Introduction to NXSYS interlocking logic

Table of Contents

Warning, advisement, disclaimers....................2

NX Interlocking Logic Design....................3

Vital and Non-Vital Circuits....................5

Tri-State style....................7

Signal Control Relays — H, HV, HY, D, DV....................9

Approach Locking Relay — AS....................10

Signal Call Relays R, PBS — not here....................11

Stop control — V, VS, VPB, NVP, RVP, (and in part HV, DV)....................11

Switch relays — N/RLP, N/RWZ, N/RWP, N/RWC, L, LS....................13

Switch locking relays — LS and L....................13

Route Locking — NS, SS....................14

Route Selection — PBS, XS, R, N/RWK, ANN, BNN, RS, etc....................15

Selection network inhibition (use of NWC and RWC therein)....................22

End-to-end routing ("Through Routing")....................23

Time signals....................24

NXSYS-specific relays and protocols....................25

Symphonic synopsis — all the actors in action....................26

Powerful Topomorphic Circuit Example....................28

Warning, advisement, disclaimers.

PLEASE READ

The following explanation is intended as a guide to help those who so desire understand the signal circuitry run by **NXSYS**, and perhaps help them design their own **NXSYS** interlockings. It explains the principles by which these circuits were designed. It is not intended as career training in, or a definitive reference, on signal engineering. While derived from standards used for many decades in New York and some other rapid transit systems, this information is not a substitute for career training and experience in safety engineering; what is presented here is only a most basic introduction to this type of design presented for general curiosity and to help others "program" **NXSYS.** The author, who is an amateur signal enthusiast, not a professional signal engineer, also wishes to share his understandings and ability to explain them. The author assumes no responsibility for any use you make of this information, including infringing on any copyrights, patents, or other applicable rights, any harm, injury, or damage which results from use of this information, or from possible errors, ambiguities, or misrepresentations in it.

While one could master the principles outlined here, the extension of these principles to real-world cases and situations not covered here in a safe and reliable manner is by no means obvious, as the author has discovered to his own chagrin. Entire massive mechanisms (e.g., traffic locking, switch emergency release, automatic control) are not discussed here at all. Please treat the information here as a book about the mechanics of airplanes: **DO NOT** attempt to fly off a cliff with what you read there, or claim to be a qualified signal engineer based upon what you read here—the author disavows all liability and responsibility if you do.

While flight simulator training is now a critical part of pilot training, and flight simulators are invaluable to non-pilots who wish to learn more about flight, no amount of time spent with the best flight simulator and its helpfile qualify one to endanger life and property at the controls of an aircraft. The same applies here.

(Note in August 2020): Relay-based signal control and interlocking is largely obsolete. Block signalling, in particular, does not allow headways as tight as does communications-based train control (CBTC). Since NXSYS, and this document, were written, relay-based wayside block signalling in New York City (as served for all of the twentieth century) has been assailed as a dangerously archaic relic responsible for all natures of transportation failures (in no small part due to the difficulty of obtaining replacement parts). Cruelly, the COVID pandemic has solved the need for tighter headways in another way, for a while, but relay-based wayside color light block signalling will not have much of a role in transportation systems of the future. Yet, these relay logic paradigms remain a beautiful *pas-de-deux* of safety and operational power, and thus merit study, perhaps as an artifact of an only recently bygone civilization.

NX Interlocking Logic Design

This document is an introduction to the design of **NXSYS** interlockings, which is the same as the basic design of the relay-based interlockings it is designed to model.

It is assumed that the reader of this document has read and fully comprehended all of the signal and interlocking concepts explained in the main **NXSYS** help file, and fully understands what all this hardware is supposed to do. No one who does not play an instrument should attempt to compose. Some acquaintance with basic electrical engineering and logic design is also assumed. As the author is a software engineer (not a signal engineer), the architecture of this description treats its subject as an abstract system in the manner of computer science.

This description does not describe the operation of every last feature, or the need for every last contact (NYCTA typical drawings 733-33 in fact do describe every contact), but describes most features and most relays. Given knowledge of the operation and intent of the system, this description, and a set of interlocking drawings (or sources, for **NXSYS**), you should be able to figure out the significance and purpose of all contacts. Please also be aware that **NXSYS**'s interlockings, as life does not depend upon them, are imperfect: they are not claimed to be bug-free, and in some cases (hopefully fewer as time goes on) transgress the principles stated here.

As with any well-designed system, the implementation of interlockings consists of elements and layers of abstraction that concisely and accurately represent its key concepts. In interlocking implementations, those elements are relays. A relay corresponds to a boolean variable in a programming language, or a significant gate in silicon logic. Its state (up (picked, coil energized) or down (dropped, coil deenergized)) represents the truth or falsity of a given assertion about a given object: a switch, signal, stop, or track section. When a relay is picked, its "front contacts" conduct current, and its "back contacts" do not. When dropped, the back contacts conduct, and the front contacts do not. The name of each relay consists of a number identifying the object, and a sequence of letters (*nomenclature*) identifying the assertion about the object represented by the relay's state.

For instance, the relay named **2R** represents signal 2 being called ("route complete"): if it is up, 2 is called, if down, 2 is not called. Relay **4714T** represents track section 4714 being unoccupied: if up, it is unoccupied, if dropped, it is occupied. Relay **15NWP** indicates by its being up that switch 15 is known to be securely in the "normal" (not thrown) state.

As each relay has two states, it can conceivably represent its defining condition or assertion in two possible ways, that is, the up/down status of the relay can correspond to the condition being true or false respectively, or to it being false or true, respectively. In signal design, the choice is always made by the following rule: the relay being dropped shall represent the safer of the two conditions, or the condition that will cause the most restrictive assumption possible: report *the most dangerous condition*, but create the *least dangerous state.* Therefore, the **H** relay of a signal picks to clear the signal. If burned out or its fuse is blown, the signal will not clear. A track relay picks to indicate the track is vacant. If the relay or track is broken, or short-circuited, or a fuse is blown, it will report the presence of a train, which will most restrict other operations. Note that this means that some relays are picked almost around the clock; such is the life calling of a railroad signalling relay.

A relay can be controlled by a circuit involving its own front contact—this provides positive feedback, and causes the relay, under appropriate conditions, to remain up once picked until some other condition breaks the feedback loop. Such a contact is known as a **stick contact,** and the relay is said to **stick** or **retain** through the stick contact and the other contacts of other relays in series with it. This fundamental and common technique allows relays to be used as memory devices. (A relay circuit cannot include its own back contact—that is the essence of an electromagnetic buzzer. Several relays including each other's back contact form a system with multiple stable states if correctly designed, and an expensive buzzer if not).

Please note: when this document describes the contract of a relay with a statement such as "The **XR** relay is responsible for checking that an exit at the first network is possible, and simulates an initiation in the second," it means that in both real-world and **NXSYS** interlockings designed according to the standards under discussion, there are relays called **2XR, 4XR,** etc., who, by virtue of the design of their circuits and the circuits in which their contacts are used, in fact perform the function described. There is nothing "intrinsic" about these relays that accomplishes these tasks: they are merely logic elements, and could be labelled or named anything at all were some other standard being followed.

On the other hand, when a statement is made of the form "**V** is actually the (train) stop itself", that means in real-world interlockings designed according to this standard, there is an actual air valve or motor controlling a train stop, and **2V** or **4V** or **228V** is a typical name assigned to it, while in **NXSYS,** the latter's panel, train, and cab view mechanisms "know about" relays with this name, observe their operation, and manipulate train stop graphics based upon their state. When a reference is made to a relay operating lamps, switches, panel lights, etc., or observing the actual position of a stop, switch, etc., while it does so in the real world only by virtue of its wiring according to the standard at hand, it does so in **NXSYS** because the simulator "knows" about that particular name (**NVP, RWP,** etc.) and implements this function in coordination with that relay.

The particular set of relays/nomenclatures known to the **NXSYS** panel simulation engine, and the semantics it ascribes to them, are not described in this file, but in **RelayLanguage.md** (in the GitHub repository).

A couple of words on terminology. Those in the field, as it were, often refer to relays that represent some locking condition or state (usually, “picked” is “unlocked”) as *lockers,* e.g., route-locking relays as *route lockers.* Also, the notation ***WC** (etc.) means **NWC** and/or **RWC** (depending on context), or similar normal-reverse or north-south pairs.

Vital and Non-Vital Circuits

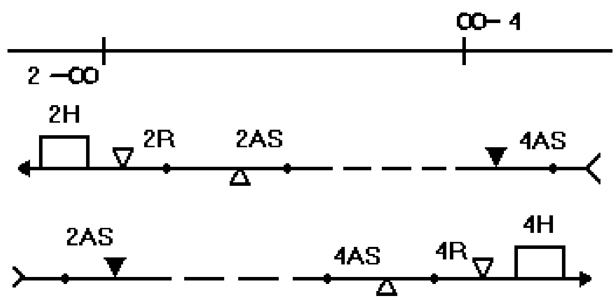
An interlocking is essentially a two-level machine, consisting internally of a higher-level “control” machine which orchestrates the operation of a lower level machine comprised of the signals and switches. This “lower-level” machine is called the **vital circuitry** of the interlocking, because life and limb depend on its proper functioning. The **vital relays** of the interlocking are those that directly implement safety-related functions: track relays, the **H** and **HV** relays which clear a signal, the **AS** relay that verifies that approach locking is reset, the switch **NWC** and **RWC** relays that verify that a switch is in correspondence and **LS** that locks it are the standard examples.

This distinction is a feature of the implementation of interlockings, not their operating specification, and thus, it cannot be inferred from the information in the main helpfile. All the relays of automatic signals are vital.

The vital (i.e., the lower-level) machine considers the non-vital (e.g., higher-level) machine to be an untrusted, potentially unsafe source of commands. For example, a signal lever can only give permission to a signal to clear—it cannot *force* it to clear. While every attempt is made to prevent the non-vital machine from creating conflicting or unsafe commands, this architecture enforces an additional degree of safety. The non-vital machine, by the same philosophy, extended, treats the tower operator him or herself as an untrusted source of commands: An incompetent, a terrorist, or a chimpanzee operating the interlocking controls cannot create an unsafe situation. The design must maintain the principle that even a catastrophic failure of non-vital circuits cannot place the vital circuits in an unsafe state.

Vital relays are required to be of a higher quality than non-vital relays. This higher-quality (“vital-type”) relay is also used in non-vital circuits whose contacts appear in vital circuits, being specifically the critical control relays by which the non-vital level conveys its commands to the vital level (**R** and **NLP/RLP** are the canonical examples). The use of cheaper relays for non-vital functions allows for economy and expanse in the design of the non-vital control circuitry. (In more modern technologies, software can serve as the non-vital level; the non-vital relay level can usefully be imagined to be an early kind of software).

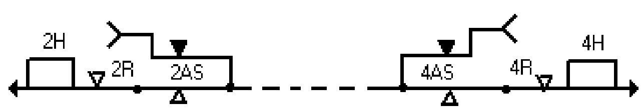
The vital relays form a network which, by virtue of its topology, cannot create conflicting or unsafe routes. For example, if two signals at two ends of one extent of track at an interlocking govern movement into it in opposing directions, the circuit for each signal’s **H** relay (which directly clears it) checks not only that the AS relay of the signal at the other end of the route is up, but that its own **AS** relay is actually dropped. This renders impossible the simultaneous picking of two conflicting **H** relays, regardless of the meaning or significance, or even correct operation, of the **AS** relay: no relay (i.e., either **AS**) can be up and down at the same time. It is thus electrically impossible for the two **H** relays of the opposing signals to simultaneously be up, and thus, it is impossible for two opposing signals to be clear at the same time, even if the non-vital **R** circuits erroneously gave permission to both signals' **H** relays to clear at once. The situation is illustrated in the following simplified diagram:



Vital consistency enforced between H relays

(In the real circuit, AS (approach lock relay) is hardly a passive bystander. Were one or the other **H** relay in the above example to become or remain picked by virtue of a failure, say a malicious insect that bores into plastic cases and sticks relay contacts, that would would cause the **AS** relay of that signal to drop (or not pick up), which would drop the other **H,** forcing the signal to red, at once.)

The actual real-world circuitry for this, and much of the circuitry under discussion, employs circuits where multiple relay coils are all part of one circuit, sharing contacts and power sources and routing current around a circuit whose topology is identical to that of the track layout controlled (I have thus dubbed them "topomorphic" circuits, i.e., *place-shaped*). This elegant technique is at least a century years old, and not only conserves contacts and wires, but contributes logically to the safety of the circuit. The two circuits above would look like this:



Topomorphic (shared-wiring) circuit for above

Notice the use of combined front-back ("**SPDT**" (single-pole, double throw)) contacts for the **AS** relays. Not only is simultaneous energization of both **H**s impossible for the reasons given above, but current would have to bridge the gap across the two stationary poles of a single moving contact for such a failure to happen. Note also how all of the conditions which are necessary for the clearing of both signals (e.g., locking of switches between them) can be expressed naturally in the shared wire (shown dotted). (**NXSYS** does not now support multiple-relay and topomorphic circuits; it may in the future).

A more powerful example of topomorphy will be shown at the end!

Typical examples of non-vital circuits are the switch selection relays **ANN, ANS, BNS,** and the **PBS** and **XS** relays which respond to the pushing of entrance and exit buttons.

The non-vital circuitry can be thought of as all the clever and complex mechanism to simulate the towerman of an old-style lever interlocking, and the vital circuitry the levers and everything they operate (although this analogy is not exact). The vital circuitry must itself be consistent and incapable of being in unsafe states, regardless of any type of failure whatsoever of the non-vital circuitry. In fact, in much recent signalling, the non-vital circuitry is replaced by software. One can even think of it as a kind of abstract software operating the "hardware" vital machine.

In an older form of Central Traffic Control no longer used in new work in New York, the central tower contains an NX panel with all the non-vital selection circuitry, and operate the vital circuits of distant interlockings by remote control. (More recently, the non-vital selection logic is at the interlocking site, and the pushbuttons of the NX panel can be operated from the local panel or the central tower).

Tri-State style

(This technique is surely used in New Jersey and Connecticut as well.)

All of the devices used in signalling have two "healthy" states: a switch is either normal or reverse, a signal clear or not, a stop up or down. Signalling, however, is about the exceptional as well as the "healthy", and all such devices are considered to have three states, the two "healthy" states and "undefined". No mechanical device is ever assumed to have acted as requested of it; response states are verified as needed.

For example, a switch can be normal, reverse, or "unclear": the latter would include in not only "in transit" or somehow stuck in transit, as it were, but also appearing to be in neither "healthy" state because of a failure reporting positive evidence of either such. The trackside switch controller has contacts on it that report the switch being fully engaged in the normal or reverse states, respectively, with all mechanical locks and bolts in place, to relays called (for each switch) **NWP** and **RWP**. If all the locks and bolts are not in place, or the switch stops in the middle, or the controller contacts fail to contact, neither relay picks, and no circuit depending upon it being in *either* healthy state will operate.

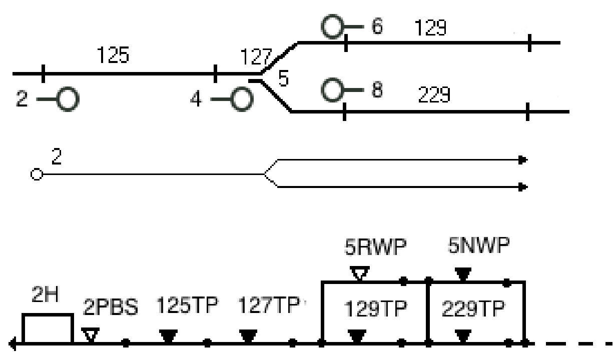
Some functions require a train stop to be up—a switch is locked by the train stops around it: they must be up for the switch to unlock. Other functions require the train stop to be down: a signal will not clear unless its stop is down. In signalling, up is not the opposite of down: either state must be verified by contacts on the device (or a relay repeating them) confirming that the device really is in the position required.

As failure to pick (broken wire or coil, blown fuse, power source, contact failure, etc.) is more common than false picking or failure to drop, every single relay reporting a position of a device (e.g., **NWP, RGP, NVP**) is defined to be *picked* when the condition it represents is true. That way, the more common class of failure engenders the safer failure, i.e., failure to confirm a condition necessary to permit an action.

Because of these issues, it is extremely uncommon to use back contacts of vital indicator relays (other than check on the relay position itself as opposed to the condition it represents, such in the **AS** back-check in the circuit just discussed—there are also cases in the implementation of the LS (switch lock) relay where it is necessary.) A relay whose circuit has two legs for a signal's control lengths, two contingencies over a facing-point switch will have a circuit which splits at **NWC** and **RWC** contacts for the same switch: use of front and back contacts (or combined front-back) on one or the other such relay is precisely what **not** to do.

(Do not confuse the above warning on back contacts of vital indicator relays with the extremely common, essential, use of back contacts on the non-vital switch indicator relay, **NWK/RWK.** See the section on non-vital route selection later on.)

Related to the above issue is that of switching between two completed legs of a circuit without dropping the circuit during the transition. Much use of this derives from the NYC standard that a facing-point switch in transit is not considered a hazard in the control length of any signal except the home signals immediately protecting it, that is, the overlap of a home or approach signal does not, in general lock a facing point switch (the case of "facing point overlap" involves throwing a red signal at a train, not the train derailing on a moving switch). Consider the following track diagram and circuit:



Front-contact continuous ("ride-out") style

Here, occupancy of 127, 129, or 229 will lock switch 5, as will signals 4, 6, and 8. But with 4, 6, and 8's approach locking reset and all these track sections vacant, 5 is not locked, even if 2 is clear. On grounds of the above paragraph, moving switch 5 (say, from normal to reverse) when 2 is clear must not "kick off" 2 during the transition, i.e., when neither **5NWP** nor **5RWP** is picked. The above circuit technique can be seen to ensure continuity during the transition between the two "good" states as long as both of those states are really "good" (i.e., the series circuit of **129TP** and **229TP** is in fact continuous). This technique, placing contacts representing different conditions in series while riding out the ones known to be ignorable with relays confirming positive conditions, finds much application in vital circuitry. (**NXSYS**' **SWIFNC** Lisp macro allows convenient programming of this circuit formula. NB**.,** ***WP,** also vital, is sometimes used here instead of ***WC** to solve timing issues.)

Signal Control Relays — **H, HV, HY, D, DV**

The most important relay associated with every signal (other than markers) is **H,** for "home". The **H** relay clears the signal and stop. If the signal has no stop (e.g., a dwarf signal), **H** actually controls the signal lamps. If a stop is involved, an additional relay, **HV,** controls the lamps, "and"ing the stop (**V** for (pneumatic) "valve") being clear and **H,** to ensure that the signal will not clear until the stop is clear, and will not clear if the stop is defective. Since **H** also clears the stop, **H** is the final authority on clearing a signal. **H** is the canonical vital circuit.

A home signal also has a **CO** relay, which clears a call-on aspect, whose circuit is almost identical with that of its **H** relay (in real life, the wiring is shared, but **NXSYS** does not yet support the representation or simulation of circuits with multiple relays sharing wires). Except for the **COS** relay which selects the call-on, the only difference between the two relays is the front-contact of the **HY** relay, checking track occupancy, in **H** but not **CO.** In the discussion which follows, virtually everything which is said about **H** applies to **CO** as well.

H (and **CO**, when applicable) implement the basic notion of control length. These relays are responsible for checking all conditions in the signal's control length required to clear the signal. And, as already mentioned, they check not only the absence of conditions that would oppose this route, but the "unsafe" states of the relays that would indicate such opposing conditions (that is, the clearing of this signal) to signals opposed to this route.

The most fundamental item in any **H** relay's circuit is *slotting*, i.e., the checking of the track circuits in its control length for vacancy, implemented by the a series chain of the front contacts of the correct track relays (**TP** in real life, often **T** in **NXSYS**—real **T** relays are arcane items that have very few contacts). For automatic and approach signals, these contacts appear in the **H** circuit. For home signals, they are subdelegated to the **HY** relay, whose sole function is this, and whose front contact is included in the signal's **H** circuit, but not its **CO** circuit.

For an interlocked signal (home, approach, or dwarf), **H** must check first and foremost the call for the signal (**R** for home or dwarf, **PBS** for approach). Secondly, **H** must check opposing route locking relays (**NS, SS**), and the approach locking relay (**AS**) of the opposing signal at the end of its route for being in the safe (up, no route) state. Thirdly, as explained above, **H** must *also* check every similar relay in its *own* direction for being *down,* to ensure that the **H**s (and **CO**s) of other, conflicting signals, which check these same relays to be *up,* can be guaranteed to be down and cannot pick up.

Finally, **H** verifies that the switches in the route are locked by checking back contacts of their **LS** (Lock Switch—switches are only free/safe to move when it is picked; its being down locks the switch) relays i.e., verifying their *restrictive* state, as well checking their switch "correspondence relays" (**NWC, RWC**), to verify not only all switches in the route being in correspondence, but trailing-point switches being in the correct state, and to choose, through the position of facing-point switches, which opposing relays are to be checked.

This means, of course, that the **H** relay cannot pick until all the same-direction route locking and approach locking which is checked has dropped out, so it must drop out as a necessary precondition for clearing the signal. Thus, the non-vital **R** (for home or dwarf) or **PBS** (for approach), which calls for the signal, drops **AS** (see the discussion of AS).

H relays for GT and ST signals (or **HY** for a home signal) will contain contacts for appropriate track-occupancy-triggered timers (**U, US**) to implement these timing functions. (*NB* Do not confuse the **U** timer of a track section, used for GT/ST, with the **U** timer of a signal, used for time locking.)

Signals that have green and yellow aspects also have a **D** or **DV** relay, which merely repeats the **H** or **HV** of the next signal down the line, to choose between these aspects. **DV** involves the "stop self-check" feature described under "stops" in the main helpfile, in a way where **HY** is used for home signals. Please see Stop Control.

H/CO circuits for home signals back-to-back with others must take into account special considerations for the shared stop (see the "Back-to-back" section of the main helpfile); parallel back contacts of same-direction route-locking and track for the approach section of the signal must appear in these circuits, preventing clearing in absence of approaching route or train, on account of the rationale discussed there.

In real life, **H/CO** circuits also check the "checking contacts" of approach timer relays, which verify that they are not in the process of timing, to verify that these timers have not gotten stuck. As this is not (presently) a concern at **NXSYS,** its interlockings do not make this check.

Approach Locking Relay — **AS**

As the **H** relay is the fundamental relay of clearing a signal, **AS** is the fundamental relay of asserting that it is not clear. As explained under 'approach locking' in the main helpfile, almost every interlocking function that seeks to verify that a signal is at stop *really* wants to ensure that it is at stop, is not called, and, if there is a train in front of it, has been at stop for a significant long time. That is precisely the assertion of the (up state of the) **AS** relay of a signal, and that description, and the discussion of approach locking in the main helpfile, determine its circuit completely.

Signal call (**R** for home or dwarf, **PBS** for approach) drops **AS**, as does the signal actually being clear (**H, HV, CO,** repeated by **RGP**). Trains in approach to the signal prevent **AS** from picking back up when the just-stated conditions for **AS** pickup are met, and start the signal's **U** timer running, which rides out the approach limit contacts when the timer has run its course. "Quick release" by the train occupying the detector section of the switches locked by the signal does the same, as described by the main helpfile. For overlapped home-signal locking, the quick release condition is the train “straddling” the near and distant track networks, as explained there.

A couple of notes: The **RGP** (red signal repeater) relay is used to verify that a signal is actually at stop by checking its immediate control relays, **H, HV,** and **CO.** If a semaphore signal were involved, **RGP** would actually check its position. As explained above, even though the relays it checks pick up to clear the signal, **RGP**’s picked state represents all those relays being *down.* Since **RGP,** in some implementations, might be connected and powered through relays at trackside, it might drop out during a temporary track signal power failure, which would drop **AS** and all relays dependent upon it. Therefore, interlocking control relays which might have to retain their state for long periods in an unattended tower and check **AS**-derived relays must take care to ride out these contacts with stick contacts to prevent their own, permanent, dropout, during such episodes. As such failures do not happen at **NXSYS**' interlockings (although can be simulated with Bobble all signal repeaters), this design guideline is not currently followed rigorously at its interlockings.

The same is true of the “quick release” contacts, which invert the normal safety protocol of the **T** relay. While normally, “occupied” is the safer state of a track section, occupation can “quick release” approach locking, which is less safe; since temporary track power failure can drop track relays, special precautions (power-check relays) are used in the quick-release leg of the **AS** relay in real life.

Signal Call Relays **R, PBS** — not here

Although the relays that indicate a call for a signal, **R** for home and dwarf signals, **PBS** for approach, are central to the operation of interlocked signals, we will postpone discussion of them until the discussion of the non-vital route selection network, because that is to what they belong.

Stop control — **V, VS, VPB, NVP, RVP,** (and in part **HV, DV**)

As stated, a signal's stop is controlled by its **H** relay. As discussed in the “stops” section of the main help file, the stop can also be driven down by the automatic-key-by (AK) and call-on mechanisms for automatic/approach and home signals, respectively, or by reverse-direction motion over it governed by opposing home signals.

V is the stop itself. At electropneumatic interlockings, it is the actual valve letting air into the cylinder which “drives” the stop down (it is counterweighted (or, more recently, spring-loaded) to be up unless driven down). At **NXSYS**, **V** controls the three different stop graphics. **NVP** and **RVP** (in **NXSYS** driven by the simulator) repeat contacts on the stop verifying it actually being fully up or down —one is not the inverse of the other (see Tri-state style). Both, according to protocol, pick for their “safe” situation—**NVP** is used to verify the stop up to lock switches (in switch LS circuits), and **RVP** is used to verify the stop down for the **HV** relay of the associated signal, and sometimes, in the slotting relay (**HY**) of signals clearing off-side motion over it. Please see the main helpfile section on “back-to-back” signals for conditions mitigating this.

Stops of automatic and approach signals are driven by the front contact **H** relay of the signal in parallel with the a back contact of the track section in advance of the signal, which latter implements AK, clears the stop for emergency reverse motion, and holds it down while a train passes the signal. While it might be thought unsafe that a failure of the track relay will drive the stop, recall that this is no more unsafe than a train being there; either will, by virtue of the control line overlap necessary to make AK safe at all, cause the stop of at least one preceding signal to come *up.*

VS is used to drive down an “off-side” stop (in other cases than back-to-back home signals, in which case the stops operate together). When there is no back-to-back signal, the off-side stop is a potential hazard, and must be driven down. **VS** is driven by the **R** relay of the signal which has cleared motion over the stop, and sticks through the back contacts of the route-locking relay of the section in approach to it; that way, the stop is held down even after the driving signal is cancelled by train motion (if not fleeted). Please refer to the discussion of Route-locking relays.

Note that **VS** is driven by a non-vital relay, **R,** but drives a vital function, the stop. The home signal **V** circuit (see any home signal at Progman St.) is quite a subtle thing; it contains checks on the track sections on either side of the stop that prevent it from actually going down, when driven down by **VS** if there is a train facing it (which is the only case in which its state matters) until the train whose motion is driving it down actually approaches: this minimizes the effect of any such failure by requiring such a train to appear in the only case that matters (i.e., when a real train faces it.) The handful of contacts in this circuit, visible in the **HomeV** relay macro, also ensure that the stop stays down as a train in either direction passes across the stop and comes up behind the train in either case.

VPB is the motorman’s call-on button, the yellow box next to the signal, which drives the stop if there is a train in front of the signal and the button is pressed. When the button is pressed and the stop goes down, **V** stays (driven) down (retains) as long as there is a train in approach to the signal.

The stop circuit for a marker signal is a simplification of that for a home signal, with no **H** relay and no call-on; all the **VS** and retaining logic is identical.

Home, automatic, and approach signals contain a “stop cycle check” feature (as described in the main helpfile “Stops” section) to verify that stops and vital relays are operating properly. The basic idea is to use a vital relay whose state theoretically doesn't matter while the signal is red to verify that the stop has really come up before clearing the signal. For an automatic or approach signal, this is **DV**, for a home signal it is **HY.** When **HV** indicates that an automatic or approach signal is red, its **DV** relay (which normally selects between green and yellow) is appropriated (by **HV** contacts) to check **NVP** instead of the next signal's **HV**; the current signal's **H** will not pick up until **DV** does, at which point it will stick around the **DV** contact. Thus, if the stop is down for whatever reason, it *must* come up (**H** being down should be sufficient reason) before **H** will pick and drive it down. The same trick is performed for a home signal using **HY** instead of **HV** and **DV; HY** will stick around the **NVP** contact. See any of the **HY** circuits at the sample interlockings.

Switch relays — **N/RLP, N/RWZ, N/RWP, N/RWC, L, LS**

NWZ and **RWZ** are the *switch control relays,* which actually operate the switch, the air cylinders in an electropneumatic interlocking, further control relays in an all-electric interlocking, and the cybernetic switches in **NXSYS.** One or the other, only one, is picked at all times, and each locks out the other; they are literally a D-type flip-flop implemented in relays. If **NWZ** is picked, the switch is "supposed to be" normal—if not normal, it will begin to move normal as soon as **NWZ** picks, and stay normal as long as **NWZ** is up. If **RWZ** is picked, the switch is "supposed to be" reverse—if not reverse, it will move reverse and stay reverse as soon as **RWZ** picks. There is no further checking beyond **RWZ** and **NWZ.**

A switch's **NWZ** and **RWZ** are operated by its *switch lever repeater relays,* **NLP** and **RLP,** which represent calls for the switch (to move). These latter two circuits are non-vital: a towerman can call for the switch at any time by manipulating manual switch keys **RL** and **NL** (in **NXSYS** simulated by clicking right on the switch). The non-vital route selection system also calls for switches by operating these relays. (**NLP** and **RLP** do, however, cross-check each other: they cannot issue both calls simultaneously.)

Switch locking relays — **LS** and **L**

What prevents these arbitrary non-vital manipulations from freely moving a switch with blithe abandon is its quintessentially vital **LS** (lock stick) relay. Unless a switch's **LS** relay be picked, **NWZ** and **RWZ** are gated off: they ignore **NLP** and **RLP**. **LS,** which is absolutely critical, checks every possible locking condition described in the helpfile: front contacts of track sections containing (or adjacent with to with no intervening signal) the switch (detector locking), the front contacts of route-locking relays for track sections containing the switch (which in turn checks approach locking (**AS** for signals protecting the switch)), direct approach locking (**AS**) for home, dwarf, and approach signals whose control lengths overlap the switch, the actual stops (**NVP**) of home signals protecting the switch being raised, facing point overlap lock (see the main helpfile), and any other condition which is supposed to lock the switch. Note that in addition to **LS'**s critical front contact gating off **NLP/RLP** access to **NWZ/RWZ**, **LS's** back contact is checked by the **H** circuits of signals clearing motion over the switch, to verify that such locking is indeed in effect.

An **L** relay is used in the cases of facing-point overlap and conditional crosslock (see the main helpfile, "Advanced locking scenarios"): all conditions **except** the facing-point overlap and conditional crosslock are relegated to the **L** relay, while the **LS** relay checks the **L** relay and the complex overlap conditions. This facilitates using a front contact of the **L** relay in the selection network to allow the latter to distinguish the facing-point overlap lock case, and allows routes to be requested that cannot be realized (preconditioning) until the train causing the overlap moves on. In the case of conditional crosslock, this strategy facilitates route selection under the assumption that the conditional crosslocks will be resolved by the completed route or routes; nonetheless, great care must be exercised in the selection network to distinguish cases in which this assumption is correct from the rest.

Although in latest standards, conditional crosslock is implemented in **L/LS,** as described, it was previously implemented in **NWZ/RWZ.** The intent and effect of both are similar: to impose an order on the moving of the two crosslocked switches, serializing the switch moves that would otherwise occur simultaneously, while attempting to factor the (potentially transient or resolvable) complex locking condition out of selection decisions.

NWP and **RWP** (*switch repeater relays*) are operated directly by the switch machine (or the **NXSYS** switch simulation) when the switch has fully moved to a stable position; when the switch is in transit, or stuck in transit, neither is picked.

NWC and **RWC** are the *switch correspondence relays,* of critical significance. These assert that the switch is "in correspondence," i.e., in the position that the switch control relays (**N/RWZ**) want it to be. Except for occasional use of **N/RWP** contacts in situations where some other function has already verified correspondence (e.g., controlling the lower head of a home signal), all interlocking function (e.g., **H** relays) uses the correspondence relays to ascertain switch position. Note that if the switch is in transit, or out of correspondence, neither is picked: the switch being in correspondence in one position or the other is not the inverse of it being in correspondence in the other position. Use of back contacts of the correspondence relays is extremely rare, but occasionally necessary.

NWK and **RWK** are non-vital relays that are rightly part of the non-vital selection network, and will be discussed there.

As discussed in the helpfile, sometimes, as when a signal more than one signal away locks a switch, approach locking is implemented for switches, in which case an **AS** relay, with a circuit similar to a signal **AS,** is used. See **13AS** at Islington for an example.

Route Locking — **NS, SS**

Route locking is a technique for semipermanently associating a train with a given route in a given direction and an intent to follow that route. Please see the section on the main helpfile for examples and scenarios. One route-locking relay per direction (north, south) is associated with each track section governed by a home signal. Route-locking relays are vital relays in a vital circuit, and are normally up, indicating the absence of the route they represent. They indicate, when dropped (their "non-safe" state), that a train has been given "rulebook" permission to go from one home signal to the next (possibly an exit signal, i.e., in the other direction).

When a home signal clears at the entrance to an interlocking, the dropping of its **AS** drops the (north or south as appropriate) route locking relay for the first track section in its route; working through ***WC** switch correspondence relays, successive route locking relays in the same direction for the track sections that make up the route, up to the next home signal (where the process repeats) drop out. If (and when) **AS** picks up before the train accepts the signal, they would all pick each other up again. It is the dropped state of the route locking relays which lights the white "line of light" on the interlocking panel.

If, however, the train passes the signal, the first route locking relay will not pick up when **AS** picks: its track section must be unoccupied for it to pick up. As a result, none of the succeeding route-locking relays for the route pick up. The all remain semipermanently down, until the train has passed over them. They "remember" that the train intends to pass in this direction over these track sections, and by their being down, lock all switches in the route, as well as forbid the clearing as well as calling of signals in the reverse direction (i.e., their front contacts are checked in vital **H** and **CO** circuits as well as non-vital **XS** and approach **PBS** circuits (see Route Selection). Note that **AS** being down drops many route-locking relays at once, so the checking of a route-locking relay often subsumes a direct check **AS**.

In real life, route-locking relays circuits for double-crossovers must exercise caution not to create dependency loops where transient failure of switch correspondence or an **AS** could create a situation where two codependent route-locking relays would never pick up again. The usual solution is seemingly-redundant checking of the **AS** instead of "cascading" in some cases. In **NXSYS** this is presently not a problem.

Route Selection — **PBS, XS, R, N/RWK, ANN, BNN, RS, etc.**

The Route Selection network is essentially a relay computer that, given an entrance to and exit from the interlocking, determines which switches and signals are to be called for to realize ("establish," "line," "line up") a route between them. The guiding design principle is that route selection should never offer or attempt to establish a route that the vital relays would not realize at that time. When calling for a signal, the route selection network takes into consideration all conditions that are necessary (other than slotting) for that signal to clear; if those conditions are not met, it will not call for the signal. Note that unlike the **H** relay, the selection network does not merely observe the state of switches: if a switch is in a position which would prevent a signal it seeks to clear from clearing, the selection network is responsible for calling for that switch (to move), if possible, before calling the signal, and will not call for the signal, or attempt a route which would, if the necessary switches cannot be moved.

Another principle is that the selection network cannot have side-effects on routes that are already established; it is not allowed to "kick off" already clear signals. Although such an action is theoretically "safe," it is extremely undesirable to throw a red signal in the face of an oncoming train. It is also a given that routes are set up and signals called deliberately; the gratuitous cancelling of a route or kicking off a signal would be a bug.

A fundamental tool of the selection network is the non-vital *switch indication relay,* **NWK** and **RWK,** for switch normal and reverse. A switch's **RWK** being picked means that the switch is in the reverse position, in correspondence (**RWC** is up), and furthermore, is either locked or called for in this position (i.e., **RLP** is up or **LS** is down). The significance of this condition is that when it is true (**RWK** is picked), calls for the switch to move normal will be rejected (as can be inferred from the switch relay description above). If, as extremely common, an approach signal requires a certain switch to be normal to clear, the selection (call) relay (**PBS**) will check the back contact of **RWK** for that switch: if **RWK** is up, calls for the signal are futile, as the switch cannot be moved normal, and will be rejected; the approach **PBS** relay will not pick up (or in some cases, will pick up only as long as the button is held, but not stick).

Think of **RWK** as meaning "the switch cannot be made normal", and **NWK** as "the switch cannot be made reverse", or, the back contacts, which are the interesting ones, of **RWK** as "**NWpossible"** and the back of **NWK** as "**RWpossible".** While the front contact of **NWC** says that the switch *is* normal, the back contact of **RWK** says that the switch *is or could be* normal. Think of it as an "asserted low" logic signal.

There are times, however, when an interlocking designer can make non-vital selection choices based upon the way a switch currently *is,* as opposed to *how it could be.* This is often the case when alternative routes are available. Such decisions are made informed by practical railroading experience and the operational scenarios of the particular interlocking.

While the vital circuits are concerned with the actual state of signals, switches, and routes, the non-vital selection network is concerned with realizable potential states, and charged with realizing them. An **H** relay will only clear its signal if **NWC, RWC** and route and approach locking relays indicate that a route is correctly lined up and locked. The selection network, on the other hand, checks not what *is,* but what *could be:* a state of the interlocking expressed in route and approach locking relays and back contacts of **NWK/RWK** is a state that *is or could be* lined up by moving switches that are declared movable by those ***WK** contacts. Thus, such a circuit is to a potential route as **NWK/RWK back** is to a switch: it is the necessary and sufficient condition for success of the manipulations needed to realize that route.

Bear in mind that the **PBS** circuit is non-vital: even if an approach signal's **PBS** is picked, the signal will not clear unless each trailing-point switch in its control length is normal and locked. In the cases where it is permissible for **PBS** to pick up with a switch locked against it, **PBS** is prevented from dropping **AS** by a back contact of **NWC—**see 20 at

Islington. Gratuitous dropping of **AS** is safe, but would cause a tie-up and the kicking-off other signals. Further bear in mind that heavy reliance on the back contacts of the ***WK** relays is not unsafe; again, the worst consequence of failure of those relays would be the non-vital network making invalid requests of the vital network.

The home signal route relay, **R,** which represents a call for a home signal, checks front contacts of switch indicator relays (***WK**) to verify the condition that the switches in the route are not only in correspondence, but called for or locked, the latter precisely the conditions that prevent the switch from moving out of the required position. It is necessary to check "locked or called for", i.e., not merely "locked", because the switch will not be locked until the signal is called (by the **R** relay being discussed!).

Perhaps the best approach, as it were, to the subject of the selection network is to consider the **PBS** relay of an approach signal, which subsumes all the functions of the selection network for it. Pressing the interlocking panel signal button for an approach signal picks (and sticks) its **PBS** relay if permissible, calling the signal. Situations which might prohibit the picking and sticking of the **PBS** relay, i.e., the call for the signal, might include trailing-point switches called for or locked (***WK**) "against" the signal's control length, or the control lengths of other signals in the opposite direction overlapping any part of the control length of the signal at issue (any such signal must, of course, be interlocking controlled; were it not, this latter situation could never be resolved). The approach locking (**AS** or derived relays) of such conflicting signals must be checked.

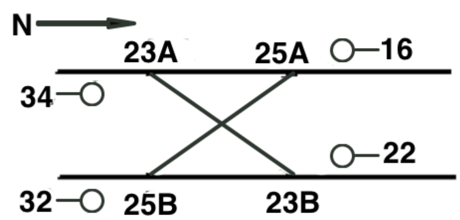
When the **PBS** relay for an approach signal picks, it calls for trailing-point switches in the control length to move to (or hold) their required positions. The **H** relay will not pick (and the signal clear) until the switches actually have moved and are in correspondence. The **PBS** relay can be dropped (and the signal cancelled) by manual action, or, if not fleeted, by a train accepting the signal.

As mentioned before, in the real world, front contacts of **AS** or relays derived from **AS** (and ultimately from **RGP**) must be bridged ("paralleled", "ridden out") by stick contacts of the **PBS** relay, to allow the **PBS** relay to remain up even in the case of a temporary **AS** dropout. Again, safety is not affected, because the **H** circuit makes the same checks, and temporary dropping-out of the vital relays is not a problem, as the memory is in the non-vital relays ("non-vital" does not mean "inessential"!)

The above discussion touches on all aspects of the non-vital network except entrance-exit route selection: it verifies that conditions for a route (in the above case, actually a single signal) are appropriate at the current time, commits to the action (in the above case, calling an approach signal), moves such switches as are necessary, and ultimately effects the call for the signal. Once the commitment is made, conditions in the non-vital network are loosened because of the track power failure issue, and because the route or signal now committed to prevents the calling of the conflicting signals or establishment of conflicting routes that would have prevented this signal or route from being committed to in the first place. The vital network continues to check all the "opposing" approach lock relays in any case.

In the case of home signal selection, which involves the "magic computation" of the route from its entrance and exit, the several functions of the non-vital network already discussed for the approach **PBS** relay are distributed over several relays.

A route consists of an entrance, which is a home signal, a set of switches in specified positions in between, and an exit (which takes its numbering from the signal there in the opposite direction, often a marker, but is largely independent of it). For instance, in the following layout, a route can be established from signal 22 to signal 34: the formal elements of the route would be entrance at signal 22, switch 25 normal, switch 23 reverse, and exit at signal 34.



Double (Diamond) Crossover

(Note: for signal 22 to clear, switch 25 must be normal, even if 23 is reversed, even though the position of 25 might seem irrelevant with 23 reversed. The two switches being thrown at once is considered a patently unsafe state in most railroad practice, and thus, this and all similar cases of double-crossovers in all interlockings consider the normal position of a trailing point crossover prerequisite for clearing moves over it, even if that move is over a reversed facing point crossover whose points precede its own.)

Especially in light the above paragraph, a symmetry (whose worth will soon become evident) obtains by considering the two ends of a crossover to be independent, when their normal position is considered. Thus, considering again our route from 22 to 34, we have an entrance at 22, 25A normal, 23 reverse, 25B normal, and exit at 34. Each of these route elements is represented by a relay:

Entrance at 22: **22PBS**

Southbound move over 25B normal: **25BNS**

Southbound move over 23 reverse: **23RS**

Southbound move over 25A normal: **25ANS**

Exit at 34: **34XS**

The *switch selection relays* derive their nomenclature from the name of the switch or half-switch, the desired position of the switch, and the direction of the movement (all Southbound in our example). This sequence of relays (up to but not including **XS**) is called the “forward selection sequence” for this route: initiating at 22 picks **22PBS**, **22PBS** picks **25BNS, 25BNS** picks **23RS, 23RS** picks **25ANS,** and **25ANS** (by virtue of the symmetry alluded to earlier) lights the exit light at 34. When the signal button at 34 is pressed in this state, **34XS** (exit stick) picks, and attempts to pick the exact same relays that **34PBS** would have were one to initiate at 34: **25ANN, 23RN, 25BNN.** Note that this includes turning on the exit light at 22, which is now called an entrance light, and indicates that the reverse selection sequence (i.e., the northbound sequence starting with **XS**) has completed and “found” the entrance.

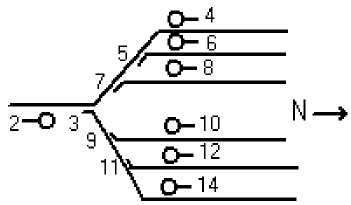
When the corresponding northbound and southbound relays for a switch or switch half (e.g., **25RN** and **25RS,** or **23ANN** and **23ANS**) are up, the switch is called (**NLP** or **RLP**) to move to or hold that position. That is how the selection network calls for switches.

Now, of course, when one initiates at 22, an exit lights up not only at 34, but at 32: route *selection,* which implies multiple possibilities, is, after all, the subject at hand. **25BNS** picks not only **23RS,** but **23BNS** as well; as should be obvious by now, **23BNS** will light the exit light at 32. One should think of the switch selection relays as tentative moves over positions of switches or half-switches, recording trailing points and forking over facing points, building a tree of possible routes.

The remaining magic is all in the counterlocking of these relays against each other. When an exit is selected, the interlocking must “climb back” along the branch of the tree that has reached the exit, and shave off all other branches (drop all other exits) as the route approaches the root, as it were. As it turns out, the condition is simple—relays representing a position are locked out (and dropped) by (i.e., check a back contact of) the relay for the move(s) that would “split apart” the switch in the trailing direction. Referring to the double crossover of our example, 25 reverse would be split by either a move southbound over 25B normal (**25BNS**), or northbound over 25A normal (**25ANN**). Therefore, **25RS** and **25RN** are locked out, or dropped, by **25BNS** and **25ANN.** 25A normal would be split open by a northbound move over 25 reverse, and thus, **25ANN** and **25ANS** both are locked out, or dropped, by **25RN.** It turns out that this “splitting the trailing-point switch” is identical to the root-seeking “shaving off branches” just described, and causes the calls for the appropriate switches to line the unique route between the selected entrance and exit.

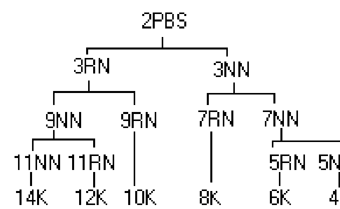
As the switch selection relays, which are all, canonically, non-vital, represent the possibility of a route over their switch in the position they name, they check back contacts of the switch indicator (***WK**) relay for the other position, and do not pick if there is no possibility at the present time of moving the switch to the position they name. They also check the back contacts of the switch lever relays **NLP, RLP,** so that even a call for a switch by manual keying or any other means (e.g., it is called for an in transit, and thus not yet in correspondence) affects the set of routes they offer. Note that this information, the back contact of the switch indicators, is used in the **PBS** of approach signals, but the switch selectors, which have no analogue, for home signals.

Although the above diamond-crossover is the standard and most useful example, consideration of the "ladder" layout below is a sure step, as it were, to understanding the switch selection sequence. Consider the following:



Ladder network selection

The following diagram shows the sequence of relays picked by an initiation at 2. The **K**'s are the exit lights at the signals indicated. Each relay picks those shown connected to it from beneath.



Northbound ladder selection seq.

When southbound selection drops a switch selection relays, all its "descendants" drop out, too. Thus, were an exit at 12 to be selected, **12XS** would pick **11RS,** which would drop **11NN,** which in turn would drop the 14 exit light. **11RS** picks **9NS**, dropping **9RN,** which would drop the 10 exit light. **9NS** picks **3RS,** dropping **3NN** and everything under it in the above, and "answering back" to the entrance light at 2.

The **XS** circuit does much more than merely respond and stick when the exit button is pushed. It is responsible for checking all conditions at the end of the route that would forbid the route, such as trailing-point switches locked against the overlap of the control length of the signal whose call is being set up, control lengths of other (approach, home, or dwarf) signals in the reverse direction overlapping the same, route-locking relays (**NS, SS**) for movements in the opposite direction for track sections in the overlap, and, not insignificantly, the very **PBS** of the signal being used as an exit, as well as other, "hostile" **XS** relays (i.e., for movements in the opposite direction) staring the potential exit in its face. (Note again that all of these checks are made in the **PBS** circuits of approach signals). All of the conditions that **XS** must check before responding to the exit pushbutton, including the switch selection relay "propositioning" it (e.g., **25BNS** for exit at 34), must also be factored into the exit light, so these conditions, if complex, other than the switch selection, are often collected into an **XL** (exit lockout) relay. In the standard design, **XL** is designed as vital, so it can be checked in the **H** circuit as well (while this would preclude **R/NWK** contacts, simplification can still be obtained this way). The standard warning about **AS**-related power drops and stick contacts applies singularly strongly to **XS,** by the way.

The **PBS** circuit of a home signal also checks for conditions that would rule out *prima facie* any possible route employing that signal as an entrance, such as the same signal already in use as an exit (the signal's **XS**) or the **PBS** relay of a home signal back-to-back with it. Other checks, such as a locked-wrong-way trailing point switch immediately in front of the signal, are less urgent than the case of an approach signal: while an initiated, sticking approach signal **PBS** in spite of a lockout condition would clear the signal at a future indeterminate time (*preconditioning*, an undesirable situation), an initiation at a home signal will not (because no exit has been selected, and none can be until the route is realizable), so standard NYCTA design makes fewer such checks than might be anticipated. What is more, allowing **PBS** to pick allows the tower operator press the home signal's button to flash the switch position lights and GK lights for the signals and switches creating the locking conditions, so that he or she can identify and possibly remove these conflicts before selecting an exit. The tradeoff between disallowing initiation and allowing initiation to produce flashing is a design issue at each signal.

Two important design tips—when you design two functions to lock each other out, **be certain** to make sure the antagonism is mutual and symmetric. If **10PBS** locks out **12XS,** make sure that **12XS** locks out **10PBS.** Failure to do this will result in a situation where one of the functions will prevent the other, but the selecting the latter when the former has already been selected will knock it down, which is unacceptable. Also make sure that there is a complete isomorphism between checks and lockouts in the vital and non-vital circuits: The non-vital level should not permit or request any state which the vital level will rule out, nor should it prohibit any state that the vital level will allow. (Of course, the non-vital ***WK** relays used in the non-vital level cannot be used in the vital level; ***WC** and **LS** contacts are required.)

A home signal **PBS** circuit must also check for conflicting initiations to maintain the consistency of the selection network. Looking at the same network, **22PBS** should be locked out by **25RS,** which would represent an initiation (or completed route) at 16 across 25 "competing" with it. Symmetrically, **23RS** will lock out **16PBS.** That is not to say that **16PBS** and **22PBS** lock each other out, but their southbound probes over the crossovers do lock each other out. Also, **22PBS** (for example) will not pick up if **25ANN** is up—this is the same move/relay that conditions an exit at 22, and indicates that an opposing initiation has reached 22 and is "propositioning" it as an exit. (Note that **25ANN,** although it will prevent **22PBS** from picking, does not lock that relay out wholesale, as the former will pick when the reverse selection chain reaches 22. Thus, the contact is in the "pick" leg of the circuit (ridden out by a stick contact) only.)

(It can now be seen that the checking of all conditions necessary to clear a signal are checked in one relay, **PBS**, for an approach signal, and distributed over several relays (**PBS, XS,** switch selection) for a home signal: conditions at the entrance checked by **PBS,** possibility of switch moves by switch selection, and conditions at the exit by **XS.** It is again emphasized that this is all the *non-vital* network, and serves to prevent it from issuing calls that cannot be realized; the **H** relay circuits for home and approach signals make all safety checks necessary, and are not significantly different from each other in content.)

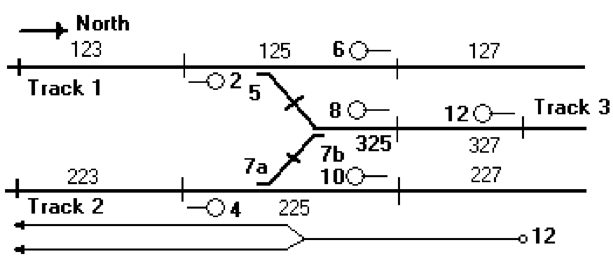
The final element of the route selection network is **R,** the signal route completion relay, which checks all of the above elements, that is, the entrance **PBS**, the switch indicators (switch in correspondence and called for) of all switches in the route, and the **XS** of the exit, which picks up when all the route elements are in place. **R** is the actual call for the signal, and should cause **H** to pick up and clear the signal and stop at once, as well as such **VS** relays as necessary to drive down off-side stops.

R's contract includes verification that *all* switches in the route, including switches locked by overlap, are "locked or called for" in correspondence in the required position. As **H** will not pick up until they are actually locked, and only **R** picking will drop **AS** to lock them, the elements before **R** in the pipeline, i.e., **XS, PBS** and route-selection relays, once the route is completed, are responsible for issuing calls for all such switches, including in the overlap. These conditions can become quite intricate when facing-point push and other special exit-end conditions obtain: care must be taken in the **R** circuit to check the ***WK** for such switches, and to protect against power-fail **AS** dropout when route-locking has to be checked to determine the proper cases.

In real life, **R** also checks the back contacts of its own **XS** (used in the same way the vital circuit uses **AS**), and occasionally certain switch selection relays, both of which techniques are relevant to multiple-relay circuits with shared wires, and not a concern at **NXSYS.**

Selection network inhibition (use of **NWC** and **RWC** therein)

NYCTA railroading standards sometimes prohibit the selection network from realizing some routes automatically. In particular, when setting up a route in crosslock situations, the involved overlap can often be kept clear by moving facing-point switches contained in it that were not actually requested as part of the route; in certain circumstances, the



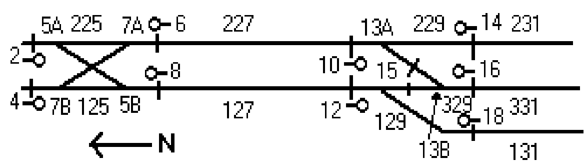
Complex conditional and crosslocking situations

selection network is restrained from taking this step. Consider the following diagram from the main helpfile:

Assume no route was set up, switch 5 reverse, 7 normal, and 12 clear, and no other signals clear or called. The control length of 12 is now routed over 5 to track 1. Now assume that the tower operator wishes to line a route from 6 to 2, and initiates at 6. The selection network *could* offer an exit at 2, as it could clearly divert the control length of 12 to track 2 by moving 7 reverse before moving 5 normal. However, in actual NYCTA practice, the exit at 2 will *not* be offered, and 5 will appear locked by conditional crosslock. The applicable railroad standard considers moving 7 reverse onto a track not already directly involved in the proposed route an unacceptable side-effect, as it would foreclose a later route on track 2 to set up a route involving only tracks 1 and 3. In order to line the route from 6 to 2 in this scenario, the tower operator is required to explicitly cancel 12 or move 7 reverse, either by manipulation of the auxiliary keys or by actually lining the route from 8 to 4, as a prerequisite.

When the selection network in this way considers certain switches "off-limits" for lining a given route, front contacts of **NWC** and **RWC**, as opposed to the usual back contacts of **RWK** and **NWK**, respectively, are employed—the switch state is treated as a static condition ("what is") rather than a potentiality ("what could be"). In these cases, the selection networks are often a complex mixture of ***WK** and ***WC** contacts.

End-to-end routing ("Through Routing")



Interlocking of two networks (sub-interlockings)

The near-miracle of end-to-end routing involves successive networks of switches chaining each other's forward and reverse selection sequences in the appropriate directions. Here is a typical scenario.

We wish to establish a southbound route from 4 to 14: We initiate at 4 in the usual fashion, picking **4PBS** and offering exits and 6 and 8, conditioning **6XS** and **8XS** to pick when an exit is selected.

The switch selection relay of the first network (2, 4, 6, 8/5, 7) which lights the first network's exit light (i.e., at 6) and conditions **6XS** to pick (in this example **5ANS**) must simulate the **PBS** relay of the next network (i.e., **10PBS**) to simulate an initiation there. However, it cannot actually *pick* that **PBS** relay, because the latter would stick, and must drop when the first initiation is dropped or some route not chaining to that second entrance (e.g., an exit at 8) is selected. For this purpose, a relay called **XR,** associated with the second entrance (in this example, **10XR**), is used. **XR** is picked by the same conditions that light the first exit light, and its circuit must make the same checks (those appropriate to an exit at the first exit), as well as checks of the vacancy of track sections between the first exit and second entrance (i.e., 227), and all the checks that the second (here, 10) **PBS** would make. Every place a **PBS** front contact of the second network appears in its selection relays, a front contact of this **XR** must appear across it. This carries forward the forward selection sequence, and drops it when the exit light at the first exit drops.

If the route is completed, an exit will be chosen at the second network (in the example, say, 14) and selection relays will chase the route back to the second **PBS,** (here **10PBS**) which in this case will not be picked; The other "hand" of the back-to-back trick, **ZS** (here **10ZS**) comes into play: seeing, with **XR** up, the reverse selection chain of the second network returning to the second entrance, **ZS** picks. The conjunction of **XR** and **ZS** actually simulates pushing the second entrance button, and picks the second **PBS.** As soon as this happens, **XR,** whose purpose has been served, drops out, **ZS** sticking around, as it were, **XR**'s now-dropped front contact (**ZS,** however, continues to retain on all of the other conditions described which picked **XR** in the first place). **ZS** also simulates pushing of the exit button in the first network (here **6XS**): a front contact of the second entrance's **ZS** relay parallels the front contact of the first exit's **XS** relay in all the first network's switch selection, but, importantly, not in the **R** circuit—actually picking the **XS** is delayed until the second entrance's **R** picks up, indicating that the first selection successfully lined the route. When that happens, the first exit's **XS** picks up, dropping **ZS** and dropping him out of the picture, and conditioning the first entrance's **R** (here **4R**) to pick up when all the first network's switches are correctly moved.

This scheme allows all the switches of all the component networks of an end-to-end route to move simultaneously, while delaying the actual route completion of any network until all successive (further from the original initiation) networks have successfully lined their respective routes: as a result, the signal at the very entrance to the through-route will not clear unless and until the entire route has been successfully lined up.

Through-routing is the showstopper of the NX/UR system, and the devil is in the details, not all of which have been mentioned here. This section is only the highest level description of end-to-end function, and the remaining details must be gleaned from observation of and experimentation with the circuits. Standard cases calling for additional complexity are one signal "with entrance and exit in the same direction", i.e., it is both the exit of the first network and the entrance of the second (e.g., 10 and 24 at Progman St.) and the presence of an intervening approach signal which must be called by the through-routing mechanism.

Time signals

[February 2022] Models for ST and GT signals may be found in any of the supplied interlockings, Atlantic Avenue and Myrtle Avenue in particular. Nothing in their basic function is very complicated: timer relays operated and held by track occupancy clear the signal or cut sections out of its control length.

But interlocked ST signals are quite complicated, because their effect upon particular switches and potential conflicting routes is usually conditional upon whether the time-controlled portion of their control lengths is active or not, i.e., whether the timer has run to completion in response to train motion, or not.

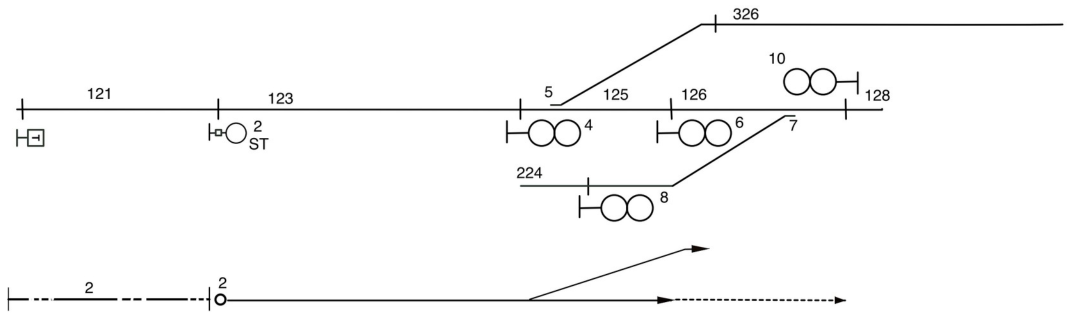


Illustration of conditional locking by ST approach signal

Consider the above scenario, where 2 is such an ST approach signal, a very common case. Here, assuming switch 5 be normal, signal 2 "conditionally" locks switch 7 normal. If 7 is locked reverse, say by a route from 8 to 10 being lined, 2 cannot be cleared, as switch 7 appears in the control length of 2. But 7 only appears in the *dotted portion* of the control length: that means that 2 can be *called,* but not cleared. If this situation obtains, 2 will display an ST ("20") aspect, and approaching it at 20 mph in its approach section, 121, will clear it (to yellow, "proceed with caution, prepared to stop at next signal").

The way this is implemented is by dividing the **PBS** relay for such signals in two, **APBS** and **BPBS.** When 2's button is pushed (assuming all else well, e.g., no exit at 4 or 6), **BPBS** picks whether the "dotted portion" is available or not; **APBS** picks if and only if the dotted portion is, in fact, available. If (or when) **ABPS** picks, 7 is (moved, if necessary, and) locked normal, whereupon the signal fully clears. The standard circuit will pick **APBS** *without prompting* if, when **BPBS** is picked, the obstructing situation (i.e., 7 locked reverse) clears by itself! Complexity increases when conditional crosslocks by such a signal are involved (e.g., we haven't talked about the effect of this on switch 5): "the proof is left to the reader", as math books used to say.

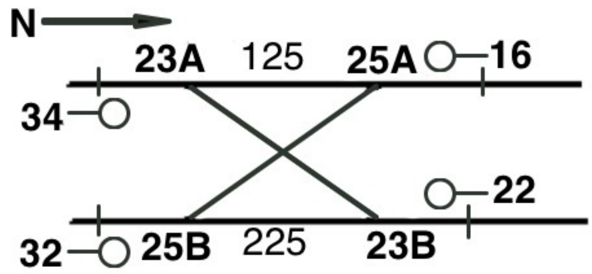
NXSYS-specific relays and protocols

See the file RelayLanguage.md (in the GitHub repository). [Feb. 2022].

Symphonic synopsis — all the actors in action

We will now describe the whole symphony setting up a route. Consider again this diagram, now with track sections marked.

Let's watch how a route is set up from 34 to 22.



Double (Diamond) Crossover

All relays to be discussed are dropped, except red signal repeaters RGP, approach lockers AS, route lockers NS/SS, and switch lockers LS, and all track relays **T** and **TP**. The picked state of these relays is their "safe" state, "all is safe." Assume both switches are normal, so their normal repeater relays **23NWP** and **25NWP**, and correspondence relays, **23NWC** and **25NWC** are picked. All **NVP (normal stop repeaters)** are picked, too.

The tower operator begins by pressing the entrance pushbutton at 34, **34PB**. This picks up, and sticks, the 34 initiation relay, **34PBS**. **34PBS** picks up the northbound route selectors, in order, **25ANN,** which picks **23ANN** and **23RN,** the latter which picks up **25BNN. 23ANN** lights up the exit light at 16, and **25BNN** lights up that at 22.

The tower operator then presses the exit button (or, in the UR dispensation, the *only* button) at 22. **22XS,** having been "propositioned' by **25BNN**, picks, and sticks. **22XS** picks **25BNS. 25BNS** picks **23RS,** which, splitting the 23 reverse position, drops **23ANN**, extinguishing the exit light at 16 which she had lit. **23RS** picks **25ANS,** which lights the exit light at 34, which is now an "entrance light".

At this point, the pairs **23RN-23RS, 25ANN-25ANS,** and **25BNN-25BNS** are picked. Those matched pairs cause the "switch lever repeaters" **23RLP** and **25NLP** to pick, calling for 23 to move reverse; 25, already normal, is now *called* normal. **23NWZ** drops, and **23RWZ** picks, which actually opens the valve magnets on electropneumatic equipment. **23NWC** (switch in correspondence) drops as soon as **23NWZ** drops.

As soon as **25NLP** picks, 25 is "in correspondence (**25NWC**) and called for normal", which is the condition for the non-vital "normal switch indicator" **25NWK** to pick. As soon as 23 moves reverse (attested by **23RWP**), the switch is *in correspondence* (reverse, **23RWZ** and **23RWP**) so **23RWC** picks, attesting to that fact. But since it is also "called for reverse", **23RWK***,* the "reverse switch indicator", picks, asserting the conjunction of these conditions.

When its entrance relay (**34PBS**) and switch indicators (**23RWK** and **25NWK**) comprise a route to an exit (**22XS**), 34 can now be called: **34R** (route relay, non-vital) picks, and remains picked (but not *stick*) as long as these conditions obtain. 34 signal is now *called,* the equivalent of its lever having been activated in a lever frame.

Now the called route must drop (i.e., engage into effect) all the locking, whose locked state must be confirmed before the signal can actually clear.

34R directly drops 34's **approach locker**, **34AS.** **34AS** dropping drops the northbound **route locker** **125NS**, which cascades (as selected by ***WC**s) over switch 23 to drop **225NS.** These dropped relays pick the panel section indicator-light relays **125SP** and **225SP**, which actually light the panel track sections white ("line-o-lite").

The dropped route lockers and approach locker drop both **switch lock relays**, **23LS** and **25LS**. That makes both switches "locked and in correspondence", which is a sufficient condition to pick **23RWK** and **25NWK**, but they are *already* picked because the switches are *called for and in correspondence,* their other "sufficient condition."

When all the switches are in correspondence, ***and locked*** (*as attested by the vital relays* **NWC and LS,** *not* the non-vital switch indicators ***WK**), and the signal (34) is called, as indicated by the non-vital **34R,** the signal's vital home relay, **34H** picks (assuming its control length is clear). **34H** drives the stop, **34V,** down (clear). **34NVP** drops.

In the meantime, **34R** (routed through switch correspondence) and **225NS** pick **22VS,** stop route-locking, which causes **22V** (stop) to drive down, which is checked by **34H** (or **32H**, as the topomorphic circuit has configured itself). When 34's stop clears, **34HV** will finally pick, clearing the signal. Both **34H** and **34HV** drop **34RGP**, the "red signal repeater", and add another "sufficient" condition for its route locking to be dropped.

The route is now established, and its entrance signal clear. All switches in it are called for and locked. Approach and route lockers are dropped. Both the locked switches and picked non-vital route selectors prevent attempts at conflicting routes being set up at the non-vital level. The route shows in white track sections on the panel. At the vital level, everything is locked as solidly as the levers and dogs in an old electromechanical lever frame.

Now along comes a train, northbound, on the upper track, approaching signal 34. As soon as the front of the train passes 34 and enters track circuit 125 (i.e., **125T** and **125TP** drop), things change. The non-vital actors retreat: assuming that 34 was not "fleeted" (set for the passing of the "fleet") by the operator, **34PBS** drops immediately, which drops the whole selection network (all the **ANS, BNS, ANN, BNN, RN,** as well as **22XS** as a consequence). **34R,** which, you will recall, is *non-vital*, drops, when **PBS** and **XS** drop. The signal is no longer called. The lever-"repeaters" **RLP/NLP** drop—the switches are no longer *called*— but, as discussed, **RWK/NWK** stay picked, because the switches are ***locked*** *and in correspondence.*

As soon as **34R** drops, **34H** and **34HV** drop, and the signal is no longer clear (but its stop is held down by the track relays). Even if **34R** didn't drop, the signal "slotting" (control length track-section checking, its **HY** relay) would set it to red.

But all the locking doesn't release! **34AS** may or may not pick, as per whether it has the "quick-release" feature or not. But the route-lockers *will not pick up:* the occupation of 125 track section prevents **125NS** from picking up, and **125NS** being down keeps **225NS** down. And either/both of those relays being down keep the switch lockers, **23LS** and

25LS, *down.* **RLP/NLP** cannot “talk to” **RWZ/NWZ** (cut off by **LS)**: nothing can move the switch now. The dropped route-locker **225NS** keeps **22VS** up and 22’s stop clear, too, so the train does not “off-side trip” itself.

125TP and/or **225TP** being down (indicating occupation) also are sufficient condition to keep both switch lockers, **125LS** and **225LS**, down—this “detector locking”, i.e., a switch may not move when a train is on it—is the most fundamental form of switch locking.

The dropped route-lockers keep the white lines-o-lite on the panel (at least the 225 part once the train has entered 125), and the locked, in correspondence switches keep the ***WK**’s picked, which prevents buttons being pushed and the non-vital network from even attempting to set up conflicting routes.

As the *back* of the train passes 34, 34’s stop will come up. Nothing else changes. But as the back of the train crosses the middle of the crossover, 125 will become vacant (**125T** and **125TP** pick), which, now that **34AS** has picked up, will pick up the route locker **125NS.** That drops the line-o-lite relay **125SP**, so that portion of the route is no longer illuminated on the panel. But both switches are still locked (**LS** dropped), because **225NS** is still dropped, and on account of detector locking.

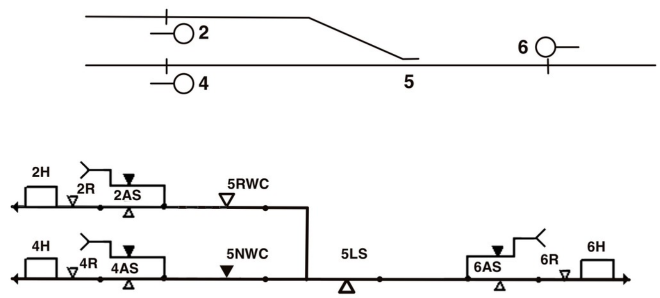
As the back of the train passes 22, leaving the strict confines of the interlocking entirely, **225T/TP** pick, which is now sufficient to pick up **225NS.** Both lines-o-lite are now dark. But the switch does not unlock immediately! **225NS** picking drops the stop route-locker **22VS**, which causes 22’s stop to come up behind the train, preventing unauthorized entry at 22. When the stop is verified up (**22NVP** picks), both **LS** relays finally pick up (I didn’t tell you recently that **LS** checks all the stops in this way, but it does). Then the switches unlock, and thus, no longer called or locked, are no longer indicating (**RWK/NWK**), and these relays drop, permitting the setup of routes conflicting with the now-released route.

Powerful Topomorphic Circuit Example

Here is an example of a simple, but powerful topomorphic circuit typical of those used in actual “all-relay interlocking” circuitry. The basic idea is that the circuit shares the exact shape (topology) of the track layout, and thus, each contact participates in all routes “through it”, in both directions, minimizing the number of contacts and maximizing the safety and integrity of the circuit.

The exact same circuitry was used in electropneumatic and electromechanical lever interlocking machines in the earlier decades of the twentieth century, using contact “bands” on the levers instead of relay contacts. The lever for a signal cannot be returned to its “normal” position unless its “indication magnet”, “**M**”, the predecessor of the **AS** relay, indicates that it is at stop and its approach locking has reset; such a lever thus has three positions, “signal is dangerous” (allowed to clear), “signal is safe” (the equivalent of **AS** being picked), and “other”/“in between”, meaning “can’t clear, but not safe”. Similarly, switch levers could cannot be fully moved to their “reverse” or “normal” positions until the switch itself has moved and complied (the old "**K**" indicator relay). In this way, the old levers simulated **R**, **AS**, **NWC**, and **RWC**!

Here is the plan and the circuit (in a real circuit, other contacts are involved, too, such as those of route-locking relays and timer-checking contacts, who comply elegantly with the plan, but we will omit those details for now).



Single switch topomorphic circuit

Here is a simple switch controlled by three signals, with four routes over it: 2 to 6, 4 to 6, 6 to 2, and 6 to 4. Yet, each switch relay contact, ***WC** or **LS**, appears *only once!*

When an **R** relay picks to clear the signal (**H**), we can see that the signal will not clear unless the following conditions all are true:

- The **AS** relay for the signal which is to clear is dropped, indicating its danger not only to this circuit, but to other components (such as route lockers, traffic locking, etc.)
- The switch, 5, is locked, as indicated by its **LS** relay being dropped.
- The switch is in correspondence one way or the other (**RWC** or **NWC**).
- The signal at the exit is safe, i.e., its approach locking is reset as indicated by *its own* **AS** relay being picked, coincidentally disconnecting the **H** of the signal there!

Route-locker contacts, both front and back, would appear in the non-shared portions of the circuit, because they are directional. (Of course, the purpose of the non-vital network is to *cause* all these conditions to be true).

This design technique can be extended to any track topology whatsoever, and applied not only to the **H** circuit shown, but **R** and other circuits as well. Unfortunately, NXSYS cannot model this technique today (it's an open design challenge).

(END)