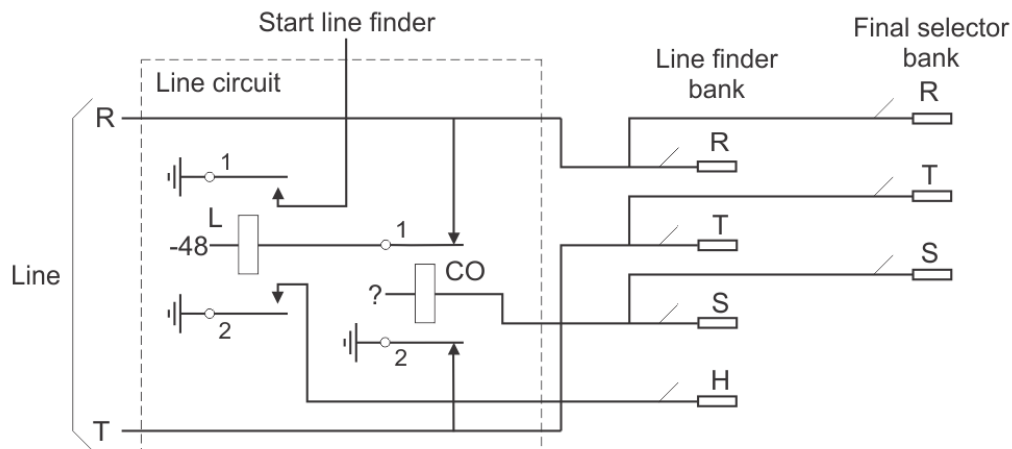


Figure 32. Panel line circuit

The line circuit comprises two relays, *line* (L) and *cutoff* (CO). Both are released when the line is idle.

We see that battery (-48 V) is applied to the ring conductor of the subscriber line through the winding of the L relay, and ground to the tip conductor (directly).

When the subscriber takes the line off-hook to place a call, current flows through the line and operates the L relay. Contact 1 of the L

causes (through a very complicated process, actually) a line finder to be started to hunt for the line. Contact 2 of L marks the line (so the line finder can indeed "find" it) by grounding the H ("hunt", of course) contact of the line's terminal on the line finder banks.

The little diagonal lines on the circuit drawing (called *multiple* symbols) remind us that the line is also connected to "more of the same", in this case, terminals on other line finders.

We also see the connection of the T, R, and S leads to the line's terminals on a final selector frame.

When the line finder in fact finds the line, the associated district selector ("reaching back" through the line finder) applies an electrical condition to the sleeve contact of the line circuit, which operates the CO relay. Yes, I am being intentionally vague about exactly what electrical condition that is, as well as exactly what the left side of the CO relay coil is connected to. That matter is in fact the essence of the current story.

The contacts of the CO relay lift the battery and ground from the line. The L relay is not needed any more, and those paths would interfere with things that must happen to the line when it is actually on a connection.

The electrical condition applied to the line circuit sleeve has a second purpose. Suppose a different caller places a call to our line, which is already part of a connection it originated. A final selector will be taken to the line's terminal on the final selector bank(s). This terminal comprises contacts for the tip, ring, and sleeve of the line.

The final selector examines the voltage on the sleeve, finds it not to be the voltage that would be exhibited by the sleeve of an idle line, and concludes (correctly) that the line is busy. The final selector declines to make a connection to the line, and returns busy tone to the caller of that second call.

Now imagine that later our line is idle again, and a calling subscriber calls that line. Again, a final selector will be taken to the line's terminal on the final selector bank(s). The final selector examines the voltage on the sleeve, this time finds it to be the voltage that would be exhibited by the sleeve of an idle line, and concludes (correctly) that the line is idle.

The final selector makes a connection to the line. One aspect of that is that it applies the "mysterious" electric condition to the sleeve, which operates the CO relay in the line circuit, again freeing the line from the paths from battery and ground in the line circuit.

Of course, then the switch train applies ringing voltage to the line, and when it is answered, a talking path is set up.

And now, as in the earlier scenario, the sleeve of the line exhibits the voltage it has when the mysterious electrical condition has been applied.

Now suppose another caller dials a call to this same line. This time, again,, when the final selector involved in this new connection looks at the voltage on the line's sleeve, it concludes that the line is busy, the result being as described earlier.

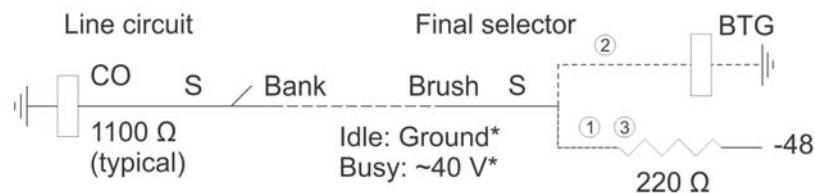
Now that we have seen the order of battle, it is time to look into this mysterious" electrical condition that is applied to the sleeve of a "connected-to" line to operate its CO relay and to mark the line as "busy" by way of the voltage on the lines sleeve.

After the connection is up, the H lead is used for a wholly different purpose, which is beyond the scope of this discussion.

21.3 The mysterious electrical condition

We will now get more specific about the "mysterious" electric condition. Figure 33 shows as much of the line circuit as we need to think about just now, for two different circuit designs.

(a) Panel dial system (GCO)



(b) Panel dial system (BCO)

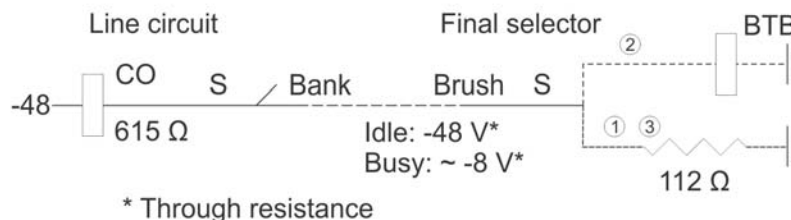


Figure 33. Cutoff relay and busy test in two versions

In none of these do we see the line (L) relay. We already know what it has to do, and how it does it.

In panel (!) (a), we see the original circuit concept (in use up to about 1929). In the line circuit, the coil of the CO relay returns to ground. (In

fact, this is spoken of as the "GCO"—ground on the CO relay—arrangement.)

The path labeled with the circled "1" is that established when the line is connected to by a line finder. The associated district selector, "reaching back" through the line finder, applies -48 V, through a 220 ohm resistor, to the sleeve. This operates the CO relay in the line circuit (with the now-familiar effect), and leaves the sleeve at about -40 V (which is the "mark" of a busy line under this system).

And a busy test is made by a final selector considering connection to the line by the path with a circled "2", There, what I show as a single relay, BTG (the "BT" being for "busy test") looks for a substantial voltage on the sleeve, the presence of which indicates that the line is busy.

Finally, to complete the story, the path labeled with a circled "3" is used by a successful connection to our line as a called line. In the very same way as when the line had been connected to, as a calling line, a line finder, the -48 V through a 220 ohm resistor causes the CO relay in the line circuit to operate, and marks the line as "busy".¹⁷

But. back to our panel line circuit, why the resistor at all? Could we not just have the selector circuit that operates the CO relay just put battery (-48 V) directly on the sleeve?

Yes, but then if, for example, a sleeve wiper or a sleeve contact "bar" in a bank would get accidentally grounded, a large current would flow. Of course this would not cause any real damage, since the fuse that protects the selector circuit (typically rated at 1-1/3 A) to blow, but then that selector would be *hors de combat*. So the resistor limited the amount of current that could flow in such a situation to approximately 0.22 A.

That is all very well, but during the years that the panel dial systems used the "GCO" arrangement, there were a number of fires reported that turned out to have originated from short circuits on a sleeve circuit (perhaps through an errant thin wire strand, which could be heated to incandescence by a current of 0.22 A).

¹⁷ This approach closely parallels that used in manual switchboard systems, where again the CO relay coil returned to ground, and when the switchboard makes a connection to a line, it applies 24 V (manual switchboards typically run from that voltage) to the sleeve through a resistive path. But there the busy voltage is only about -4 V.

And there were other disadvantages to the “GCO” arrangement that emerged, some related to the arrangements for serving groups of “PBX trunks” (as discussed in section 24).

21.4 BCO to the rescue

So, in the massive 1929 redesign of the panel dial system, the line circuit was changed to that the coil of the CO relay ran to battery, as we see in panel (b) of the figure. This was known as the “BCO” (battery on the CO relay) arrangement. Then ground—through a 112 ohm resistor— would be applied to the sleeve to operate the CO relay and mark the line as busy (the sleeve voltage then being about -8 V). And the busy test was made by a relay (this time the fanciful BTB) observing the voltage on the sleeve. If it was not essentially -48 V, the line would be seen as busy.¹⁸

Why the resistance? Well, it has to do with hunting over multi-line groups (such as groups lines that are actually PBX trunks. (This functionality is discussed in some detail in section 24.)

21.5 The name of a “generation”

The switch from the GCO arrangement to the BCO arrangement came at a turning point in the evolution of the details of the panel system. Even though there were several major redesigns of the system (some with pivotal conceptual changes) during the reign of the GCO arrangement, in later years it became common to think of panel offices as being of two vintages, “GCO” and “BCO”. “What kind of switching equipment is in the office you’re working in now?” “Panel”. “What kind?” Well, we have two units of GCO and two units of BCO.”

22 THE DISTRIBUTING FRAMES

22.1 Introduction

In the discussions above, I have blithely spoken of such and such things being semi-permanently connected, and so forth, in some certain way. Now we will look at the physical realities by which many of these connections are accomplished.

Much of this is done on the *main distributing frame*¹⁹ (MDF) and the *intermediate distributing frame* (IDF) of the central office. There are large structures on which, by way of semi-permanent wiring:

¹⁸ This approach closely parallels that used in the step by step system, where again the CO relay coil returned to battery, and when the switching system makes a connection to a line, it applies ground to the sleeve.

¹⁹ This is sometimes seen written, inaccurately, as “distribution frame”.

- a particular subscriber's line, arriving at the central office on a certain pair of a certain cable, is given a telephone number by associating it with a particular terminal on the appropriate final frame.
- a particular telephone line is associated with a particular line circuit and its corresponding terminal on a line finder frame).

In the "traditional" form (certainly used almost universally in offices with panel switching equipment), both of these structures consist of a large "jungle-gym-like" metal frame, on each side of which is an array of terminal blocks with numerous small metal terminals (or the equivalent). On one side these are arranged in horizontal rows, and on the other side in vertical columns.

22.2 A map of the battle zone

Figure 34 shows in block diagram form the overall arrangement of the MDF and IDF. I will discuss some of its implications after we look at the creatures themselves.

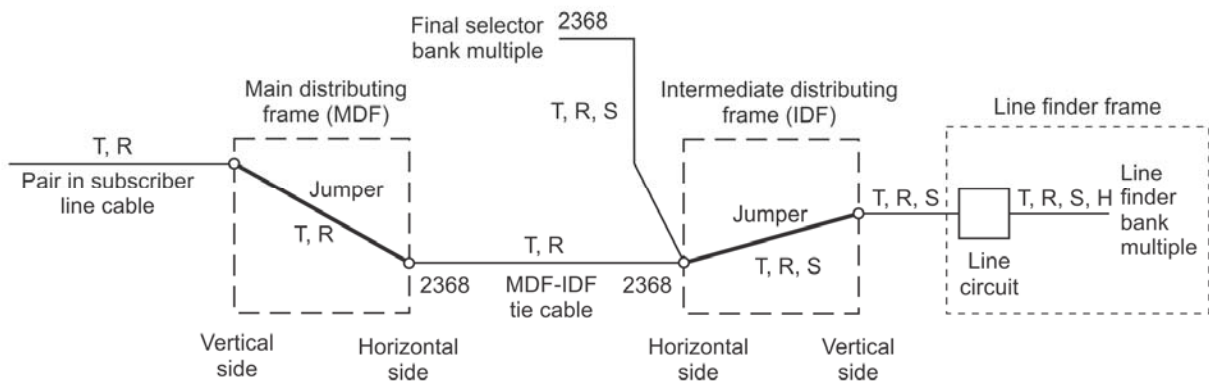


Figure 34. Arrangement of the MDF and IDF

22.3 The main distributing frame (MDF)

On the MDF, all the pairs of all the incoming subscriber line cables are permanently connected to terminals on blocks on the vertical side, organized by cable number and pair number.²⁰ The pairs of the line multiple are permanently connected to terminals on blocks on the horizontal side, organized by telephone number.

²⁰ Actually, these are not just terminal blocks but also "protector units" which incorporate, for each pair, components that protect against high voltages that might inappropriately appear on the conductors and from excessive currents that might somehow flow in the line conductors. This is of course a gigantic topic in its own right, but I will not pursue it further here.

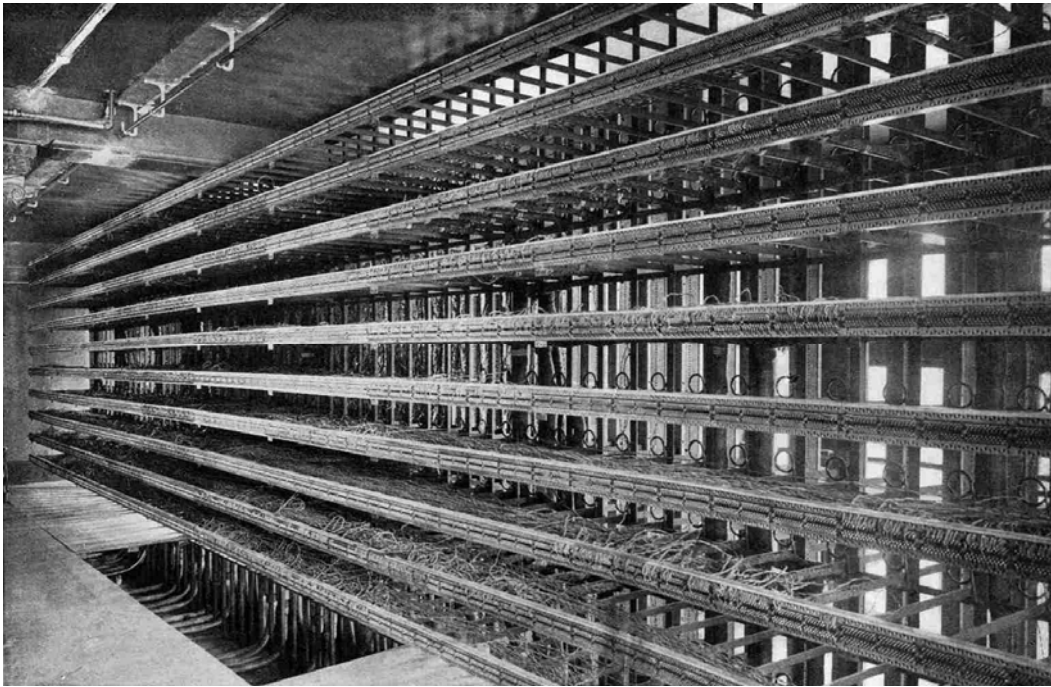


Figure 35. Main distributing frame (horizontal side)

Figure 35 illustrates a rather antique MDF (as befits our context), seen from the horizontal side. We see, though an open trapdoor, the arriving subscriber line cables, destined for the vertical side of the frame. They more often arrive directly through the floor from a basement “cable vault”. The cables from the horizontal side probably arrive at the right end of the frame (not visible here).

22.4 Jumpers

When a subscriber arranges for new service, he is assigned a telephone number, and a certain pair in a certain cable is assigned to carry his line.

To effectuate this at the central office, workers²¹ run a length of two-conductor wire (of a very durable type) from:

- the terminals on the vertical side on which the assigned cable pair is terminated, to
- the terminals on the horizontal side for the assigned telephone number, these terminals are in fact organized by telephone number (we will see later how that comes about).

This length of wire is called a *jumper*.

²¹ Known formally as “framemen” (this was of course before gender-neutral job titles), and colloquially as “frame monkeys” (a gender-neutral term, by the way).

The horizontal-side terminal blocks are supported by metal bars extending out from the central "spine" of the frame (best seen in the second horizontal row from the bottom in figure 35). These make a sort of very open shelf. There are also large diameter metal rings ("distributing rings") behind each vertical column at the height of each such "shelf".

Following from the horizontal side, the jumper is fed through a small hole in the wood base of the terminal block and is laid on the "shelf" made of the block supports of that horizontal row. It is led to the vertical-side column of the cable pair terminals to which it will be connected. It is fed through the ring at that point and led up or down to reach that terminal.

The connections at each end were soldered. We see that in figure 36. This actually on the vertical side of an IDF (but the work was much the same on the MDF).

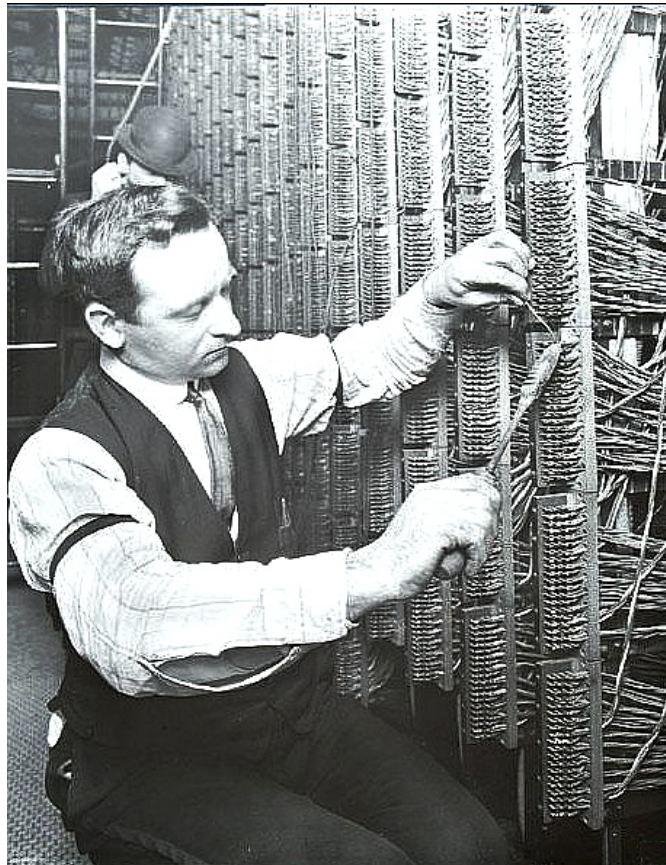


Figure 36. Soldering jumpers on the vertical side of the IDF

This is not an electric soldering iron, This type was heated in a small furnace fed by bottled gas (probably on the floor just out of sight in the picture).

Note the natty attire of the switchman (IDF work was often done by switchmen rather than framemen, which is not to suggest that framemen were attired any less nattily). (But see also section 23.)

Keep in mind that in a large central office there may be at least 10,000 of these jumpers in the MDF at any given time, so the job of placing new ones or removing obsolete ones in such a mass is not trivial.²² Normally, two framemen are needed to do the job (one on each side of the frame) and they may use long poles with hooks at the end to manipulate the jumper.

22.5 The intermediate distributing frame (IDF)

Probably, that telephone number has already been associated with a particular line circuit and thus a terminal on a line finder frame, to allow the line given that number to originate calls. This is done at the IDF.

The IDF consists of a metal frame much like that of the MDF, on each side of which are sets of terminal blocks. As for the MDF, on one side, these are arranged in horizontal rows, and on the other side, in vertical columns.²³ As on the MDF, in the interior of the frame the supports for the horizontal terminal blocks make up "open shelves" there are again metal distributing rings.

The blocks on the horizontal side carry terminals to which are connected all the pairs of the final selector multiple. The terminals here are organized by telephone number. These terminal blocks are also permanently connected to the blocks on the horizontal side of the MDF via *tie cables*. Thus, when a jumper is run from a subscribers cable pair (on the vertical side of the MDF) to a terminal on the horizontal side of the MDF, that has in fact associated that pair with the final selector terminals for that number.

The blocks on the vertical side have terminals which are wired (via a cable) to line circuits, which are mounted in the line finder frame. From each line circuit, conductors go (on that frame) to a terminal on the line finder bank.

²² Sometimes, the telephone company may adopt the policy that, when service is discontinued or a telephone number changed, the jumper is disconnected at both ends, but not "pulled" and discarded, so as to reduce the overall labor involved. Of course, after years of this practice, the jumper shelves become infested with literally tons of "dead jumpers", greatly increasing the labor to emplace new jumpers. "Pay me now or pay me later."

²³ Here these are normal terminal blocks, not "protector units", as in the case of the vertical side of the MDF, which makes the mechanical arrangements a little different..

Each telephone number is assigned (on a semi-permanent basis, not normally changed each time the number is assigned to a subscriber) a particular line circuit and line finder terminal). This assignment is based on the expected calling traffic from a line of that class; lines of different classes are, for the most part, assigned telephone numbers from certain blocks to facilitate this process. The objective of this plan is to spread the calling traffic evenly over the line finder frames.

This association of a line circuit and line finder terminal to each telephone number is effected at the IDF. Basically, a jumper is run from the terminal on the horizontal side for the telephone number of interest to a terminal on the vertical side leading to the assigned line finder terminal (by way of the line circuit).

22.6 Number of conductors

We see at each point on figure 34 the number (and identities) of the conductors in the various jumpers and office cabling runs.

Of course, the tip and ring of the line itself (T, R) are ubiquitous.

Once we get "to the right" of the MDF-IDF tie cable, we see the sleeve lead (S) added to the complement. This lead of course is used for various control purpose, perhaps most importantly to operate the CO (cutoff) relay in the line circuit when a connection is made to the line by either a line finder or a final selector. A corollary function is to advise a final selector, contemplating making a connection to a line, if that line is already busy (either by being connected to by a line finder or another final selector.)

There is one additional lead running from the line circuit to the line finder multiple, the "H" lead. When a line requests service, the line circuit puts ground on the H lead, and the line finder looks for that ground in order to recognize the line requesting service. And thus "H" stands for "hunt". Mezzanine distributing frames

In a large central office both MDF and IDF can be quite large. If the building layout does not allow them to be as "long" as is needed at the standard height (perhaps 11'6"—central office equipment rooms generally had 15' high ceilings), then the frame was made higher, and extended through a large opening in the ceiling/floor between floors in the building.

There would then often be platforms ("mezzanines") at various heights from which the workers would operate. (In the more customary

“single-floor” frames, rolling ladders²⁴ were used for access to the upper portions.)

23 ON THE ATTIRE OF PANEL OFFICE SWITCHMEN

During the era when the panel system was introduced, and in fact for a couple of decades later, central office switchmen wore suit trousers and a vest, and always a tie. We see a nice example of this in Figure 36.

But of course in as panel office, a four-in-hand tie could easily get entangled in the drive roller system or the sequence switch drive shaft, not healthy for either the switchman or the machine. So it became the custom that switchmen working in panel offices would wear a bow tie, and this then spread somewhat to switchmen working in any kind of office.

24 PBX TRUNK HUNTING

A small law office may have 3 subscriber lines, while a large department store might have 80 (in the later case, actually coming into a *private branch exchange* —PBX—at the store). In either case, the organization wants be able to promote a single telephone number (formally called the *guide number*), which a caller can dial, with the result that the connection should be actually made to any of the 3 (or 80) lines that is not busy.

In the step by step system, special connectors are used to provide this *modus operandi*, and subscribers needing 3 (or 80) lines will be given a number that is served by one of these special connectors (a different kind to accommodate the 80-line case than to accommodate the 3-line case).

But in the panel system, the provision for dealing with this situation is inherent in the system, and does not require that the guide number be in any particular number block (there are some constraints on it, however).

The lines in a group requiring this treatment are spoken of as “PBX trunks”, even though in the case of the law office with 3 lines there is no PBX involved.

The scheme revolves around being able to “mark” a line for one of two treatments if it found busy. One treatment is that if it is found

²⁴ They were suspended and guided at the top by a trolley running in a channel-style rail suspended from the ceiling. These were also used for access to the tall equipment racks (again, typically 11’6” tall) of the switching system itself.

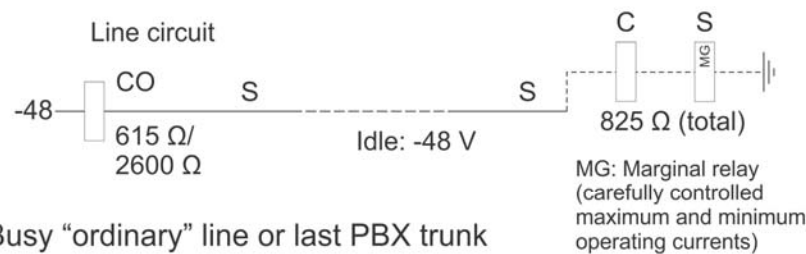
busy, that is the end of the story. The final selector returns busy signal back to the caller and resets. The second treatment is that the final selector then tries the next terminal.

So “ordinary” lines (not part of a hunting group) are marked for the “busy is busy” treatment.

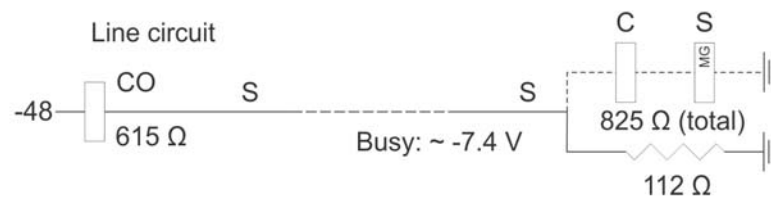
But lines in a hunting group are marked for the “if busy, try the next one” treatment, except for the last one of the group, which has the regular “busy is busy” marking.

In figure 37, we see some of the circuit arrangements that are involved in doing this (in a BCO-style office).

(a) Idle line



(a) Busy “ordinary” line or last PBX trunk



(b) Busy PBX trunk (not last one)

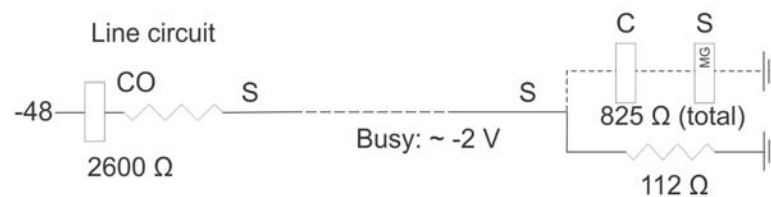


Figure 37. PBX trunk hunting

The difference between the two types of line is executed by a change in the resistance of the path that operates the CO relay in the line circuit. For a regular line (busy is busy), the resistance of that path is nominally 615 ohms (the resistance of the CO relay coil itself). But for a line that is to have “if busy, try the next one” treatment that

resistance is augmented with a resistor, bringing the total resistance of the path to 2600 ohms.²⁵

In panel (a), we see the idle situation for either type of line circuit. The open-circuit sleeve voltage is -48 V (though a resistance, of course). Now, we look in a little more details into what we before fancifully called the "BTG" relay. We see that in fact the busy test circuit comprises two relays, C and S. Relay C is a general purpose type, whose operate current is not precisely controlled in manufacture (but still is certain to fall between reasonably-close limits). Relay S is a "marginal" relay, whose operate current is well controlled in manufacture (and periodic field test and adjustment) to lie within certain quite close minimum and maximum limits (relatively low, in this case).

If a final selector comes to such a line, a substantial current flows through both C and S, operating both. The operation of C is taken to mean that the line is idle, and we know what that leads to.

In figure (b), we see an "ordinary" line, busy. The open circuit voltage on the sleeve is about -7.4 V. The current through C and S is now much less. C does not operate, but S does. The failure of C to operate is taken by the final selector to mean that the line is busy, but the operation of S is taken to mean that this is not an "if busy, try the next one" line. So the final selector does not connect to the line and returns busy tone to the calling line.

In figure (c), we see an "if busy, try the next one" line, busy. Because of the higher resistance of the CO relay path, the current through the 112 ohm resistor is less, and so the voltage on the sleeve is now only about -2 V. The current through C and S is now less yet. Neither C nor S operate. The failure of C to operate is taken by the final selector to mean that the line is busy, and the failure of S to operate is taken to mean that this is "if busy, try the next one" line. And it is busy, So the final selector moves to the next terminal and sees what it finds there.

In such a scenario, the final selector does not then stop at the next terminal to see what it finds. It moves continuously (albeit at its slow up drive speed), and looks at each line on the fly.

And of course, if it gets to the least line of the group, and that terminal shows busy—the situation in panel (b)—the selector stops and returns busy tone to the calling line.

²⁵ Every line circuit has that resistor, but "from the factory" it is shorted out with a short (!) "jumper". To change the class of the line, that jumper is just cut away.

A similar scheme (but sort of “other way up”) was used in the earlier GCO arrangement of operating the CO relay and marking the sleeve as busy. With it the “busy is busy” and “busy so hunt” states were not as clearly distinguishable, and so misbehavior of the relays in the final selector could cause the scheme not to behave properly, one of the motivations for moving to the BCO arrangement.

25 EQUIPMENT FINISH

I commented earlier on the corrosion-resisting finishes used on steel component during two different eras.

Also of interest is the evolution of the overall color scheme for panel central offices. The earliest offices had frames finished in a durable black asphaltum paint over a light gray primer, both of those hand-applied and air-dried. Items such as relay strip covers, and components in “cans” such as capacitors and repeating coils, were finished with various types of baked black japan enamel. It was black, black, black.

Designations were stamped²⁶ on frames, individual relays, relay strip covers, sequence switches, and the like in an “orange” ink (the actual color description was “vermillion”). Years ago some of us interested in this system, and having seen examples in that “livery”, called it the “Halloween” color scheme.

Why black? Beats me. Perhaps because this was a “machine”, and “machines” were in general black in those days.

In about 1927, perhaps inspired by the fact that step-by-step equipment, following the custom of Automatic Electric Company, was finished in an light “aluminum paint” finish, AT&T officials came to think that the working conditions in panel offices (including the effective utilization of illumination) would be improved if a lighter-colored livery were used.

Bell Telephone laboratories developed a new finish for central office frames (the No. 55 aluminum finish) and matching finishes for relay covers and the like (which had different requirements because of their usage). The choice of an aluminum-based finishes was that this was one of the few light finishes that could be baked (as was done with such things as relay strip covers), for durability, without discoloring (although the possibility of an actual gray finish was seriously investigated).

²⁶ The process was done using rubber stamps mounted on long wooden sticks. It was called by the technicians “stenciling”, a wholly inappropriate term.

This new color scheme was rushed into use starting in 1927.

Stamped designations on the aluminum-colored surfaces were then done in black. On individual relays, where the stamping was on a brown or black phenolic surface (very common), that was done in white.

During World War II, materials restrictions made it difficult to use aluminum as the basis for central office finishes, and light gray paint (not aluminum based) came into use as a temporary expedient.

But the new “temporary” finish was considered very attractive, and Bell Telephone Laboratories set about to develop a light gray (not aluminum based) finish suitable for ongoing use. Improvements in finish chemistry by that time made this practical. The resulting finish system then became the norm for central office equipment. Its most common form was designated the No. 525 gray finish.

26 THE ROTARY SYSTEM—PANEL’S COUSIN

When AT&T was developing a machine switching system suitable for large metropolitan areas, two different selector constructions came to the fore. Each had its pros and cons. Both were sufficiently credible that it was decided to proceed with the development of two different “subspecies” of the switching system, one using each selector concept. The idea was that after one or the other mostly-complete design approaches was chosen, it would be far enough along that it could soon be completed and ready for initial service.

Both systems followed the same overall concepts: common control using a sender, motor driven selectors, brush tripping to effect the most coarse level of selection, and control of the selectors via revertive pulsing.

One of the systems became the *panel dial system* we have been hearing about. In its selector design, from which it gets its name, the bank terminals for up to 60 selectors are formed *en bloc*, and the selector brushes run along a linear path.

In the alternate design, the selectors each have their own bank. The terminals are arranged in a curved bank and the brushes rotated²⁷. And so it was not surprising that this became known as the *rotary system*.

Of course the fact that each selector has its own bank requires that, if we were for example to have a group of 40 selectors all accessing the same collection of selectors in the next stage, the banks of all 40

²⁷ The selectors were in fact much like that we see in figure 12.

selectors would have to be externally “multiplied”, this requiring a veritable river of conductors running across the rear of all the banks, with literally thousands of soldered connections. (This is much as we have in the step by step system.)

As the two systems we examined, the following comparisons loomed:

- The panel type selector avoided the great labor of multiplying the banks of the various selectors with external wiring (by virtue of the integrated bank construction). But there was a large tooling cost associated with making these banks. Costly dies were required to punch out all the different contact strips—most of them quite long—used in the system.
- With the rotary selector, there was the large labor cost of multiplying the banks. But the tooling for the banks was relatively simple.

So; briefly, the panel system was capital-intensive, while the rotary system was labor-intensive.

An additional factor was that the “reach” of a rotary system selector was only 200 terminals, while for a panel selector, it was 500 terminals. A greater “reach” here is advantageous in arranging for most efficient use of the switching network, especially in the context of a larger metropolitan area.

It was recognized that, in the U.S. economic system at the time (1900s-1910s), with labor rates rising, and investment capital relatively plentiful, the best economic picture came from the more capital-intensive but less labor-intensive system: our beloved panel system. And the greater “reach” of the selectors was considered an important benefit in very large metropolitan area systems, which loomed large in the Bell System’s interests. Thus panel won the beauty contest, and (as we heard earlier) came to have a gigantic role in the mechanization of the Bell Telephone System.

But it was also recognized that in other parts of the world (Europe, South America) the economics favored the more labor-intensive but less capital-intensive alternative: the rotary system. And in the cities in those regions where the system would likely be used, the number of subscribers was usually not nearly as great as in the U.S. Thus the lesser “reach” of the rotary selectors was not as great a factor as in the U.S. So AT&T decided to promote the rotary system for manufacture and use in other parts of the world.

To most effectively pursue this, AT&T transferred the work on the rotary system to its Belgian manufacturing organization, Western Electric International, in Antwerp. They completed the design of the

rotary system in good style and put it into manufacture. It became very popular in many regions, in Europe, Africa, and South America, and most of all in New Zealand, where it was used in the big push to mechanize the national telephone network in about 1927.

As part of the settlement of a large antitrust action in the U.S., AT&T was forced to divest itself of most of its overseas operations, including Western Electric International. That was sold to International Telephone and Telegraph Company (ITT). The operation in Belgium became the Bell Telephone Manufacturing Company (that had in fact been essentially an earlier name of that part of Western Electric International). That eventually became part of ITT's overall telephone manufacturing enterprise, International Standard Electric²⁸. And it is that latter company name that became most associated with the manufacturing of the rotary system.

Only four rotary systems were installed in the U.S, all by fairly "progressive" non-Bell telephone companies, in Jacksonville, Florida; Rochester, N.Y.; Las Vegas, Nevada; and Elkhart, Indiana. The last of these, in Elkhart, was decommissioned sometime in the early 1980s.²⁹

We should note that there is often (for no reason I can understand) confusion between this system and the notion of the "rotary" telephone dial, a metaphor for "machine switching" overall, or later as distinguished from the "pushbutton dial". ("So, what switching system did you have in Elkhart?" "Rotary". "Yes, we had the rotary system for many years in Cleveland, but then got pushbutton dialing.")

27 AND SO MUCH MORE

In this article I have just "scratched the surface" of this amazing creature. There are ever so many features I haven't mentioned (I hardly know them all myself), including elaborate provisions for continually checking to see if anything has not operated properly, and dealing with it if so; provisions for manually-initiated testing; and the like.

Then there is the matter of, if completed calls are "counted" for billing purposes, how does that work?

And how is the ringing handled on multi-party lines?

²⁸ The begats here are very entangled, and I don't pretend to understand the whole thing.

²⁹ I had the wonderful opportunity to visit that machine shortly after it had been taken out of service but was still "lit" (the owning company having in mind that somebody might want to buy it).

And what about calls to the “local operator”, or the long distance operator? And how about incoming calls from the long distance network?

Another fascinating and gigantic area, to which I have only barely alluded, is that of how panel central offices interoperate with manual central offices over the often protracted program of converting a major city completely to “dial” operation. Among other things, this involved a wholly-different signaling system, when later came into use outside its original realm.

28 SUMMARY OF VINTAGES

The table in Appendix A summarizes the major design changes in the panel system through its period of adolescence, 1920-1929.

29 ISSUE HISTORY

Issue 6, (this issue) June 15, 2018. Added photos of original Newark office common motor drive system. Improved description of duplex motor. Various editorial corrections and improvements.

Issue 5, June 4, 2018. Extensive revisions.

Issue 3, April 12, 2018. Improved the description of the 1203-type selector and the concept of translation in the sender for two-digit offices

Issue 2, April 12, 2018. Included description of the 1203-type power rotary selector. Corrected the material on the rotary sender link. Updated the discussion of translation in the sender for two-digit offices. Improved the discussion of the brush finger shoes. Various editorial corrections and improvements.

Issue 1, April 11, 2018. Initial issue.

30 ACKNOWLEDGEMENTS

Thanks to the many telephone equipment aficionados who have been kind enough to post in the Internet a number of training manuals on the panel system, which were invaluable as I prepared this article. This collection was much more extensive than my own, which in any case had flown the coop over many years of relocation and “downsizing”.

Special thanks go to R.E. Hersey of Bell Telephone Laboratories, whose monumental tutorial on the Panel Dial System (done in 1928-1929 as the “course notes” for an “out of hours” training course) was a major reference for me as I prepared this article.

Also valuable is a scan of what appears to be "C. Ryan's" copy of an extensive training course book on the panel dial system of the "BCO" type (dated February, 1955), complete with extensive annotations. And the same for a comparable book on the "GCO" type of panel office.

And thanks to "neverether" for uploading these scans and many other valuable documents from the collection of the Connections Museum, Seattle, to the Internet Archive.

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Appendix A
Panel office vintages 1920-1929

Year introduced	Line access	Translation	Sender access	Cutoff circuit	No. in service
1920	Line switch (rot ¹)	Sender	Sender selector (rot.)	GCO	15
1920	Line finder (300 ²)	Sender	Sender selector (rot.)	GCO	69
1924	Line finder (400 ²)	Sender	Sender selector (rot.)	GCO	15
1926	Line finder (400)	Sender	Sender link (pwr rot. ³)	GCO	18
1927	Line finder (400)	Sender	Sender link (panel ⁴)	GCO	40
1928	Line finder (400)	Decoder ⁵	Sender link (panel)	GCO	19
1929	Line finder (400)	Decoder	Sender link (panel)	BCO	Note 6

Notes:

1. Using stepping rotary selectors (200-type)
2. Number of lines potentially served by one line finder group (called "300 point" vs. "400 point").
3. Using "power" rotary selectors (1203-type)
4. Using panel selectors
5. Before the advent of the decoder for translation, the senders used rotary selectors for dial pulse counting and registration. After the introduction of the decoder, these sender functions were all done by relays.
6. Ongoing for many years. This was the "real thing".