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ALL ABOUT SIGNALS

JOHN ARMSTRONG

A special reprint of articles from the June and July 1957 issues of TRAINS, *the* magazine of railroading.

PROBLEM:
2 or more tr

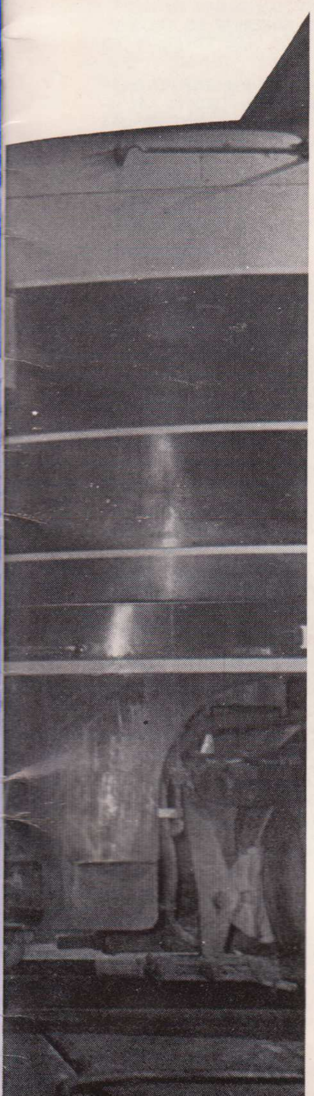
ANSWER:
SIGNALS

ains on 1 track

Because you cannot "steer" a train, you must rely on the order board, the semaphore, or the color-light signal to provide the space between trains that is safety. TRAINS' expert explains, in easy steps, the progress from crude but effective manual-block safety to the speed insured by 1957's complexity of wires, relays, motors and lights. Here are signals — from A to Z

JOHN ARMSTRONG

Artwork based on author's sketches



Diesel photos, James P. Gallagher; signal photo, David H. Noble.

DELAY a 100-car freight for an hour in the process of waiting for orders, crawling out of a siding while the rear brakeman closes the gate and clambers aboard, and heading into the hole again because there isn't quite clearance time to make the next station ahead of a faster train in the rear, and a $10 per diem bill alone has been run up on the cars, to say nothing of the effect on running costs which averaged $38.80 per train-hour in 1954.* So it's no wonder such signaling and control triumphs as the Reading's one-man Master Control Center, providing automatic routing through trackage formerly requiring eight interlockings, and Seaboard's centralized traffic control system, guiding trains through nonstop meets all the way from Miami to Richmond, are thought of primarily as traffic expediters, necessary to allow the cars, locomotives and tracks of a railroad to earn their keep. Likewise, the unblinking vertical row of lights in the cab of the GG1 speeding its Pennsy TrucTrain through a heavy Jersey fog finds favor with the management not so much as a safety device as a tool for maintaining competition-beating schedules and protecting the investment in 75-foot flats, terminal ramps and roller bearings.

How did this signaling system of wires, relays, motors and lights grow to its present state of complex perfection? How does it function? And how did it make the transition from a defense against disasters to a profitable source of return on plowed-back earnings? To gain some idea, it is only necessary to look at the 1956 system which, like the lemon tree carrying blossoms, green fruit and ripe fruit at the same time, still illustrates much of the development process. Its major features can conveniently be studied in the framework of three basic accomplishments — allowing trains to follow each other closely without rear-end collisions, getting them through junctions and crossings without conflict, and handling opposing movements on single track with safety and dispatch.

Time-spacing the trains

As soon as a pioneer railroad acquired its second locomotive it was faced with the problem of the rear-end collision. The original system for keeping a following train off the back of its predecessor was time-spacing, a perfectly valid principle since trains which are at the same point at different times obviously cannot collide. The basic system illustrated in Fig. 1 (page 4) is still in use on 110,000 miles of line in the U. S., almost exactly half of the total mileage but representing only a sliver of the total traffic, as can be judged from the small portion (2300 miles) of double track included.

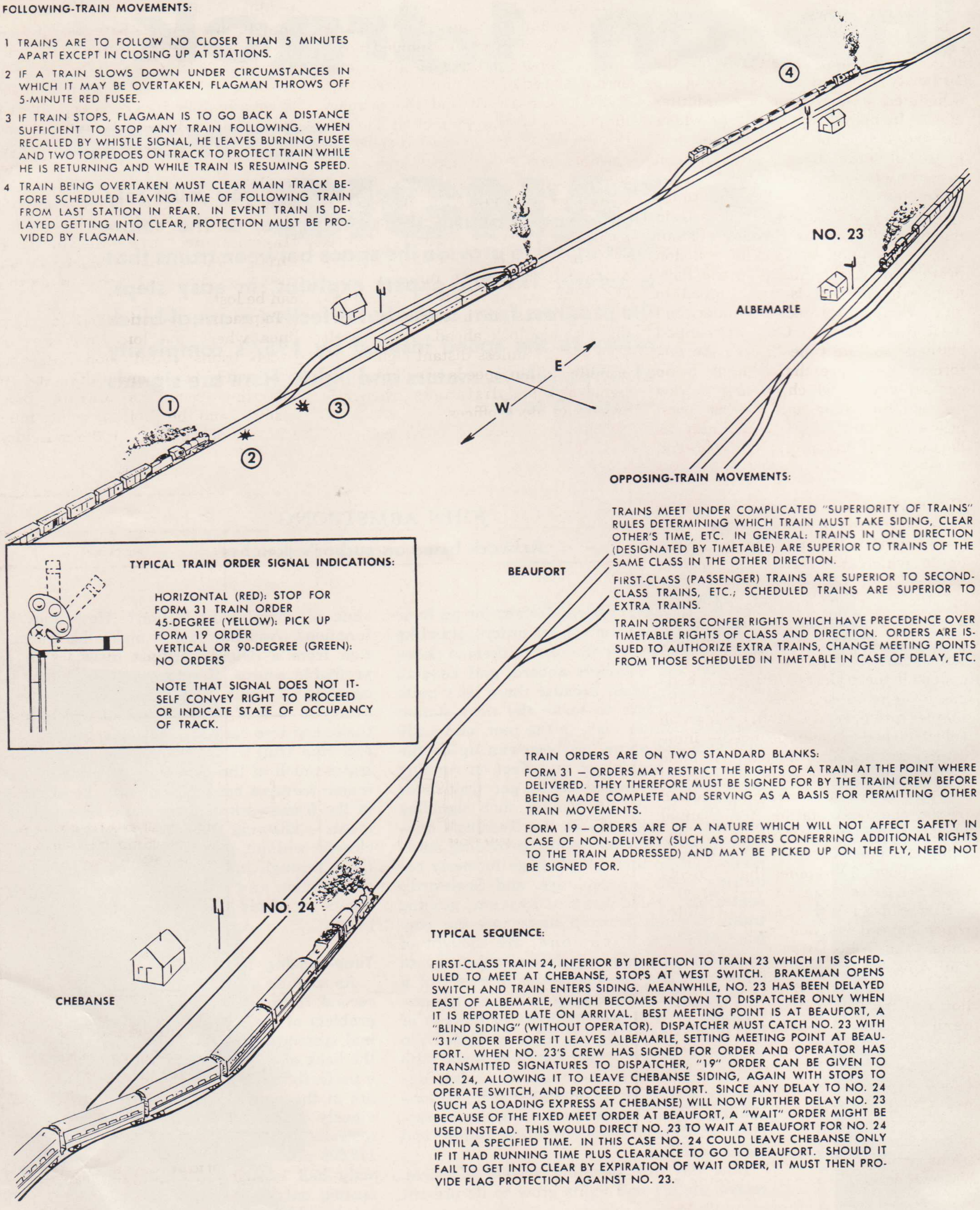
Trains run on the basis of timetable sched-

*Figures are from the Signal Section, Association of American Railroads, which annually compiles train operating cost figures in form suitable for evaluating signaling savings.

FIG 1 ESSENTIALS OF TIMETABLE AND TRAIN ORDER OPERATION

FOLLOWING-TRAIN MOVEMENTS:

1. TRAINS ARE TO FOLLOW NO CLOSER THAN 5 MINUTES APART EXCEPT IN CLOSING UP AT STATIONS.
2. IF A TRAIN SLOWS DOWN UNDER CIRCUMSTANCES IN WHICH IT MAY BE OVERTAKEN, FLAGMAN THROWS OFF 5-MINUTE RED FUSEE.
3. IF TRAIN STOPS, FLAGMAN IS TO GO BACK A DISTANCE SUFFICIENT TO STOP ANY TRAIN FOLLOWING. WHEN RECALLED BY WHISTLE SIGNAL, HE LEAVES BURNING FUSEE AND TWO TORPEDOES ON TRACK TO PROTECT TRAIN WHILE HE IS RETURNING AND WHILE TRAIN IS RESUMING SPEED.
4. TRAIN BEING OVERTAKEN MUST CLEAR MAIN TRACK BEFORE SCHEDULED LEAVING TIME OF FOLLOWING TRAIN FROM LAST STATION IN REAR. IN EVENT TRAIN IS DELAYED GETTING INTO CLEAR, PROTECTION MUST BE PROVIDED BY FLAGMAN.



TYPICAL TRAIN ORDER SIGNAL INDICATIONS:

HORIZONTAL (RED): STOP FOR FORM 31 TRAIN ORDER
45-DEGREE (YELLOW): PICK UP FORM 19 ORDER
VERTICAL OR 90-DEGREE (GREEN): NO ORDERS

NOTE THAT SIGNAL DOES NOT ITSELF CONVEY RIGHT TO PROCEED OR INDICATE STATE OF OCCUPANCY OF TRACK.

OPPOSING-TRAIN MOVEMENTS:

TRAINS MEET UNDER COMPLICATED "SUPERIORITY OF TRAINS" RULES DETERMINING WHICH TRAIN MUST TAKE SIDING, CLEAR OTHER'S TIME, ETC. IN GENERAL: TRAINS IN ONE DIRECTION (DESIGNATED BY TIMETABLE) ARE SUPERIOR TO TRAINS OF THE SAME CLASS IN THE OTHER DIRECTION.

FIRST-CLASS (PASSENGER) TRAINS ARE SUPERIOR TO SECOND-CLASS TRAINS, ETC.; SCHEDULED TRAINS ARE SUPERIOR TO EXTRA TRAINS.

TRAIN ORDERS CONFER RIGHTS WHICH HAVE PRECEDENCE OVER TIMETABLE RIGHTS OF CLASS AND DIRECTION. ORDERS ARE ISSUED TO AUTHORIZE EXTRA TRAINS, CHANGE MEETING POINTS FROM THOSE SCHEDULED IN TIMETABLE IN CASE OF DELAY, ETC.

TRAIN ORDERS ARE ON TWO STANDARD BLANKS:

FORM 31 – ORDERS MAY RESTRICT THE RIGHTS OF A TRAIN AT THE POINT WHERE DELIVERED. THEY THEREFORE MUST BE SIGNED FOR BY THE TRAIN CREW BEFORE BEING MADE COMPLETE AND SERVING AS A BASIS FOR PERMITTING OTHER TRAIN MOVEMENTS.

FORM 19 – ORDERS ARE OF A NATURE WHICH WILL NOT AFFECT SAFETY IN CASE OF NON-DELIVERY (SUCH AS ORDERS CONFERRING ADDITIONAL RIGHTS TO THE TRAIN ADDRESSED) AND MAY BE PICKED UP ON THE FLY, NEED NOT BE SIGNED FOR.

TYPICAL SEQUENCE:

FIRST-CLASS TRAIN 24, INFERIOR BY DIRECTION TO TRAIN 23 WHICH IT IS SCHEDULED TO MEET AT CHEBANSE, STOPS AT WEST SWITCH. BRAKEMAN OPENS SWITCH AND TRAIN ENTERS SIDING. MEANWHILE, NO. 23 HAS BEEN DELAYED EAST OF ALBEMARLE, WHICH BECOMES KNOWN TO DISPATCHER ONLY WHEN IT IS REPORTED LATE ON ARRIVAL. BEST MEETING POINT IS AT BEAUFORT, A "BLIND SIDING" (WITHOUT OPERATOR). DISPATCHER MUST CATCH NO. 23 WITH "31" ORDER BEFORE IT LEAVES ALBEMARLE, SETTING MEETING POINT AT BEAUFORT. WHEN NO. 23'S CREW HAS SIGNED FOR ORDER AND OPERATOR HAS TRANSMITTED SIGNATURES TO DISPATCHER, "19" ORDER CAN BE GIVEN TO NO. 24, ALLOWING IT TO LEAVE CHEBANSE SIDING, AGAIN WITH STOPS TO OPERATE SWITCH, AND PROCEED TO BEAUFORT. SINCE ANY DELAY TO NO. 24 (SUCH AS LOADING EXPRESS AT CHEBANSE) WILL NOW FURTHER DELAY NO. 23 BECAUSE OF THE FIXED MEET ORDER AT BEAUFORT, A "WAIT" ORDER MIGHT BE USED INSTEAD. THIS WOULD DIRECT NO. 23 TO WAIT AT BEAUFORT FOR NO. 24 UNTIL A SPECIFIED TIME. IN THIS CASE NO. 24 COULD LEAVE CHEBANSE ONLY IF IT HAD RUNNING TIME PLUS CLEARANCE TO GO TO BEAUFORT. SHOULD IT FAIL TO GET INTO CLEAR BY EXPIRATION OF WAIT ORDER, IT MUST THEN PROVIDE FLAG PROTECTION AGAINST NO. 23.

ules, or if they're extra, on the authority of train orders setting up schedules, a minimum of 5 minutes apart. In light-traffic territory where the actual spacing between trains is a matter of hours, there is little problem in most cases; but as traffic becomes more dense the fact that the time-spacing is impaired every time a train unexpectedly slows down or stops places the whole burden of collision protection on the hustle of the flagman, who at best is ill-equipped to give adequate protection under bad weather conditions. Only at manned stations can the time interval be enforced; elsewhere there simply is no certain way by which an engine crew can tell how long ago the last train passed by* until they encounter its flagman or, unhappily, its rear-end markers.

The manual block system

An alternate principle for keeping trains apart is the space-interval system in which at any given time a train has exclusive possession of a section, or "block," of track. This is fundamentally a more enforceable idea because this space cushion protecting a train does not diminish and then disappear if the train falls behind schedule for any reason. As soon as the simpler predecessors of the telegraph (electric bells, magnetic needle indicators, and the like) became available so that an operator could be advised whether or not a preceding train had passed the next station, the manual block system became possible and developed rapidly. The system shown in Fig. 2 (page 6) typifies that protecting some 28,000 miles of road today.

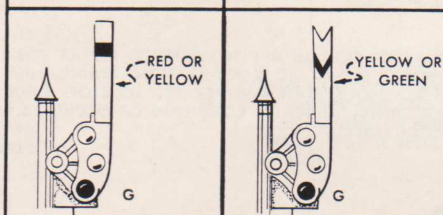
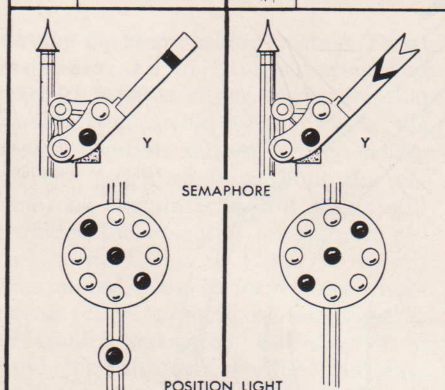
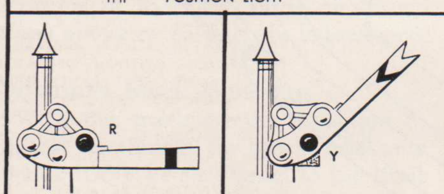
Under detailed Standard Rules which have developed over the years under the Association of American Railroads and its predecessors, manual block affords a high degree of protection and the I.C.C. order of 1947 concerning train speed permits speed limits up to 79 miles an hour in such territory, while limiting passenger trains to less than 60 miles an hour and freights to less than 50 miles an hour on nonsignaled track. A complete record of the times of passage of trains at adjacent stations as well as his own is kept by each operator so that the condition of each block is known at all times, and he must obtain permission of the operator at the other end of the block before clearing his signal to allow an approaching train to enter. A standard numerical code is used to speed the process.

Since flag protection is still required by the rules should a train stop or slow down in block signaled territory, a longer succession of human errors is required before a rear-end collision can result and the primary individual in the protection system, the operator, can at least display his warning signal promptly and effectively without having to slog through sand, sleet or snow. Manual block is primarily a safety rather than a capacity-increasing or economy feature, however, because of a couple of limitations. It is, for one thing, a "one-block" system in which the signal indication gives no information about the second block ahead. As a result (see Fig. 2) unless distant signals are provided, train speeds are limited by signal-sighting distances when approaching block offices.

The big enemy of track capacity, though, is the block length. Usually it is the distance between stations, a matter of 5 to 15 miles. From the time even a fast train enters a block, a lot of railroad is tied up until it emerges, and with the 40-hour week firmly in effect, spiraling wages, and traffic continuing to shift away from the small station, the distance between open offices is not going to decrease. One assist comes in the use of "permissive" blocking in which a freight train following another freight is permitted to enter and proceed through an occupied block, moving at restricted speed prepared to stop short of a train or obstruction but (by the 1947 I.C.C. order) not to exceed 15 miles an hour. If passenger trains are involved, a flagman must precede the train through the occupied block; in any case, with such long blocks much time can be lost.

In practice, operation on light-traffic lines where the long intervals between trains afford good following-train safety is not much different under time-spacing or manual block systems, and the choice is pretty much a matter of the policy of the individual

TYPICAL MANUAL BLOCK

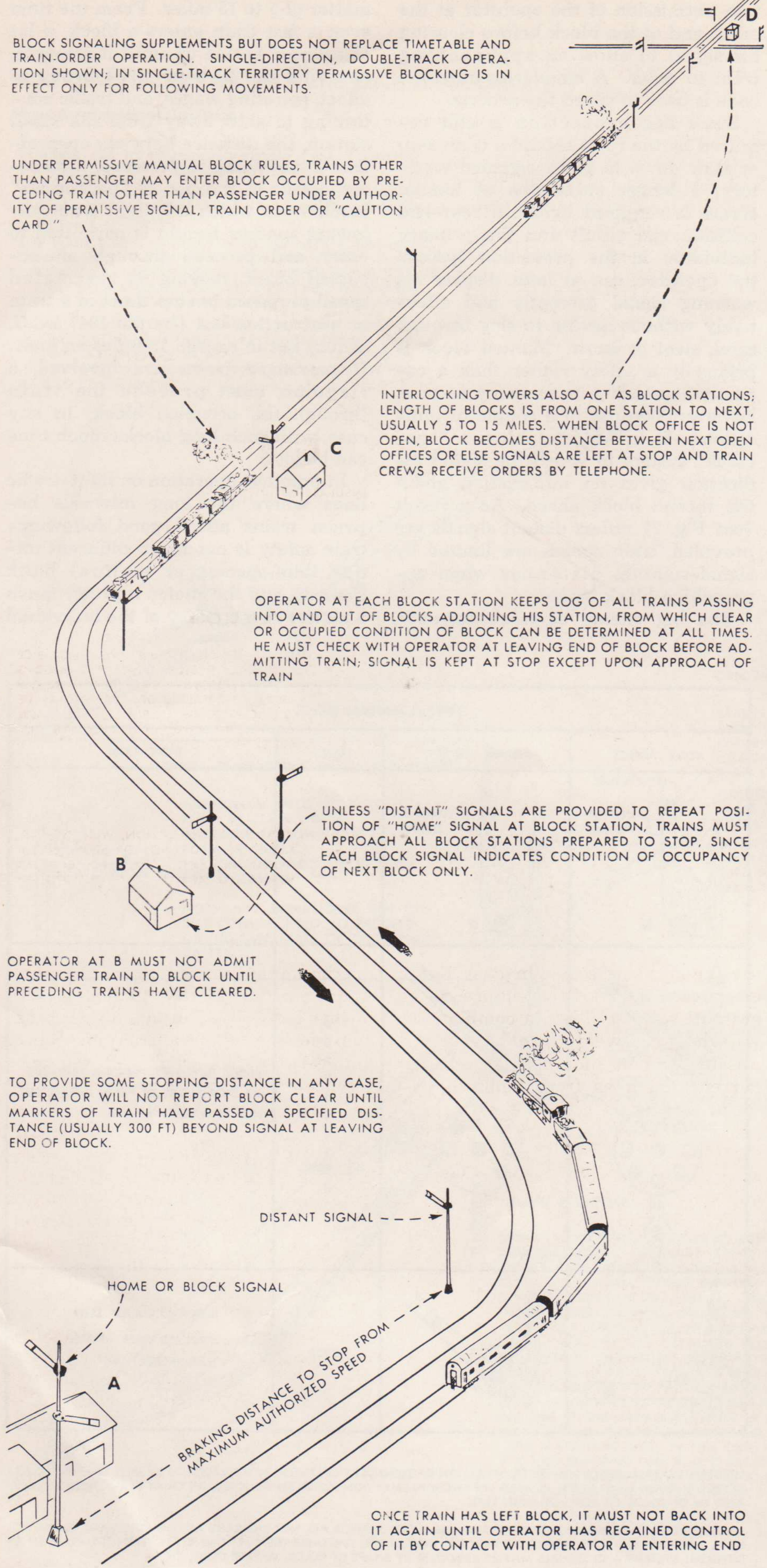
HOME ASPECT	DISTANT ASPECT	NAME	INDICATION
		CLEAR	PROCEED; BLOCK CLEAR
		PERMISSIVE	BLOCK OCCUPIED; PROCEED PREPARED TO STOP SHORT OF TRAIN AHEAD, BUT NOT TO EXCEED 15 MPH
		STOP	BLOCK OCCUPIED; STOP (PROCEED ONLY UNDER FLAG PROTECTION)

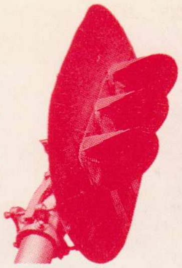
THE TERM "MANUAL BLOCK" REFERS TO OPERATION OF SIGNALS BY OPERATOR, NOT TO METHOD OF EFFECTING CHANGE IN ASPECT; THOUGH MOST OFTEN SIGNALS ARE MECHANICALLY CONNECTED SEMAPHORES, THEY MAY BE ELECTRICALLY OPERATED OR OF COLOR- OR POSITION-LIGHT TYPE.

SINCE INDICATIONS CORRESPONDING TO MANUAL BLOCK ASPECTS ARE NOT THE SAME AS FOR AUTOMATIC BLOCK SIGNALS, PARTICULARLY WITH RESPECT TO PROCEED INDICATION, TIMETABLE INSTRUCTIONS STATE TERRITORY COVERED BY DIFFERENT SYSTEMS AND SIGNALS MAY BE IDENTIFIED BY SHAPE OF BLADE, MARKER LIGHT, ETC.

*Some very early fixed signals worked on the time-spacing principle, being tripped to the stop position by the passage of a train and then returned by clockwork to clear at the end of a time interval.

FIG 2 MANUAL BLOCK SIGNALING





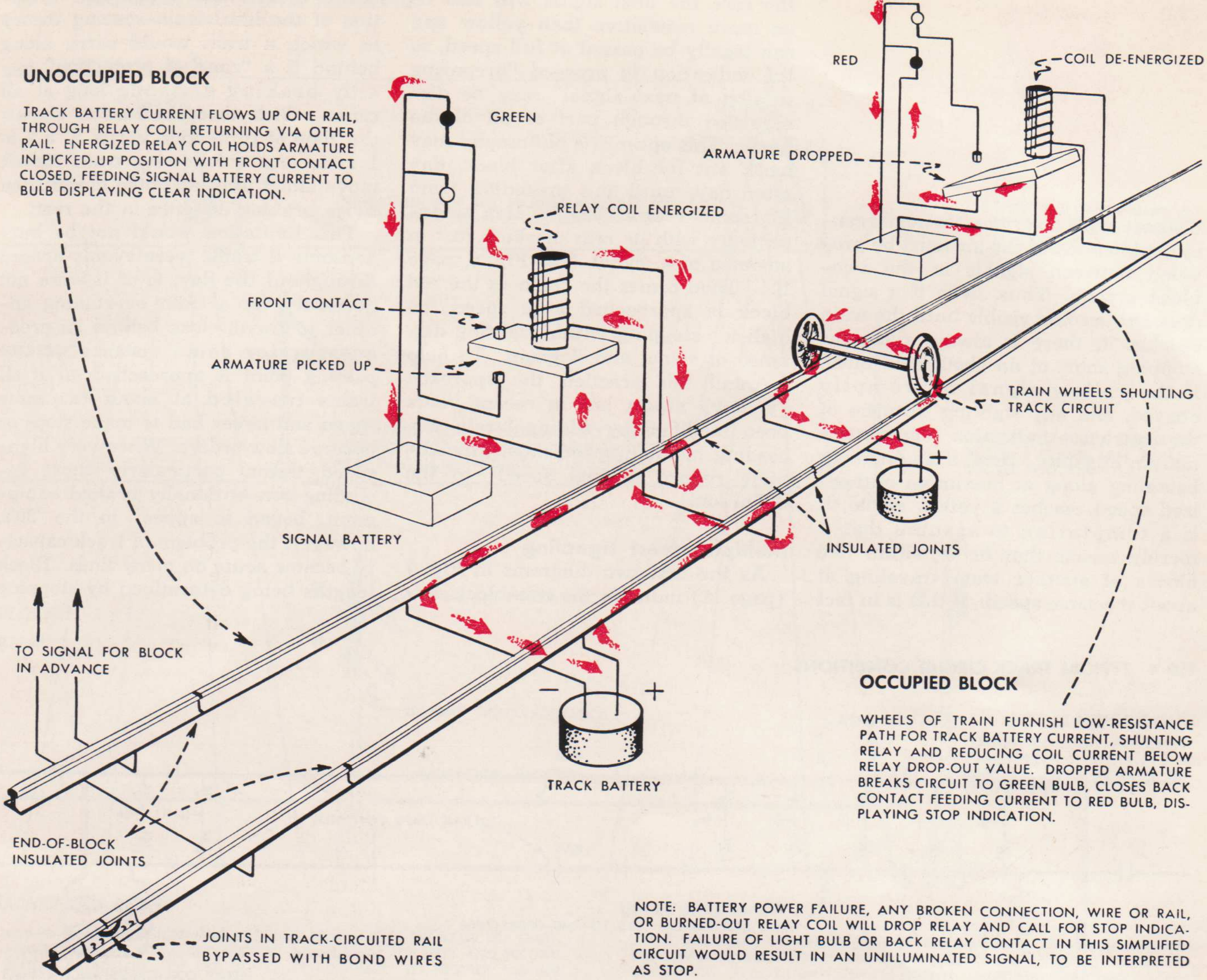
road. Soo Line and Burlington, for example, operate on a 100 per cent block signal basis, even though during much of the year there will be no more than one train at a time on many of their branches through the granger country. Rock Island and Great Northern, on the other hand, use block rules only on their more heavily traveled lines where automatic signals are justified. Use of a single basic system over most of a railroad avoids frequent mental gymnastics in switching from one set of rules to another and in that sense tends toward safety.

The track circuit

Since the invention of the basic track circuit by Dr. William Robinson in 1872 the answer to most of the limitations of manual block has been the automatic operation of the signals by the trains themselves (Fig. 3). Not only is the human element eliminated in the setting of signals to stop behind the train but the ingenious fail-safe nature of the closed circuit virtually eliminates hazard from malfunction of the automatic portions of the system as well. Since the track circuit is fundamental to all modern signaling, it may be well to digress a bit and look at some of the precautions that have been found necessary over the years and at the clever engineering that has brought solutions to difficulties.

As Fig. 4 (page 8) indicates, the actual track circuit is an electrical engineer's nightmare compared with normal indoor, well-insulated, copper-wire control circuits. Primarily because of the extremely variable, and often considerable, leakage of the current between the rails, numerous conflicting requirements are put upon the designer in selecting and adjusting circuit components to provide utter safety and still not tie up the railroad with false-red indications every time it rains. What with acid-generating cinders falling in the ballast and refrigerator cars dripping brine, the track actually becomes a storage battery of sorts, charged up by the track battery and tending in some situations to impair the ability of the circuit to detect broken rail; it is a tribute to the dedicated men in the signal manufacturing companies and railroad signal departments that this problem and others, such as applying track circuits

FIG 3 THE TRACK CIRCUIT



to electrified railroads,* have been licked.

As noted in Fig. 3, the closed track circuit is of a fail-safe nature with respect to broken rails, dead batteries and loose connections. The one thing it is not proof against is a false-clear from a relay failure in which the armature does not separate the front contacts upon de-energization. Relays used in track circuits and in line (trackside) circuits in which they control the actual displaying of a signal, movement of a switch, or similar functions are defined as "vital" components and are designed and built to an exceptionally high standard of reliability. The armature is in such an orientation that gravity will pull it to the de-energized position, and all moving parts are sealed in glass. Front contacts are of silver-impregnated graphite against silver, a combination which won't weld together in the unsafe position should a very heavy current (such as from lightning effects) be encountered, but which still provides the essential low circuit resistance. Even in their modern, streamlined, plug-in form these vital-circuit relays are huge by telephone or electronics standards, but they do a tough job faithfully whether the temperature in their trackside enclosure is 150 above or 35 degrees below zero.

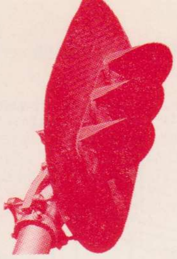
Automatic block signaling

With the track circuit available to control the signals, the blocks may now economically be shortened to the limit imposed by braking distance. It is then logical to have the distant signal for the next block signal located either on the same mast or in the same three-indication signal arm (Fig. 5, page 9), thus providing a two-block system under which trains can travel at the maximum authorized speed, assured that the first restrictive indication will always be received in time to permit a stop short of the train ahead. Since automatic signals can't tell the difference between a passenger and non-passenger train, in an automatic block signal system on multiple track the permissive (*stop and proceed*) indication applies to trains of all classes. This feature now becomes a major help since the crawl to the next signal is only a matter of a mile or so instead of the distance to the next open station.

Installation of ABS is still a popular means for saving money and expediting traffic; in 1955, 525 additional miles of track were brought under its protection with 754 signals, increasing the total in the United States to 81,300 miles of line and 112,000 miles of track.

There can always be human abuses of the system, of course; the most notorious is "riding the yellow." Under A.A.R. and I.C.C. regulations, braking

*Direct-current-propulsion roads are signaled by alternating current track circuits, also used occasionally on steam roads where stray currents (such as those from cathodic corrosion-prevention schemes used to protect trackside steel structures) are a problem. A.C. electrifications are signaled with A.C. circuits of higher frequency using frequency-sensitive relays. Key to the system is the use of "impedance bonds" between track circuits which readily pass propulsion currents in both rails around the insulated joints but offer high resistance to track circuit A.C. trying to flow from one rail to the other.



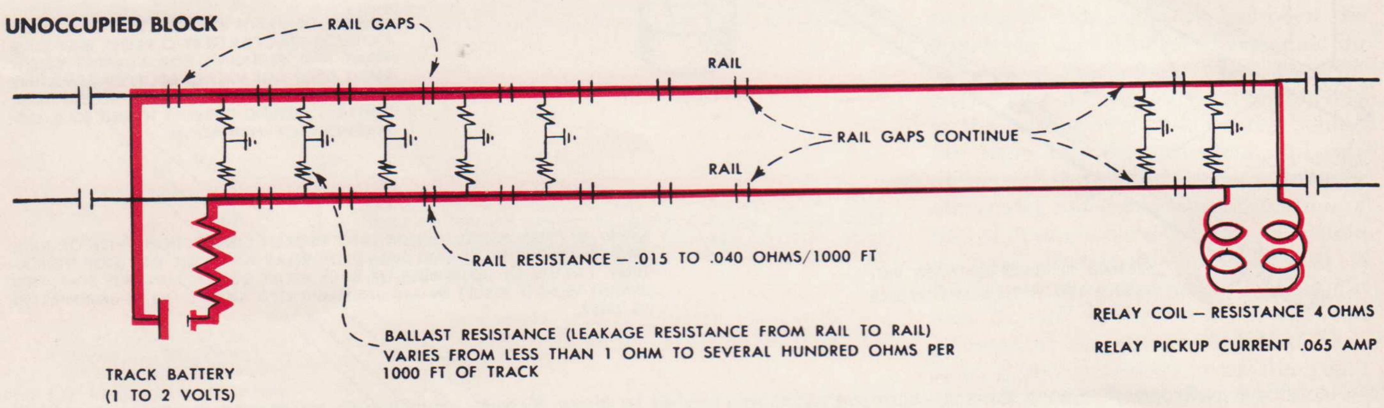
distance with a service (nonemergency) application of the air must be provided between signals in the two-block system. Thus, even if a signal does not become visible until the train reaches it, there is always room for stopping short of an obstructed block if the yellow signal is promptly obeyed, and any sighting distance of the restrictive indication represents a margin of safety. Now, if an engineer barreling along at maximum authorized speed reaches a yellow signal, it is a temptation to assume that it merely means that he is within two blocks of another train traveling at about the same speed. If this is in fact the case the next signal will also be no more restrictive than yellow and can legally be passed at full speed, so the indication to proceed "preparing to stop at next signal" may be disregarded through part or all of the block. This optimistic philosophy may work out for block after block, day after day, until the preceding train for some reason has to stop unexpectedly with its rear markers just in advance of a signal (see Fig. 6, page 10). Then comes the crash as the red block is approached at a speed too high for stopping within sighting distance of signal and flagman. To help forestall this practice, the *approach* (yellow) aspect has in recent years been modified by adding "train exceeding medium speed must immediately reduce to that speed" to the definition.

Multiple-aspect signaling

As the first two diagrams in Fig. 7 (page 11) indicate, the two-block system is a somewhat crude approximation of the ideal train-spacing theory in which a train would carry along behind it a "zone of protection" exactly braking distance long at all times. With three-indication signals the zone of protection varies in a 2 to 1 ratio and a following train cannot move along uninterrupted closer than twice braking distance in the rear.

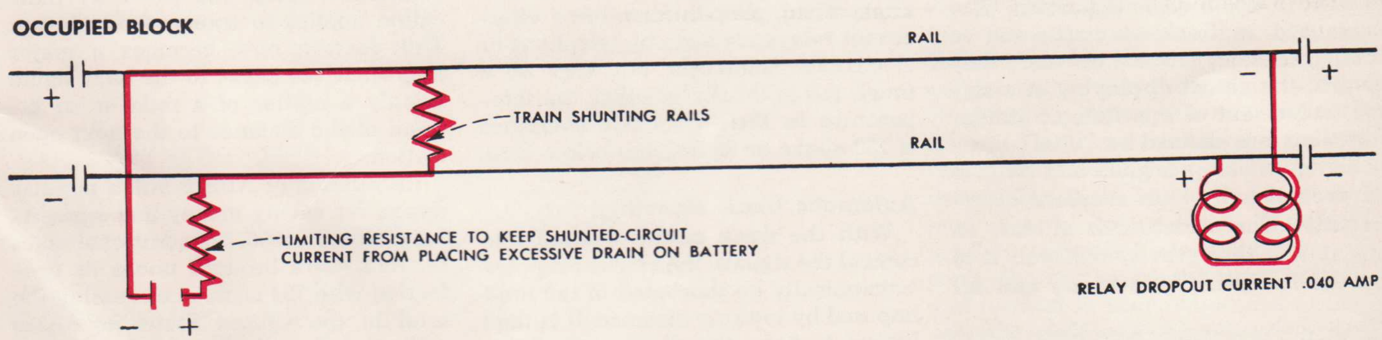
This limitation would not be burdensome if traffic were evenly spaced throughout the day, or if it were not necessary for a train overtaking another to travel close behind its predecessor for some distance as the passing point is approached, or if all trains traveled at about the same speed and never had to make stops or observe slow orders. When very high-speed trains, particularly those including conventionally braked equipment, began to appear in the '30's, however, the problem of track capacity became acute on many lines. Block lengths being determined by stopping

FIG 4 TYPICAL TRACK CIRCUIT CONDITIONS



TRACK CIRCUIT CURRENT, A MAXIMUM AT BATTERY END OF CIRCUIT, IS DRAINED AWAY BY LEAKAGE ALL ALONG RAILS. REMAINING CURRENT AT RELAY MUST BE SUFFICIENT TO PICK UP RELAY UNDER MAXIMUM RAIL RESISTANCE CONDITIONS. LEAKAGE RESISTANCE UNDER MOST UNFAVORABLE CONDITIONS (IN EARLY MINUTES OF SHOWER AFTER LONG DRY SPELL, FOR EXAMPLE, WHEN DUST HAS BECOME WET AND HIGHLY CONDUCTIVE BUT HAS NOT YET BEEN WASHED AWAY FROM BALLAST) LIMITS THE PRACTICAL LENGTH OF TRACK CIRCUITS. NORMAL MAXIMUM LENGTH FOR STEADY CURRENT D.C. CIRCUITS IS ABOUT 1 MILE. IF BLOCK IS LONGER, IT MUST BE SUBDIVIDED INTO SHORTER TRACK CIRCUITS.

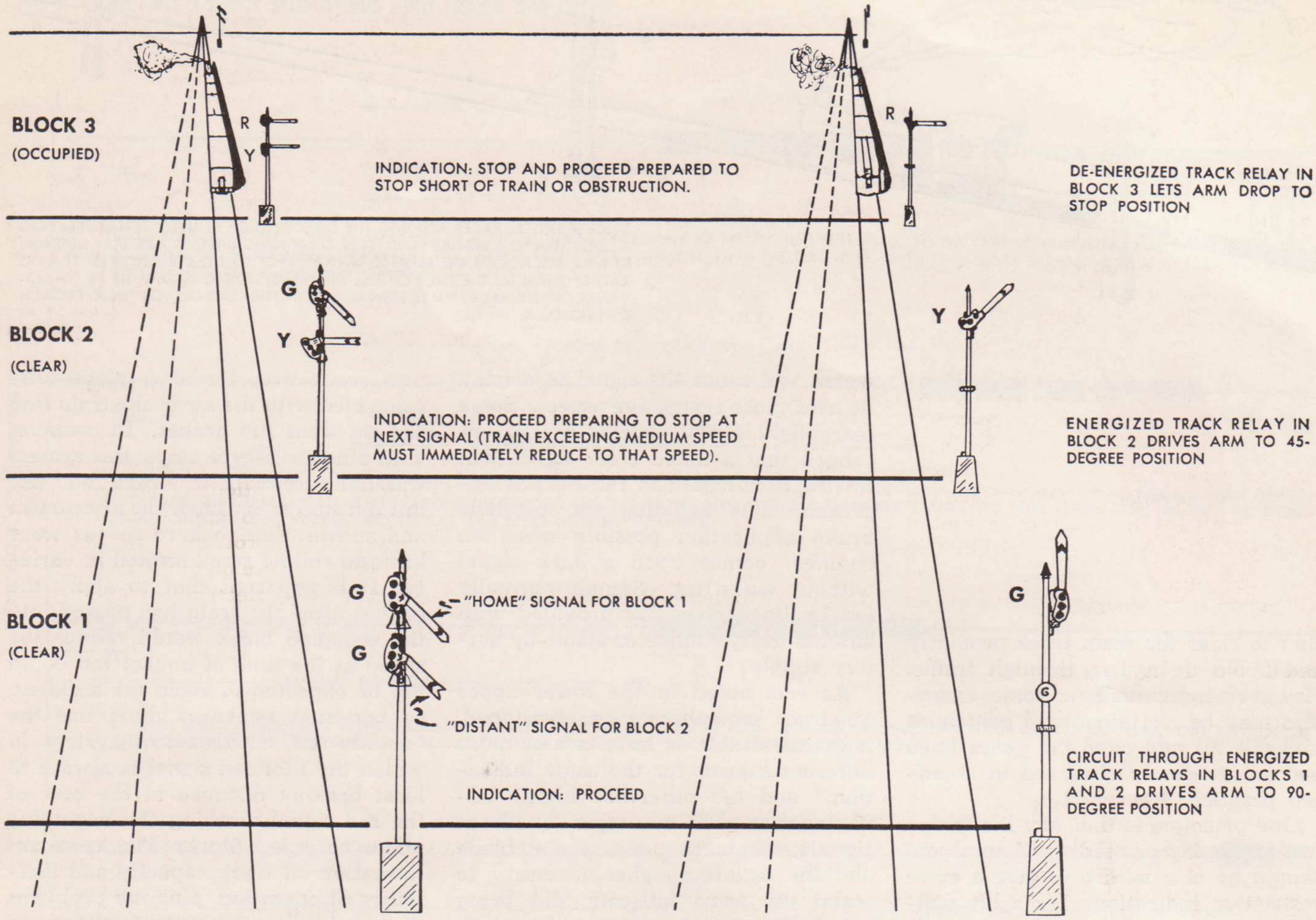
RAIL RESISTANCE VARIES SEASONALLY: WHEN IT IS HOT, EXPANDED RAILS PRESS TIGHTLY TOGETHER AT JOINTS; WHEN IT IS COLD, CONTRACTED RAILS PULL AGAINST JOINT FASTENINGS. AT INTERMEDIATE TEMPERATURES CONDUCTION IS PRIMARILY THROUGH JOINT BOND WIRES AND RESISTANCE IS HIGHER. RESISTANCE ALSO VARIES WITH WEIGHT OF RAIL AND ITS TEMPERATURE.



TRAIN OCCUPYING BLOCK MUST PROVIDE LOW ENOUGH RESISTANCE TO SHUNT TRACK CIRCUIT CURRENT TO EXTENT THAT REMAINDER PASSING THROUGH RELAY COIL IS BELOW DROP-OUT VALUE (TYPICALLY ABOUT 65 PER CENT OF CURRENT REQUIRED TO PICK UP RELAY). A.A.R. SIGNAL SECTION STANDARDS REQUIRE CIRCUIT TO OPERATE ON ANY SHUNT OF 0.06 OHM (TYPICAL OF LIGHT TRAIN ON RUSTY RAIL) OR BETTER. SHUNTING IS MOST DIFFICULT UNDER LOW-LEAKAGE CONDITIONS (DRY WEATHER OR FROZEN BALLAST).

SHOULD INSULATED JOINTS FAIL, BATTERY IN ADJACENT TRACK CIRCUITS MIGHT AUGMENT RELAY CURRENT TO CAUSE FALSE ENERGIZATION; THIS IS USUALLY GUARDED AGAINST BY REVERSING POLARITY OF ALTERNATE CIRCUITS AS INDICATED

FIG 5 TWO-BLOCK AUTOMATIC SIGNALING
(TWO OR MORE TRACKS)



LOWER QUADRANT

LOWER QUADRANT SIGNALING REQUIRES TWO BLADES OR ARMS PER MAST, FUNCTIONING AS HOME AND DISTANT SIGNALS FOR THE FIRST AND SECOND BLOCKS IN ADVANCE OF THE SIGNAL, RESPECTIVELY. TO PROVIDE FURTHER ASSURANCE AGAINST A FALSE OR MISINTERPRETED INDICATION, THE CIRCUIT CONTROLLING THE DISTANT ARM IS ALSO INTERRUPTED WHEN THE FIRST BLOCK IN ADVANCE OF THE SIGNAL (SEE FIG 6) IS OCCUPIED, PLACING BOTH ARMS AT DANGER. LOWER QUADRANT ARMS MUST BE COUNTERWEIGHTED TO RETURN TO HORIZONTAL POSITION WHENEVER OPERATING MECHANISM IS DE-ENERGIZED OR FAILS.

UPPER QUADRANT

UPPER QUADRANT SIGNALING BECAME RECOMMENDED STANDARD IN 1908, BUT CONSIDERABLE LOWER QUADRANT MILEAGE REMAINS IN SERVICE, USUALLY USING NIGHT (COLOR-LIGHT) ASPECTS SHOWN. PRIOR TO WORLD WAR I, COMMON CLEAR ASPECT WAS WHITE, WITH GREEN FOR CAUTION. AUTOMATIC BLOCK SIGNALING IS USUALLY PERMISSIVE (STOP AND PROCEED BEING MOST RESTRICTIVE INDICATION). POINTED-END SEMAPHORE BLADE INDICATES THIS BY DAY. VARIOUS LITTLE-STANDARDIZED MEANS, SUCH AS A STAGGERED MARKER LIGHT BELOW ARM, MAY BE USED FOR NIGHT INDICATION. "G" OR "P" ON LETTER PLATE IS USED ON UPGRADE SECTIONS TO SIGNIFY THAT TONNAGE TRAINS MAY PASS STOP-AND-PROCEED INDICATION AT REDUCED SPEED WITHOUT STOPPING.

distances for the fastest trains operated, respacing of signals would normally be indicated as the necessary prelude to hotshot schedules, with the result that slower trains would thereby be spaced so far apart that track capacity would be inadequate at times.

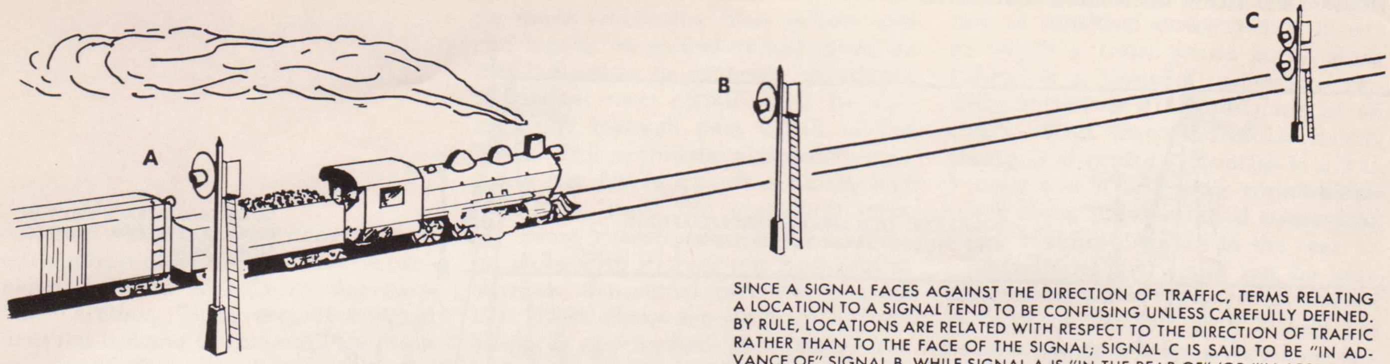
A general answer has been the installation of four-aspect, three-block signaling of critical sections of line, with a fifth aspect providing warning for four blocks in particularly congested territory. As Fig. 7 shows, multi-aspect signaling can provide for higher-speed trains with less sacrifice of capacity for slow trains, or it can handle denser traffic without delay while maintaining the same braking distance. Since most four- or five-indication installations have been in territory already equipped with conventional block signals, the railroads involved have naturally sought a compatible system involving the least modification to the existing units. The result has been a somewhat confusing variety of aspects for the extra indications, which is our cue for a look at the ideas behind the choice of signal types and aspects.

Signal aspects, indications and types

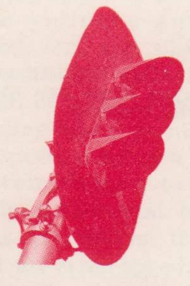
By definition, a signal conveys an indication (*proceed*, for example) by displaying an aspect (a green light) having a name (*clear*). Ideally each aspect should correspond to a single indication, so that the signal itself would convey complete instructions. This goal is met only partially, the chief reason being that fundamentally different operating rules apply in timetable and train-order, manual block, automatic block, interlocking, and centralized traffic control territories.* The key is the employees timetable, which states unequivocally and in detail which rules are in effect where. Each railroad's rulebook, in turn, states the relationship between aspect and indication under each type of operation by having an individual, numbered rule for each aspect. These rules are for the most part those recommended by the A.A.R., but each road has its variations and no road uses all the aspects available. Some special cases must still be detailed in the timetable as special instructions applying to each subdivision or district. These also cover signals of entirely different class than is usually considered part of the signaling system, such as the dispatcher-controlled howlers used on the Western Pacific to advise switching crews within ear-

*Note the radical differences in meaning of a yellow night aspect in train-order, manual and automatic block signals (Figs. 1, 2 and 5).

FIG 6 "IN ADVANCE OF" — "IN THE REAR OF"



SINCE A SIGNAL FACES AGAINST THE DIRECTION OF TRAFFIC, TERMS RELATING A LOCATION TO A SIGNAL TEND TO BE CONFUSING UNLESS CAREFULLY DEFINED. BY RULE, LOCATIONS ARE RELATED WITH RESPECT TO THE DIRECTION OF TRAFFIC RATHER THAN TO THE FACE OF THE SIGNAL; SIGNAL C IS SAID TO BE "IN ADVANCE OF" SIGNAL B, WHILE SIGNAL A IS "IN THE REAR OF" (OR "IN APPROACH TO") SIGNAL B.



shot to clear the main track promptly and avoid delaying through traffic. However individualistic some examples may be, certain broad principles underlie all and over the years have become generally observed in standard practice.

One principle is that any likely defect in display or reading of an aspect should be of a nature to give a more restrictive indication. It's a bit difficult to realize in these days of red-yellow-green traffic lights on every corner that until the early years of this century a single white light was almost universally used as the night indication for *proceed*, although this violated the fail-safe principle in that a cracked red roundel could easily fall out of the semaphore spectacle and give a false *proceed* indication. In the 1906-1908 period intensive research, railroad-sponsored at the Corning Glass Works, led to distinctive, closely specified standard-color lenses, including a yellow for the *approach* aspect which was neither greenish nor reddish. This paved the way for the adoption of green, previously used most often for caution, as the *proceed* aspect. By the end of World War I white was out, and its use is now prohibited by I.C.C. order.

Another firm principle of safe signaling is that any imperfectly displayed signal must be interpreted as being at its most restrictive aspect. This was particularly critical with lower-quadrant semaphores, in which an extinguished lower-arm light could be hazardous by changing an approach indication into an apparent upper-quadrant clear aspect. Present practice with color signals frequently calls for special filament-check circuitry which will cause the signal to display its next more restrictive aspect. Some searchlight signal aspects are so arranged that a failed *clear* signal will set the next signal in the rear at *approach*, thus avoiding the big-hole brake application possible when an engineer comes upon a dark signal without warning. Signals normally fed by line power are provided with automatically connected stand-by battery supply.

As was noted in the lower-upper quadrant semaphore case mentioned, it is undesirable to have two or more different aspects for the same indication,* and the otherwise highly advantageous shift to upper quadrant signals, eliminating the second blade and the counterweights necessary to make the arms fail-safe, did bring into being a whole new set of aspects. With the advent of 24-hour light signals (Fig. 8, page 12), night and day aspects were made the same, but whole new families of signals evolved rapidly, providing, if anything, an even greater variety to delight the railfan and annoy vice-presidents in charge of standardization. In general, each road has chosen a standard type of signal for new installations and as short a list of aspects as will meet its needs, but since anything built for utter reliability will never really wear out, the older standards linger on.

Automatic train control

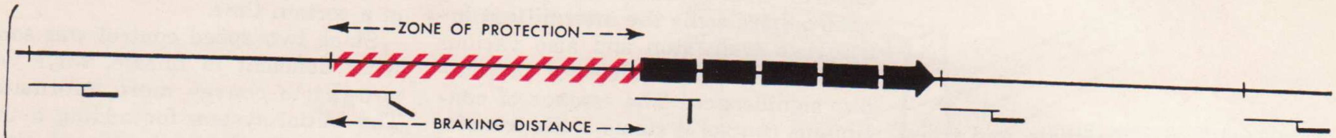
As soon as automatic signaling was well established, inventors naturally turned their minds toward eliminating the last link in the safety chain still dependent upon human alertness by providing some means for automatically stopping the train when called for by the signal. One of the early (1880) systems was the essence of simplicity: a projection on the signal, moved into tripping position when the indication was restrictive, broke a glass tube connected with the air brake train line and on went the brakes. In common with other trip-type stops, this system was not successful in steam road use but did find some favor on interurban and subway lines where speeds were low and rolling stock limited in variety. It is apparent that to apply the brakes after the train has passed into the occupied block would reduce the speed at the time of impact but could not be expected to avoid the accident, so trip-stop systems must use the "double-red" indication system in which the first red signal is always at least braking distance in the rear of the red signal marking the beginning of an occupied block. The resultant limitation on track capacity and flexibility of operation, plus the problems of spurious tripping of the train equipment from ice and other wayside obstructions, and the dangers from train slack run-ins under the unsubtle automatic brake applications have been enough to limit trip-stop systems to commuter and subway use, where they are very much in use today.

In steam road use the intermittent inductive train stop system of the general type shown in Fig. 9 (page 13) has become well accepted, however, and is in service on some 9300 miles of road. Since the air brakes will be "dynamited" automatically only if the train crew fails to act, the warning of the inductor can be transmitted to the locomotive equipment at the first restrictive signal, and track capacity is not affected. On many roads the operation of the acknowledging contactor is recorded on the Valve-Pilot or other speed record tape so that a record of the manner in which the crews observe the restrictive signal indications is available. Train stop by itself is purely a safety feature, adding nothing to track capacity or ability to reduce delays. In its order of 1947 regarding train speeds, however, the I.C.C. permitted speed limits to remain above 80 miles an hour in those territories equipped with train stop,

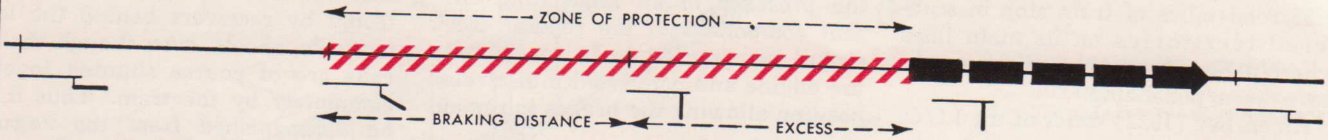
*It is impossible to compile a really complete presentation of signal aspects. One of the most extensive appeared in the September 1943 issue of TRAINS [pages 18-19]. Perhaps the most confusing area is in the differentiation between stop-and-stay (absolute) and stop-and-proceed (permissive) indications, which was generally handled by square and pointed blade ends in semaphore signaling but has not been well standardized in light signal practice. The rulebook of each individual road is the only real authority in such cases.

FIG 7 MULTIPLE-ASPECT SIGNALING AND TRACK CAPACITY

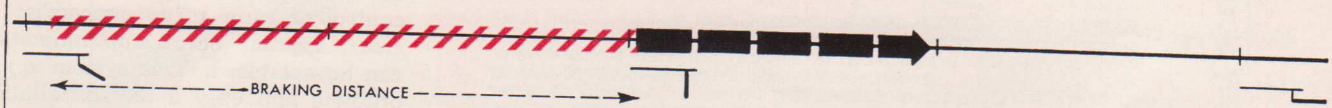
TWO-BLOCK, THREE-INDICATION



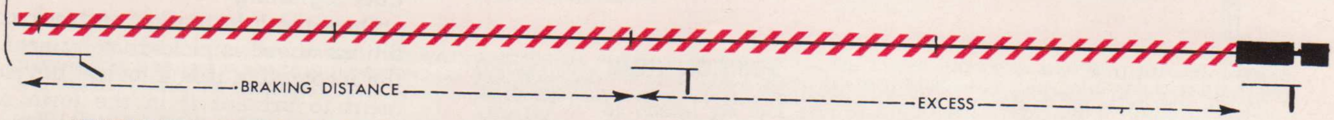
WITH A TRAIN STOPPED JUST IN ADVANCE OF A BLOCK SIGNAL, THE ZONE OF PROTECTION EXTENDING TO THE LAST RESTRICTIVE SIGNAL IN THE REAR MUST BE EQUAL TO THE BRAKING DISTANCE AT THE FASTEST TRAIN SPEED AUTHORIZED IN THE TERRITORY. WITH TWO-BLOCK SIGNALING, THIS MEANS THAT BLOCK LENGTH MUST EQUAL MAXIMUM BRAKING DISTANCE.



WITH A TRAIN JUST PASSING A SIGNAL, TWO SIGNALS IN THE REAR ARE AT STOP AND ZONE OF PROTECTION IS AT A MAXIMUM. THIS MAXIMUM ZONE LENGTH IS THE MINIMUM SPACING BETWEEN TRAINS IF THE SECOND TRAIN IS TO PROCEED WITHOUT RECEIVING RESTRICTIVE INDICATIONS, AND IN THE TWO-BLOCK SYSTEM THIS SPACING EQUALS TWO BLOCKS, TWICE THE BRAKING DISTANCE.



IF TRAIN SPEED AUTHORIZED IS INCREASED 50 PER CENT, SAY FROM 60 TO 90 MPH, BRAKING DISTANCE IS APPROXIMATELY DOUBLED. ONE METHOD OF COPING WITH THIS IS TO RESPACE SIGNALS TO THE NEW BRAKING DISTANCE, AS HAS BEEN DONE HERE.



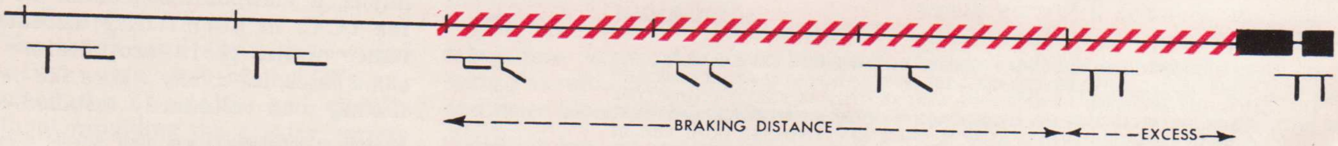
RESULTING MINIMUM SPACING, FOUR TIMES THE OLD BRAKING DISTANCE, IS A SEVERE PENALTY TO TRACK CAPACITY BECAUSE OF INCREASED DISTANCE BETWEEN TRAINS, AND A FURTHER HANDICAP BECAUSE TRAIN RECEIVING A YELLOW SIGNAL HAS A LONGER BLOCK THROUGH WHICH TO PASS BEFORE REACHING NEXT SIGNAL AND BEING ABLE TO RESUME SPEED IF TRACK HAS CLEARED.

THREE-BLOCK, FOUR-INDICATION

RETAINING OLD SIGNAL SPACING BUT PROVIDING THREE-BLOCK SYSTEM WITH ADDITIONAL ASPECT (APPROACH MEDIUM) BETWEEN CLEAR AND APPROACH ALLOWS 25 PER CENT GREATER TRACK CAPACITY THAN RESPACING SIGNALS, WITH SHORT-BLOCK ADVANTAGE IN CASE RESTRICTIVE INDICATION IS ENCOUNTERED. SECTIONS OF FOUR-INDICATION SIGNALING MAY BE INTRODUCED ON DESCENDING GRADES, WHERE LONGER STOPPING DISTANCES OTHERWISE WOULD LIMIT SPEED AND CAPACITY.

FOURTH INDICATION MAY ALSO BE GIVEN BY DOUBLE YELLOW OR SINGLE FLASHING YELLOW ASPECT, RETAINING SINGLE RED, YELLOW AND GREEN FOR STOP, APPROACH AND CLEAR ASPECTS; NO SINGLE ASPECT HAS BEEN UNIVERSALLY ACCEPTED.

FOUR-BLOCK, FIVE-INDICATION



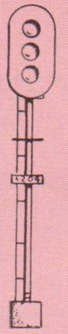
FOUR-BLOCK, FIVE-INDICATION SIGNALING EFFECTS A FURTHER INCREASE IN TRACK CAPACITY, IS USED MOSTLY IN APPROACH TO BOTTLENECKS WHERE TRAINS ARE LIKELY TO RECEIVE RESTRICTIVE INDICATIONS OFTEN, NEED TO BE ABLE TO RESUME SPEED PROMPTLY

train control or cab signals, and train stop thus becomes one way to continue to maintain fast schedules. The biggest single result of this order was the installation on the Santa Fe of 2133 road-miles of train stop in scattered territories on its main lines where a 79-mile-an-hour limit would have been penalizing.

An earlier (1922) order of the I.C.C. required all large roads to equip at least one division with automatic train control of some type, although the equipment available was still far from perfected. Out of the welter of semi-experimental systems installed as a result, there came the intermittent inductive train stop and also various continuous control ideas of present-day significance. The essence of continuous control systems is the transfer of information from the track to the locomotive at all times, in an appropriately fail-safe manner. Early systems were of two-speed type, in which the presence of an alternating current component in the regular track circuit was sensed by a receiver on the engine and converted into a relay position allowing the brakes to remain released. Absence of the A.C., brought about by a restrictive signal or any failure of the equipment, required that the train crew forestall the automatic application of the brakes by a service reduction in train pipe pressure within a certain time.

Since two-speed control was somewhat deficient in finesse, ways were sought to convey more information. The initial system for adding a third speed involved use of a "loop" circuit in which A.C. is fed along both rails simultaneously from one end of the block to the other, returning by line-side wire. This current will be detected by receivers behind the locomotive's wheels, even though the two rails are of course shunted together completely by the train. Thus it can be distinguished from the regular track circuit current which can be picked up only by receivers located ahead of the first axle, and with the aid of speed-measuring equipment on the locomotive a reasonably complete control of train speed appropriate to *clear*, *approach* and *stop* indications can be exercised. This system is now obsolete and only a few installations remain in service. The continuous coded system is now the accepted method of providing this feature.

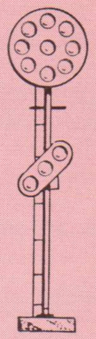
FIG 8 MODERN SIGNALS



COLOR-LIGHT

MAIN-LINE, HIGH-SPEED USE OF 24-HOUR COLOR-LIGHT SIGNALS BECAME FEASIBLE IN 1914 WITH THE PERFECTION OF CONCENTRATED-FILAMENT LAMPS GIVING A SATISFACTORY SIGHTING DISTANCE IN DAYLIGHT WITH MODERATE CURRENT CONSUMPTION. THEY ARE STILL FAVORED BY ROADS WHERE CURVATURE OR OTHER OPERATING CONDITIONS PREVENT TAKING FULL ADVANTAGE OF THE GREATER SIGHTING DISTANCE OF THE MORE EXPENSIVE SEARCHLIGHT SIGNALS. ROUNDELS MAY BE ARRANGED IN USUAL VERTICAL ROW, OR HORIZONTALLY (READING AND CHICAGO & NORTH WESTERN), OR IN TRIANGULAR GROUPING (NEW YORK CENTRAL AND OTHERS). DESIGN PRECAUTIONS ARE NECESSARY TO PREVENT SUNLIGHT REFLECTIONS FROM PRODUCING FALSE INDICATIONS. CONTRARY TO TRAFFIC SIGNAL PRACTICE, "IRISH" ARRANGEMENT (GREEN ON TOP) IS USUAL.

POSITION LIGHT

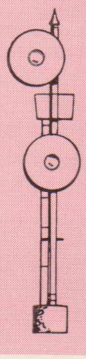


POSITION-LIGHT SIGNALS WERE INTRODUCED IN 1915, AND ARE MOSTLY RESTRICTED TO PENNSYLVANIA AND AFFILIATES (NORFOLK & WESTERN, LEHIGH VALLEY). SINGLE COLOR PERMITS USE OF FOG-PENETRATING YELLOW IN HIGH SIGNALS, WHITE IN DWARFS. INDICATION CAN BE READ WITH ONE LIGHT IN ROW OUT; EACH HEAD CAN GIVE FOUR INDICATIONS, INCLUDING LOWER-QUADRANT 45-DEGREE POSITION USED FOR PERMISSIVE. PARTIAL UNITS MAY BE USED FOR INTERLOCKING AND APPROACH-MEDIUM INDICATIONS REQUIRING TWO HEADS, LOWER UNIT BEING LIGHTED ONLY AS NECESSARY. PENNSYLVANIA USES TWO SPECIAL INDICATIONS: CIRCLE OF LIGHTS IS INSTRUCTION TO LOWER PANTOGRAPH; FIVE-BULB X IS TAKE-SIDING SIGNAL.

COLOR-POSITION

FIRST USED IN THEIR MODERN FORM IN 1921, COLOR-POSITION SIGNALS ARE IN USE ONLY ON BALTIMORE & OHIO AND RELATED LINES. SINGLE MAIN HEAD IS USED, MODIFIED WITH LUNAR WHITE OR YELLOW MARKERS ABOVE AND BELOW AS NECESSARY TO PROVIDE HIGH-, MEDIUM- AND LOW-SPEED ROUTE INDICATIONS, ETC. COLOR OF REMAINING LAMP GIVES USABLE INDICATION IN CASE OF FILAMENT FAILURE. LOWER-QUADRANT 45-DEGREE POSITION IN LUNAR WHITE IS PERMISSIVE ASPECT; UPPER WHITE MARKER STAGGERED TO LEFT WITH VERTICAL GREEN ON MAIN SIGNAL IS APPROACH-MEDIUM ASPECT.

SEARCHLIGHT



SEARCHLIGHT SIGNALS, USING A SINGLE LAMP AND LENS SYSTEM TO PROJECT THREE COLORS, APPEARED IN 1920, WERE IMPROVED IN 1930 WITH COMPOUND LENS SYSTEM GIVING 1 MILE RANGE WITH AS LITTLE AS 5-WATT POWER CONSUMPTION. RELAY-TYPE MECHANISM MOVES MINIATURE SPECTACLE IN OPTICAL PATH TO PROVIDE VARYING ASPECTS; SINCE ANY REFLECTED LIGHT WILL BE OF PROPER COLOR, EFFICIENT MIRROR CAN SAFELY BE USED BEHIND LAMP. SPECIAL DEFLECTING LENSES ARE USED TO PROVIDE BEST COVERAGE FOR RIGHT- AND LEFT-HAND CURVED TRACK IN APPROACH TO SIGNAL. REGULAR BEAM IS EXTREMELY NARROW – SIGHTS ARE PROVIDED ON UNIT FOR ACCURATE AIMING AT PATH OF APPROACHING CAB.

Cab signaling

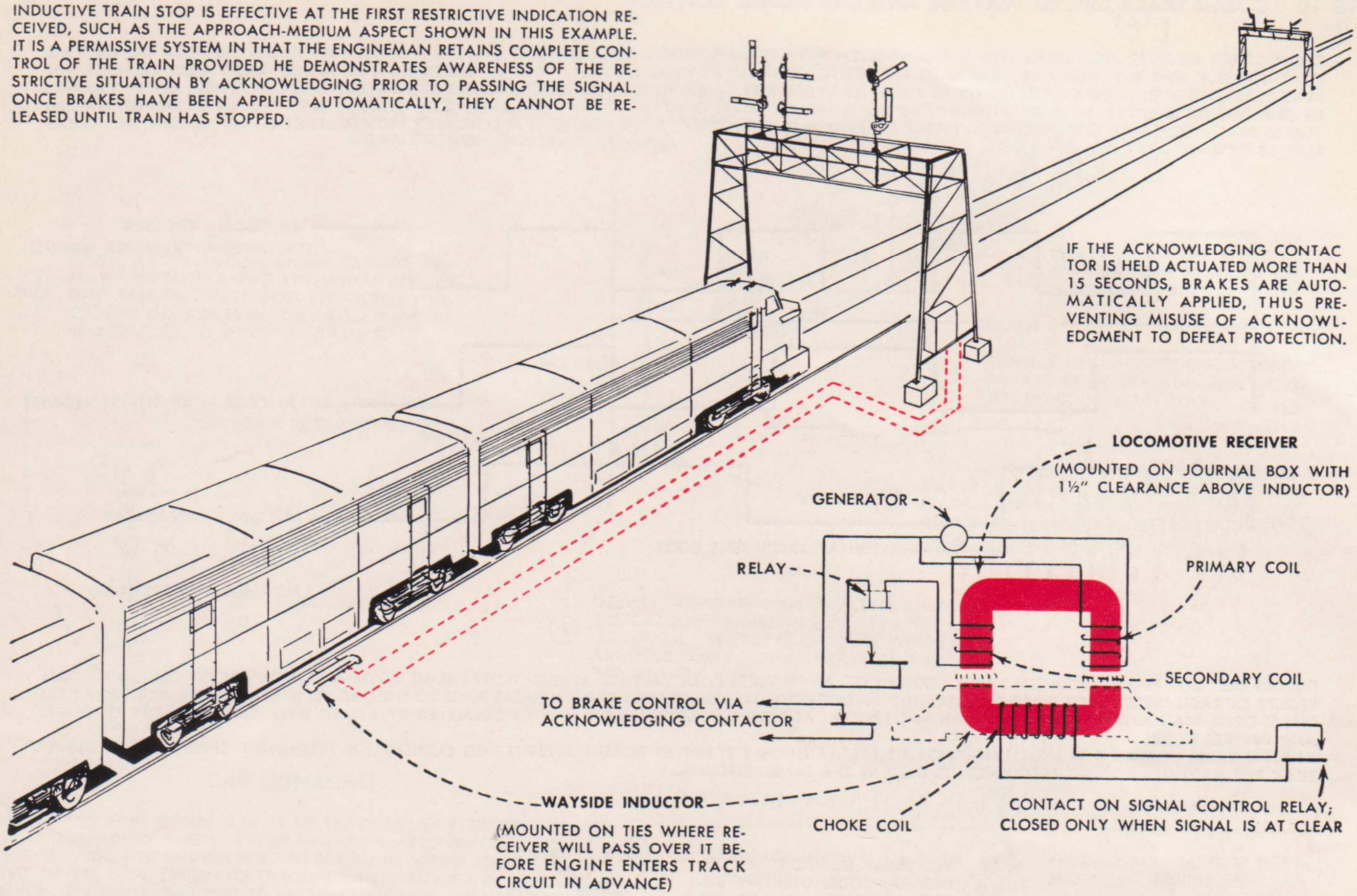
Once the information on track conditions ahead is picked up by gear on the locomotive it is a logical development to present it in the form of a cab signal indication. In the continuous train control system, the information is more up-to-date in many cases than is otherwise available, since any change in the condition of occupancy of the block ahead will be picked up by the receiver whether or not the wayside signal is yet visible.* It is this traffic-speeding feature of continuous cab signaling that has endeared it to managements and crews alike. Being able to resume speed promptly when the caboose of a freight far ahead in the fog is safely in the clear can be a very significant time-saver.

With the state of the road kept in front of the crew at all times and any more restrictive change announced by a whistle which must be acknowledged, the automatic brake-applying feature of the continuous system was regarded by some roads as superfluous, a viewpoint concurred on by the I.C.C. in permitting discontinuance of the train-stop feature in some cases, especially where the petitioning road voluntarily installed ex-

*Except at interlockings and other definite stopping points, wayside signals are not essential with cab signaling, and several installations do not have them. The longest recent installation, Union Pacific's Omaha-Ogden line, retains wayside signaling because locomotives not operating at speeds in excess of 80 miles an hour are not required to carry cab signal equipment.

FIG 9 INTERMITTENT INDUCTIVE TRAIN CONTROL

INDUCTIVE TRAIN STOP IS EFFECTIVE AT THE FIRST RESTRICTIVE INDICATION RECEIVED, SUCH AS THE APPROACH-MEDIUM ASPECT SHOWN IN THIS EXAMPLE. IT IS A PERMISSIVE SYSTEM IN THAT THE ENGINEMAN RETAINS COMPLETE CONTROL OF THE TRAIN PROVIDED HE DEMONSTRATES AWARENESS OF THE RESTRICTIVE SITUATION BY ACKNOWLEDGING PRIOR TO PASSING THE SIGNAL. ONCE BRAKES HAVE BEEN APPLIED AUTOMATICALLY, THEY CANNOT BE RELEASED UNTIL TRAIN HAS STOPPED.



WHEN RECEIVER ON LOCOMOTIVE PASSES OVER WAYSIDE INDUCTOR, PRESENCE OF INDUCTOR CORE CAUSES INCREASED MAGNETIC FLUX IN RECEIVER. THIS INDUCES A REVERSE VOLTAGE IN THE SECONDARY COIL, REDUCING THE RELAY COIL CURRENT BELOW THE DROP-OUT POINT, AND APPLIES THE LOCOMOTIVE BRAKES, UNLESS THE ENGINEMAN HAS OPERATED THE ACKNOWLEDGING CONTACTOR TO INDICATE THAT HE IS AWARE OF THE RESTRICTIVE SIGNAL.

WHEN SIGNAL IS CLEAR, A CONTACT ON THE SIGNAL CONTROL RELAY CLOSES A CHOKE COIL CIRCUIT IN THE INDUCTOR. THIS SHORT-CIRCUITED COIL IMPEDES ACTION OF INDUCTOR ON RECEIVER TO THE EXTENT THAT THE LOCOMOTIVE CAN PASS THE SIGNAL WITHOUT RECEIVING A BRAKE ACTUATION.

tended mileages of cab signaling alone. At least one road, however, has installed brake-applying and speed-control equipment after having previously obtained permission to operate without these features. A series of accidents had occurred in which in each instance the information given to the engineman was established as being correct and yet the train was not operated safely in accord with it.

Cab signaling is now in service on 3950 miles of heavily traveled line totaling 8600 miles of track. An additional 1025 miles of road and 1950 miles of track are covered by automatic train control, with varying combinations of cab indications and speed control actuated by continuously energized circuits.

Coded control

The track-and-loop three-speed continuous system of the '20's exhausted the available rail circuits without providing the greater variety of indications needed in the densely trafficked territories where cab signaling would be most useful. So it was necessary to go to the coded system described in Fig. 10 (pages 14-15) which can provide the extra intelligence through the pulse rate in a single circuit. Early coded cab signal installations were superimposed upon the regular steady-energy track circuits controlling the wayside signals, and alternating current was used because direct-current pulses could not be picked up and amplified reliably by the locomotive receiver.*

As the coded-circuit equipment became more highly developed and dependable it became apparent that the same system which worked the signals in the cab could also control the wayside signals, in the manner also illustrated in Fig. 10. In the process, two advantages probably as great in ultimate importance as the cab signals themselves were realized.

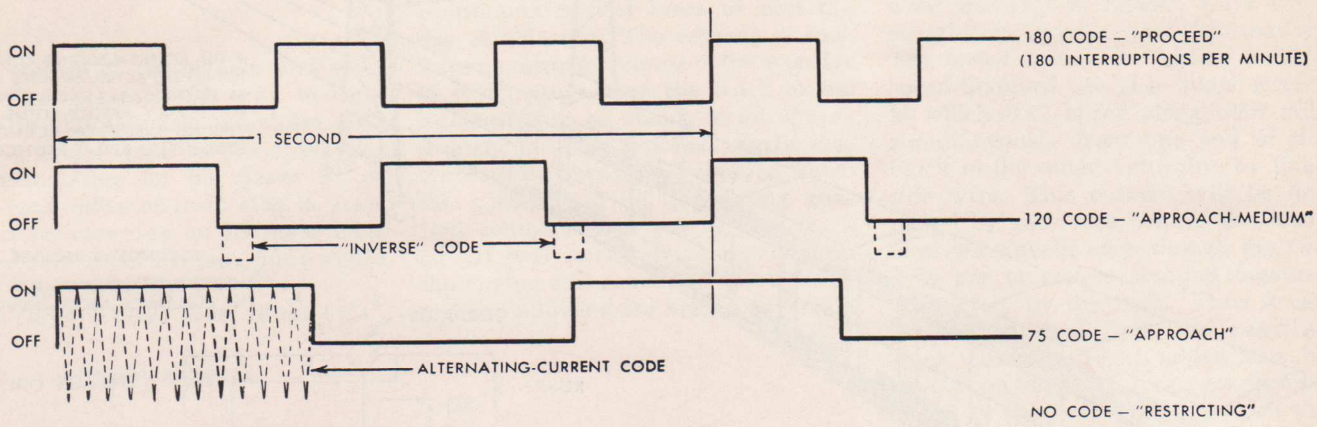
The first was the elimination of many line wires. As a block signal system is refined to "feel ahead" more and more blocks, it becomes necessary to carry a more complex message back through the intervening miles, and the cost of providing and maintaining wire circuits for this becomes large in comparison with the cost of relays and other local circuits. It may also become large in comparison with the savings effected by the signaling system, so that the railroad will tend to spend its funds for other improvements instead, a thought most painful to the equipment manufacturer and the signal department alike. They therefore are eternally searching for ways to reduce the line wires needed to do the job. Prior to coding, a good deal of progress was made through the use of polarized direct current circuits in which, for example, an energized circuit with positive on the left wire would control a signal to the yellow aspect while reverse polarity would be interpreted by the signal relay as a call for the green aspect. With a de-energized circuit leaving the signal at red, three indications could be transmitted with two wires.* Coding opens

*It has not been well publicized, but the railway equipment manufacturers and railroads have always been among the foremost in adapting electrical and electronic advances to their needs; the locomotive receiving equipment first experimented with in 1916 by Union Switch & Signal and in service in the early '20's represented the first industrial use of electronics outside of the communication field. Present-day equipment has already been transistorized.

*Signal-controlling line circuits do not generally use a common grounded return circuit, in the interest of safety. With each circuit separated electrically from its neighbors, *two* short-circuits between wires or to ground must occur before safety is jeopardized.

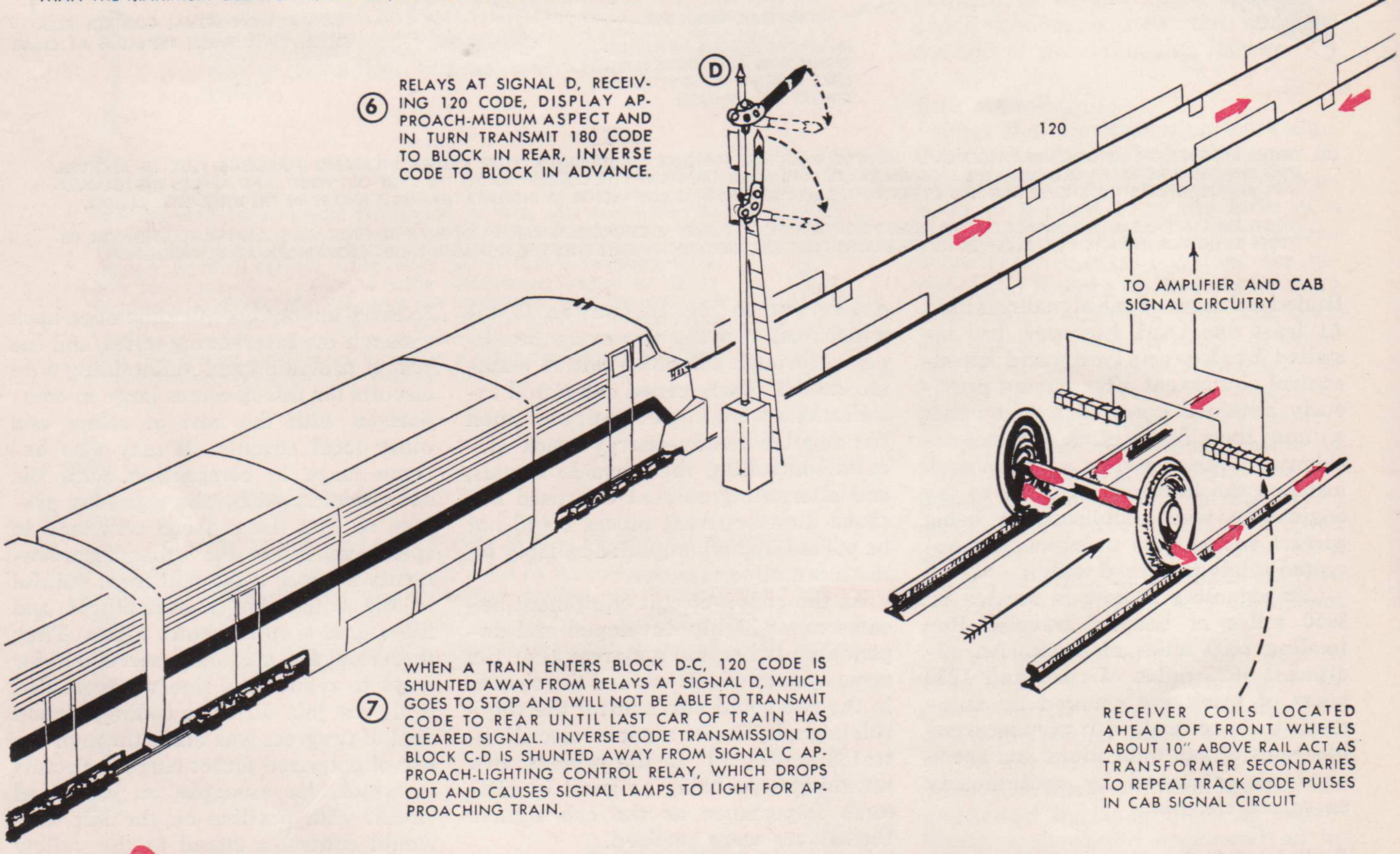
FIG 10 CODED TRACK CIRCUIT WAYSIDE AND CAB SIGNAL CONTROL

CODED TRACK CIRCUITS, FIRST DEVELOPED IN CONNECTION WITH TRAIN-CONTROL CAB SIGNALING SYSTEMS BECAUSE THEY COULD TRANSMIT INDICATIONS CONTINUOUSLY TO A MOVING TRAIN, MAY ALSO BE USED TO CONTROL WAYSIDE SIGNALS WITHOUT REQUIRING LINE WIRES. THEY ALSO INCREASE THE PRACTICAL LENGTH OF A TRACK CIRCUIT TO AS MUCH AS 11,000 FEET. THEREFORE MUCH BLOCK SIGNALING INSTALLED SINCE 1933 USES CODED CIRCUITS OF ONE TYPE OR ANOTHER, WITH OR WITHOUT CAB SIGNALING OR TRAIN CONTROL. ONE OF THE BASIC CODE SYSTEMS USED, D.C. RATE CODING, IS ILLUSTRATED HERE. THE CODED CIRCUIT CARRIES DIRECT CURRENT INTERRUPTED AT VARIOUS RATES IN ACCORDANCE WITH MESSAGE BEING TRANSMITTED CODES MAY BE PICTURED AS FOLLOWS:



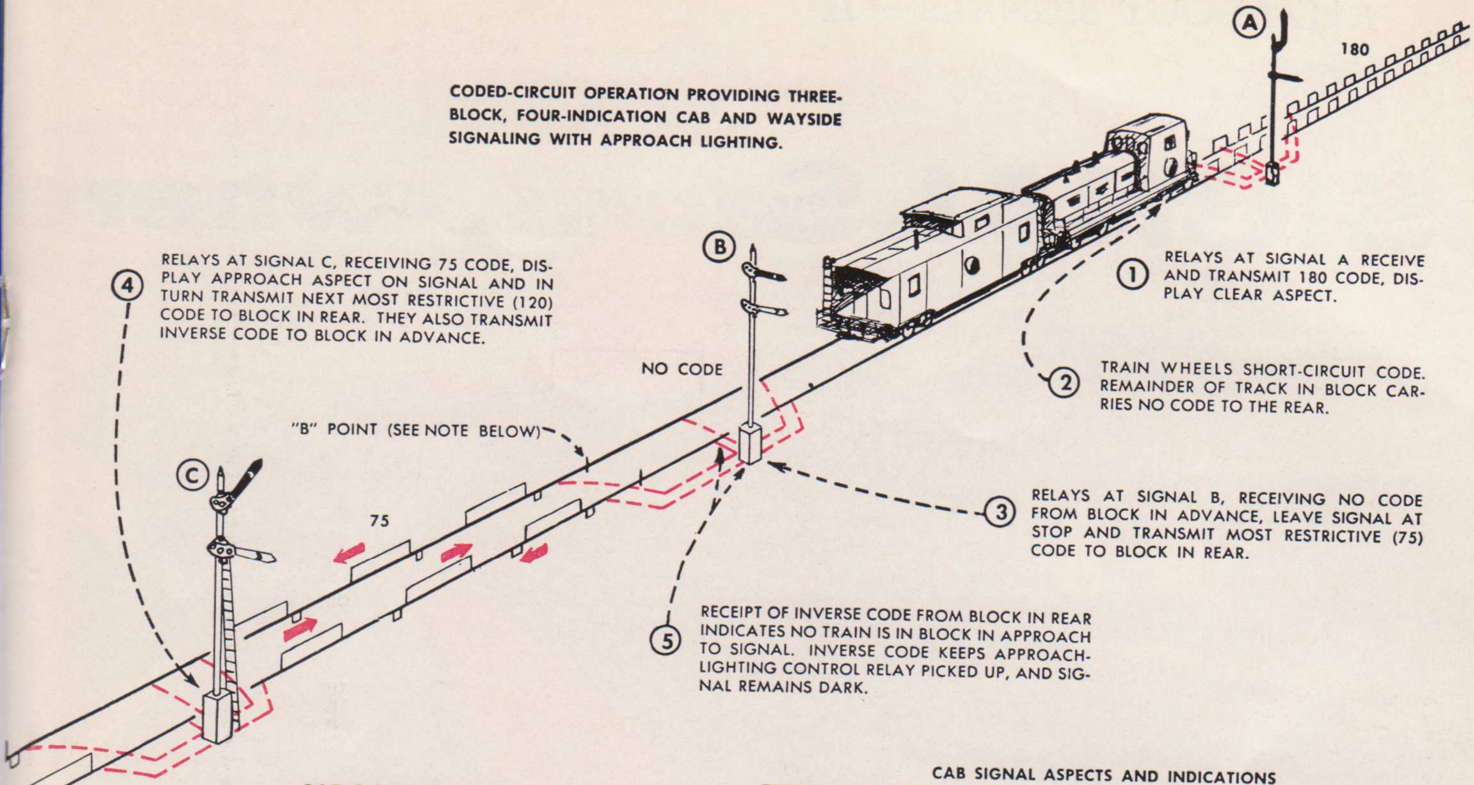
DURING THE "OFF" PERIODS BETWEEN DIRECT CODE PULSES AN "INVERSE CODE" MAY BE APPLIED TO TRANSMIT INFORMATION IN THE OPPOSITE DIRECTION. RECEIPT OF EACH DIRECT-CODE PULSE TRIGGERS THE INVERSE-CODE TRANSMITTER TO APPLY A SHORT PULSE TO THE CIRCUIT, WHICH IS THEN RECEIVED AT THE DIRECT-CODE TRANSMITTER DURING ITS STAND-BY PERIOD. ADDITIONAL INFORMATION MAY BE CONVEYED BY USE OF DIFFERENT POLARITIES OF DIRECT AND INVERSE CODES.

IN SOME CASES (FOR ALL CAB SIGNALING PRIOR TO 1951, AND ON ELECTRIFIED ROADS) ALTERNATING CURRENT (OF FREQUENCY SEVERAL TIMES HIGHER THAN THE MAXIMUM CODING FREQUENCY) IS USED IN THE TRACK CIRCUITS.



up the field completely, since the various code frequencies can in turn be polarized.

Perhaps as complete an example of the elimination of line wires by coded circuits as you could ask for is the General Railway Signal installation on the New York Central main line west of Batavia, N. Y. Here five- and six-indication signals are provided in the approach to interlocking plants, with the signals approach-lighted; train-approach circuits serve to lock up the routes through the junctions so that they cannot be changed in the face of a fast-moving train. In addition, at highway grade crossings the flashers must be controlled so as to



CAB SIGNALING

TRAIN APPROACHING SIGNAL D PICKS UP 180 CODE VIA RECEIVERS LOCATED IN FRONT OF LEADING WHEELS. PULSES INDUCED IN RECEIVER COILS ARE ELECTRONICALLY AMPLIFIED AND DECODED TO DETERMINE ASPECT TO BE DISPLAYED (GREEN, IN THIS CASE). WHEN LOCOMOTIVE ENTERS BLOCK C-D, 120 CODE IS RECEIVED. CAB SIGNAL CHANGES TO APPROACH MEDIUM AND WHISTLE BLOWS IN CAB UNTIL TURNED OFF BY DEPRESSING AND RELEASING ACKNOWLEDGING CONTACTOR. WHISTLE WILL BLOW AND MUST ALSO BE ACKNOWLEDGED AS EACH SUCCESSIVE MORE-RESTRICTIVE INDICATION IS RECEIVED. SHOULD PRECEDING TRAIN CLEAR BLOCK A-B WHILE FOLLOWING TRAIN IS STILL IN BLOCK C-D, CAB SIGNAL WOULD IMMEDIATELY CHANGE TO CLEAR, WITH A SHORT BEEP ON WHISTLE CALLING ATTENTION TO MORE FAVORABLE CONDITION.

IN SOME CASES, CODE FROM SIGNAL AT STOP ASPECT IS FED INTO TRACK AT THE "B" POINT, BRAKING DISTANCE (AT MEDIUM SPEED) IN REAR OF SIGNAL, PROVIDING RESTRICTING ASPECT PRIOR TO ENTRY INTO OCCUPIED BLOCK. NOTE THAT CAB SIGNAL REPEATS INDICATION OF CONDITION OF BLOCK IN WHICH TRAIN IS LOCATED, NOT THAT OF SIGNAL IN ADVANCE.

WHERE NO WAYSIDE SIGNALS ARE USED, CORRESPONDING CAB SIGNAL INDICATIONS ARE MOVED BACK ONE BLOCK, SO THAT RESTRICTING INDICATION IS RECEIVED AT LEAST ONE BLOCK IN REAR OF OBSTRUCTION.

CAB SIGNAL ASPECTS AND INDICATIONS

1. CLEAR (180 CODE)	G OR	PROCEED
2. APPROACH-MEDIUM (120 CODE)	Y / G OR	PROCEED APPROACHING NEXT SIGNAL AT MEDIUM SPEED
3. APPROACH (75 CODE)	Y OR	PROCEED PREPARING TO STOP AT NEXT SIGNAL; TRAIN EXCEEDING MEDIUM SPEED MUST IMMEDIATELY REDUCE TO THAT SPEED.
4. RESTRICTING (NO CODE)	R / Y OR	PROCEED AT RESTRICTED SPEED

THREE-INDICATION SYSTEMS USE INDICATIONS 1, 3 AND 4; TWO-INDICATION SYSTEMS USE INDICATIONS 1 AND 4.

stop as soon as the rear car of a train clears. All of these functions, totaling up to eight in some blocks, are handled through the two running rails by the use of polarized direct and inverse codes.

The second advantage of the coded track circuit comes from the fact that the code-following track relay must pick up with each pulse. Therefore, the train shunt need only be enough to reduce the track current at the relay (see Fig. 4) below the pick-up value, rather than below the drop-out value. In practice this means that with coded circuits a higher voltage can be used and, with given ballast resistance conditions, track circuits can be about twice as long as with steady-energy circuits. There are also safety advantages, in that any stray currents in the rails will not be pulsating in such a way as to affect the track relay.

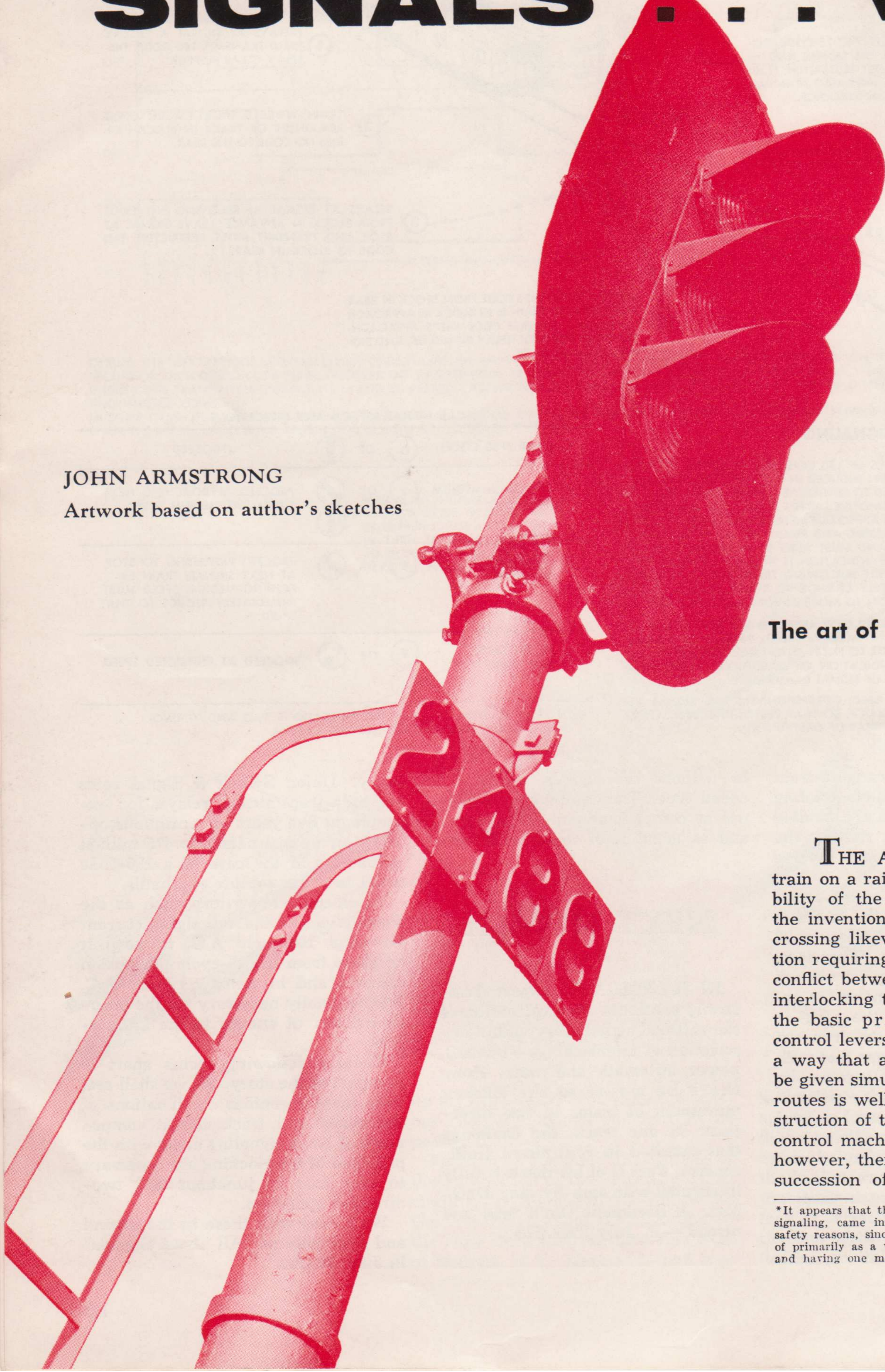
The net result is that most automatic block signal installations, with or without cab signals, are now of coded type. The equipment needed is not as complex as you might expect, and as usual is of remarkable reliability. Union Switch & Signal rates its code-transmitting relays, for example, at five years of continuous operation (amounting to 475 million actuations in the case of a 180-code unit) between routine overhauls.

In electrified territory such as the Pennsylvania's the cab signal current is coded 100-cycle A.C. to keep it separate from the 25-cycle propulsion current, and in steam territory A.C. was originally necessary for the proper transfer of energy to the locomotive.

Keeping following trains apart is just part of the story. As we shall see, even more ingenious combinations of the signal and track circuit components of block signaling along with the principle of interlocking are necessary to take care of junctions and two-direction operation.

We'll deal with these in the second and final part of "All about Signals" in July Trains.

SIGNALS . . . where



JOHN ARMSTRONG
Artwork based on author's sketches

The art of keeping trains apart —

THE ADVENT of the second train on a railroad brought the possibility of the rear-end collision, and the invention of the turnout and the crossing likewise introduced a situation requiring signaling development: conflict between routes. The familiar interlocking tower is the answer, and the basic principle whereby signal control levers are interlocked in such a way that a clear indication cannot be given simultaneously on conflicting routes is well known. Since the construction of the first truly interlocked control machine* in England in 1857, however, there has been a continuing succession of additions to the rudi-

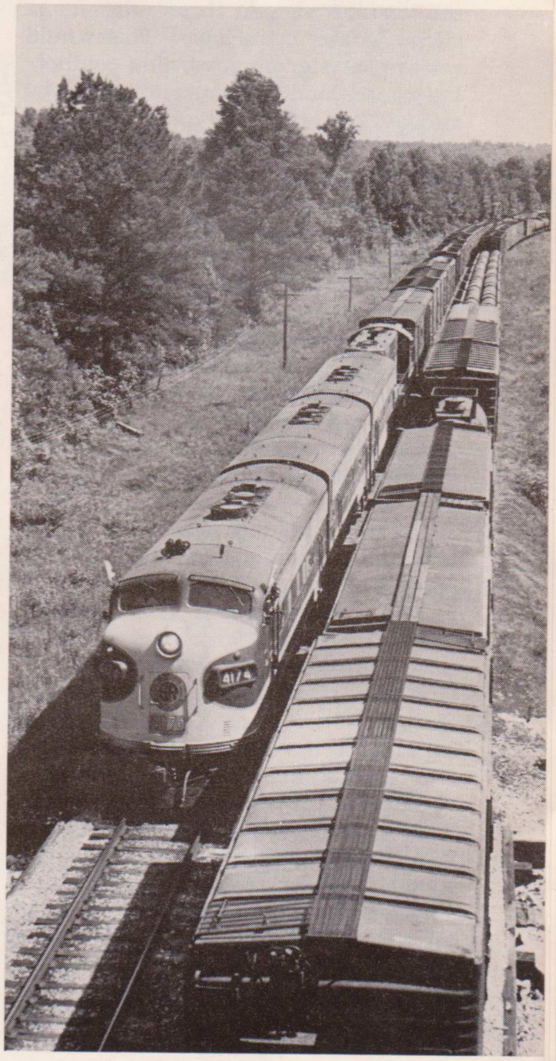
*It appears that the original interlocking, unlike block signaling, came into being for economic rather than safety reasons, since the first installations were thought of primarily as a way to avoid the stopping of trains and having one man tend many switches.

tracks cross

Herbert H. Harwood Jr.

or trains meet

but not too far apart — has evolved from the old armstrong interlocking tower to a C.T.C. panel that puts an entire division, even a railroad, at your fingertips. And science isn't finished yet



J. P. Lamb Jr.

mentary type of mechanical locking and today we find detector, route, sectional-route, switch, signal indication, traffic, time and approach locking to be necessary for safeguarding and expediting high-speed traffic. Fig. 11 (page 19) points out how these types of lockings fit into the picture.

Mechanical interlocking

Each type of locking has come through several stages of development and has influenced the choice of means for operating the plant. Take, for example, "detector," or "section," locking, needed to prevent the throwing of switches under trains. Since early interlockers were entirely mechanical, about the only possible device was the "detector bar," a member attached to the switch-throwing linkage in such a way that it rose above the railhead while the points were shifting. If a train was on the track the wheels would hold the bar down so that the switch could not be thrown. With any slack in the linkage, though, the points might open a dangerous amount before the bar would stop the motion, so it was soon realized that a separate lock directly on the switch points — which would have to be released completely before the points could budge — was essential. Called the "facing point lock" because it was not deemed necessary on trailing-point switches, this device is still common in mechanical interlockings.

Electric locking

A single-lever "switch-and-lock" mechanism was ultimately devised in

which the first motion of the lever in the tower withdrew a pin locking the points. Further motion then threw the switch, but before the lever could complete its motion and release other machine functions the pin was driven back into the point-locking position. Detector bars were a continuing headache, though, so it was not long after the invention of the track circuit that electrically released lever-locks were developed.* Track-circuit-controlled relays could then unlock the mechanical switch levers only when the track through the switch was unoccupied.

Once inadvertent throwing of switches under trains was effectively prevented it became evident that other, more subtle, perils existed. The towerman could clear a route for one train and then, after it had accepted the distant signal, throw the home signal to red in its face. This would release the signals governing conflicting routes and other trains could be allowed to enter the plant, perhaps colliding with the first train which would of necessity have overrun the home signal. By delaying release of other functions until any train affected had had time to stop, time locking took care of this possibility, but at the expense of seriously reduced flexibility in accepting trains. Should a train for which a route had been cleared be delayed in arrival, the time-locking delay (typically about 4 minutes) would prevent other routes from being cleared promptly. With track circuits available as a tool, time locking could be refined into approach locking, effective only if a train had actually entered the approach circuit.

Improvements could also be made in route locking, which in the basic interlocking provides assurance that once the signal governing a route through the plant is cleared all switches in the entire route are locked. This is necessary lest a high-speed route be changed to a low-speed one after a train has already entered it at a speed too high for the new alignment. It is also essential, though, that the signal be put at stop as soon as the train has passed it to provide block protection against following trains. With mechanical locking only, this would release the switches and thus defeat the route locking. With a track-circuited system, route locking can be maintained irrespective of signal indication so long as the train occupies the route, resolving the dilemma. The final refinement, in the interest of expediting traffic, is sectional-route locking, in which the train's passage through successive sections releases promptly those functions no longer affecting its safety.

*It should be noted that, for reasons similar to those calling for the use of facing-point locks, the interlocking of one lever by another is accomplished by locking the latch which prevents the lever from being moved, rather than by locking the lever itself.

Electromechanical interlocking

Strictly mechanical interlockings have not been built in recent years and 50 were retired from service in 1955, but over 1000 of the 4200 interlockings in use in the United States are still of this type, and it will be a long time before the last assemblage of man-sized levers directly connected to switches and signals through long lines of 1-inch pipe is consolidated into a C.T.C. installation or replaced by the miniature levers and push-buttons of an all-relay interlocking.

Power operation of signals became practical in the 1880's and — first in England and then in the United States — the hybrid electromechanical interlocking became popular. Switches, locks, derails and movable-point crossings are pipe-connected to levers in these plants, while smaller levers, usually interlocked with the mechanical levers, control the signals. Track circuits and electric locking are used, and a track model board with lights indicating track occupancy, switch locking, and so forth, is usually provided. Since the most remote elements of the plant are the distant signals, while switches are usually within the 1000-foot or so range of mechanical connections, the electromechanical combination can handle more extensive trackage and provide adequate distant-signal spacing for safe high-speed approach.

Electric locking, and the systems dependent upon it, by no means had smooth sailing at first. As with many improvements in automatic devices, it had to suffer through a period in which the relative ease with which an operator could gimmick the locking with a piece of wire kept it in some disrepute. By 1900, however, its acceptance was general.

Power and relay interlockings

After various false starts with hydraulic, electrohydraulic and pneumatic-hydraulic systems, practical electropneumatic and electric-motor switch machines were developed shortly before the turn of the century. Power interlockings then became feasible and soon were the principal type for new installations. Use of power switch controls removed the limit on the length of territory that could be controlled. Since no brawn had to be applied to the levers they could shrink to little more than handles, greatly reducing the bulk of the machine. Schematically, however, interlockings of the power type built up until the early 1930's are not essentially different from their mechanical predecessors. Mechanical locking between the levers performs the basic interlocking, with electric locking right in the machine handling track-circuit-controlled functions.*

It became increasingly desirable, naturally, to consolidate the functions of individual small interlockings into nearby plants. The expense for line wire to bring all the necessary track circuit indications and switch and signal controls back to the tower led gradually toward locating much of the actual locking, in the form of vital-circuit-type relay contacts, at the field location. Line wires then were needed only to direct switches to throw and signals to clear *if permitted by the local locking*, and to return indications of their actual position. Application of typical ingenuity to the line-wire reduction campaign in due course brought things to the point where control of a single switch and its governing signals (such as at the end of double track) could be accomplished with a total of two line wires, the same wire serving in sequence the purposes of switch control and signal position indication.

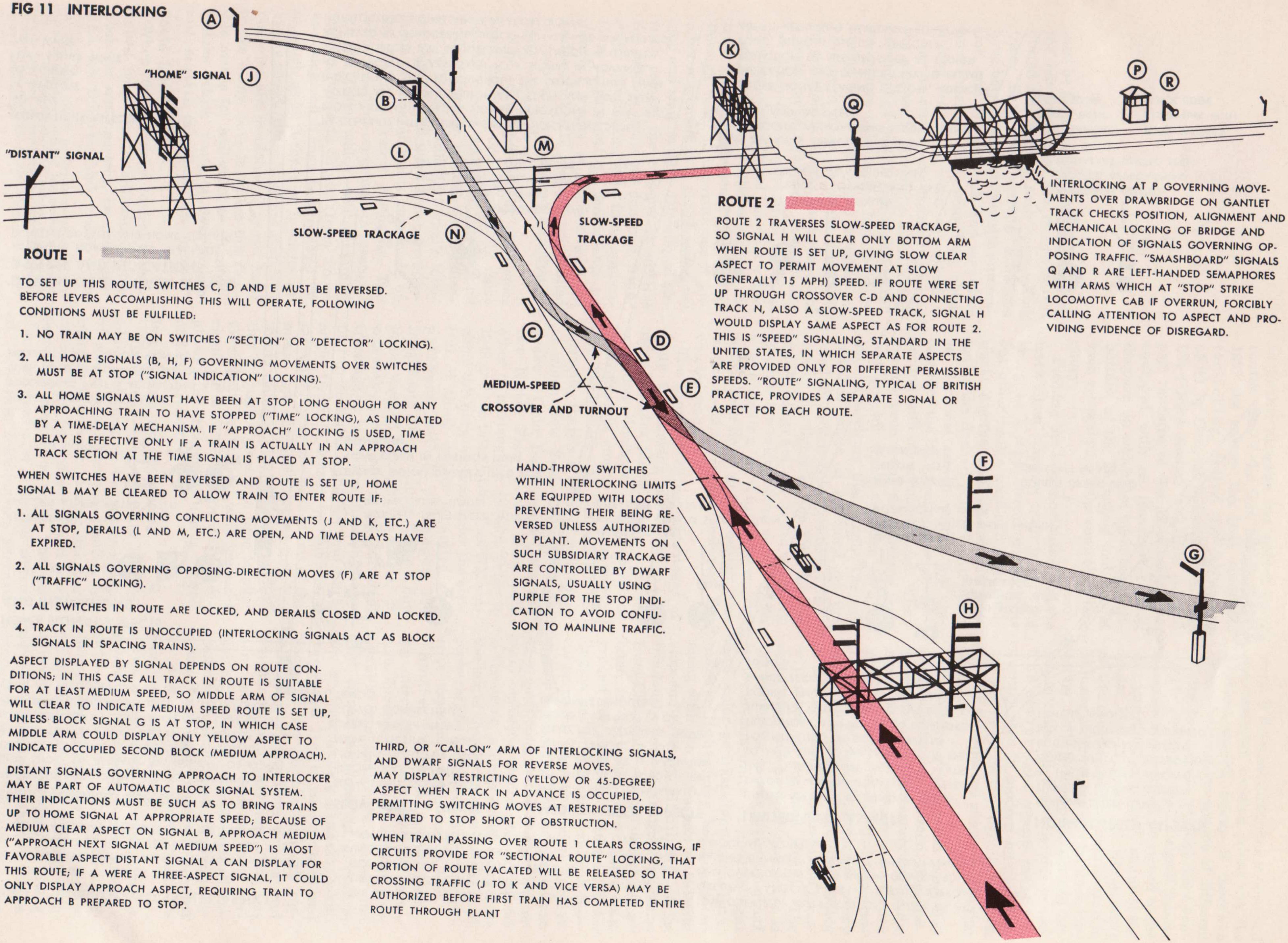
The next logical step, first taken in 1929, was to rely entirely on the relay safety circuits. In relay interlocking, freely moving miniature levers are mounted in a small machine which displays field conditions on a track diagram board. The machine houses only communication-type functions, putting into effect permissible manipulations (as determined by the interlocking-equivalent relay circuits located in the tower's first-floor relay room and in relay sheds at trackside) by electric or electropneumatic switch and signal controls.

Automatic interlocking

At the very largest interlockings where individual-lever control is in effect, several operators are kept busy lining up the routes called out by the train director in charge. On the other hand, a country grade crossing between two lines is a pretty sleepy place, even though its interlocking

*One additional type of locking required in power interlocking is electric switch-indication locking. If the levers are interlocked at the tower, it is essential that the correspondence between the position of the switch lever and the switch points be insured before signals and controls dependent on switch position are released; otherwise, any obstruction to full closure of the switch points or failure in the switch machine or its control circuits would be undetected. This locking is the electrical equivalent of the facing-point lock or the switch-and-lock mechanism.

FIG 11 INTERLOCKING



ROUTE 1

TO SET UP THIS ROUTE, SWITCHES C, D AND E MUST BE REVERSED. BEFORE LEVERS ACCOMPLISHING THIS WILL OPERATE, FOLLOWING CONDITIONS MUST BE FULFILLED:

1. NO TRAIN MAY BE ON SWITCHES ("SECTION" OR "DETECTOR" LOCKING).
2. ALL HOME SIGNALS (B, H, F) GOVERNING MOVEMENTS OVER SWITCHES MUST BE AT STOP ("SIGNAL INDICATION" LOCKING).
3. ALL HOME SIGNALS MUST HAVE BEEN AT STOP LONG ENOUGH FOR ANY APPROACHING TRAIN TO HAVE STOPPED ("TIME" LOCKING), AS INDICATED BY A TIME-DELAY MECHANISM. IF "APPROACH" LOCKING IS USED, TIME DELAY IS EFFECTIVE ONLY IF A TRAIN IS ACTUALLY IN AN APPROACH TRACK SECTION AT THE TIME SIGNAL IS PLACED AT STOP.

WHEN SWITCHES HAVE BEEN REVERSED AND ROUTE IS SET UP, HOME SIGNAL B MAY BE CLEARED TO ALLOW TRAIN TO ENTER ROUTE IF:

1. ALL SIGNALS GOVERNING CONFLICTING MOVEMENTS (J AND K, ETC.) ARE AT STOP, DERAILS (L AND M, ETC.) ARE OPEN, AND TIME DELAYS HAVE EXPIRED.
2. ALL SIGNALS GOVERNING OPPOSING-DIRECTION MOVES (F) ARE AT STOP ("TRAFFIC" LOCKING).
3. ALL SWITCHES IN ROUTE ARE LOCKED, AND DERAILS CLOSED AND LOCKED.
4. TRACK IN ROUTE IS UNOCCUPIED (INTERLOCKING SIGNALS ACT AS BLOCK SIGNALS IN SPACING TRAINS).

ASPECT DISPLAYED BY SIGNAL DEPENDS ON ROUTE CONDITIONS; IN THIS CASE ALL TRACK IN ROUTE IS SUITABLE FOR AT LEAST MEDIUM SPEED, SO MIDDLE ARM OF SIGNAL WILL CLEAR TO INDICATE MEDIUM SPEED ROUTE IS SET UP, UNLESS BLOCK SIGNAL G IS AT STOP, IN WHICH CASE MIDDLE ARM COULD DISPLAY ONLY YELLOW ASPECT TO INDICATE OCCUPIED SECOND BLOCK (MEDIUM APPROACH).

DISTANT SIGNALS GOVERNING APPROACH TO INTERLOCKER MAY BE PART OF AUTOMATIC BLOCK SIGNAL SYSTEM. THEIR INDICATIONS MUST BE SUCH AS TO BRING TRAINS UP TO HOME SIGNAL AT APPROPRIATE SPEED; BECAUSE OF MEDIUM CLEAR ASPECT ON SIGNAL B, APPROACH MEDIUM ("APPROACH NEXT SIGNAL AT MEDIUM SPEED") IS MOST FAVORABLE ASPECT DISTANT SIGNAL A CAN DISPLAY FOR THIS ROUTE; IF A WERE A THREE-ASPECT SIGNAL, IT COULD ONLY DISPLAY APPROACH ASPECT, REQUIRING TRAIN TO APPROACH B PREPARED TO STOP.

HAND-THROW SWITCHES WITHIN INTERLOCKING LIMITS ARE EQUIPPED WITH LOCKS PREVENTING THEIR BEING REVERSED UNLESS AUTHORIZED BY PLANT. MOVEMENTS ON SUCH SUBSIDIARY TRACKAGE ARE CONTROLLED BY DWARF SIGNALS, USUALLY USING PURPLE FOR THE STOP INDICATION TO AVOID CONFUSION TO MAINLINE TRAFFIC.

THIRD, OR "CALL-ON" ARM OF INTERLOCKING SIGNALS, AND DWARF SIGNALS FOR REVERSE MOVES, MAY DISPLAY RESTRICTING (YELLOW OR 45-DEGREE) ASPECT WHEN TRACK IN ADVANCE IS OCCUPIED, PERMITTING SWITCHING MOVES AT RESTRICTED SPEED PREPARED TO STOP SHORT OF OBSTRUCTION.

WHEN TRAIN PASSING OVER ROUTE 1 CLEARS CROSSING, IF CIRCUITS PROVIDE FOR "SECTIONAL ROUTE" LOCKING, THAT PORTION OF ROUTE VACATED WILL BE RELEASED SO THAT CROSSING TRAFFIC (J TO K AND VICE VERSA) MAY BE AUTHORIZED BEFORE FIRST TRAIN HAS COMPLETED ENTIRE ROUTE THROUGH PLANT

ROUTE 2

ROUTE 2 TRAVERSES SLOW-SPEED TRACKAGE, SO SIGNAL H WILL CLEAR ONLY BOTTOM ARM WHEN ROUTE IS SET UP, GIVING SLOW CLEAR ASPECT TO PERMIT MOVEMENT AT SLOW (GENERALLY 15 MPH) SPEED. IF ROUTE WERE SET UP THROUGH CROSSOVER C-D AND CONNECTING TRACK N, ALSO A SLOW-SPEED TRACK, SIGNAL H WOULD DISPLAY SAME ASPECT AS FOR ROUTE 2. THIS IS "SPEED" SIGNALING, STANDARD IN THE UNITED STATES, IN WHICH SEPARATE ASPECTS ARE PROVIDED ONLY FOR DIFFERENT PERMISSIBLE SPEEDS. "ROUTE" SIGNALING, TYPICAL OF BRITISH PRACTICE, PROVIDES A SEPARATE SIGNAL OR ASPECT FOR EACH ROUTE.

INTERLOCKING AT P GOVERNING MOVEMENTS OVER DRAWBRIDGE ON GANTLET TRACK CHECKS POSITION, ALIGNMENT AND MECHANICAL LOCKING OF BRIDGE AND INDICATION OF SIGNALS GOVERNING OPPOSING TRAFFIC. "SMASHBOARD" SIGNALS Q AND R ARE LEFT-HANDED SEMAPHORES WITH ARMS WHICH AT "STOP" STRIKE LOCOMOTIVE CAB IF OVERRUN, FORCIBLY CALLING ATTENTION TO ASPECT AND PROVIDING EVIDENCE OF DISREGARD.

FIG 12 INTERLOCKING SIGNAL ASPECTS

IN GENERAL THE OPERATOR DOES NOT SELECT THE ASPECT TO BE DISPLAYED, APART FROM "CLEARING" THE SIGNAL AT THE ENTRANCE TO THE ROUTE SET UP. THE INTERLOCKING MACHINE THEN DISPLAYS THE PROPER ASPECT ON THE BASIS OF: (1) THE MAXIMUM PERMISSIBLE SPEED OVER THE TRACKAGE IN THE ROUTE; AND (2) THE STATE OF OCCUPANCY OF THE ROUTE. ASPECTS BELOW ARE FOR AN UNOCCUPIED ROUTE, EXCEPT AS NOTED. CORRESPONDING ASPECTS SUCH AS "MEDIUM APPROACH" (RED OVER YELLOW OVER RED) APPLY IF SECOND BLOCK IN ADVANCE IS OCCUPIED. ASPECTS SUCH AS "MEDIUM APPROACH SLOW" (RED OVER YELLOW OVER GREEN) GOVERN ROUTES HAVING DIFFERENT PERMISSIBLE SPEEDS IN DIFFERENT BLOCKS IN ADVANCE.

RESTRICTED-SPEED ASPECTS

RESTRICTED SPEED IS DEFINED AS PERMITTING A STOP SHORT OF A TRAIN, BROKEN RAIL OR OTHER OBSTRUCTION, AND IS ORDINARILY UNDERSTOOD AS LESS THAN 15 MPH. RESTRICTING ASPECT SIGNALS ARE USUALLY SEMI-AUTOMATIC, CAN BE DISPLAYED WITH BLOCK OCCUPIED TO PERMIT MOVES SUCH AS THIS COUPLING-UP OPERATION.

SLOW-SPEED ASPECTS

SLOW SPEED IS NORMALLY SPECIFIED AS 15 MPH, LIMITING SPEED FOR ORDINARY TURNOUTS, CROSSOVERS AND SHARPLY CURVED CONNECTING TRACKS.

MEDIUM-SPEED ASPECTS

MEDIUM SPEED IS NORMALLY SPECIFIED AS 30 MPH (OR IN SOME CASES AS ½ MAXIMUM SPEED), TYPICAL OF SAFE SPEED FOR DIVERGING MOVEMENTS OVER NO. 15 OR LONGER TURNOUTS

LIMITED-SPEED ASPECTS

LIMITED SPEED, A SPECIFIED VALUE BETWEEN MEDIUM AND MAXIMUM SPEEDS, HAS COME INTO USE IN RECENT YEARS TO TAKE FULL ADVANTAGE OF THE SPEED POTENTIALITIES OF SUCH IMPROVED TRACKWORK AS THE NO. 20 EQUILATERAL TURNOUTS OFTEN USED AT THE ENDS OF DOUBLE TRACK. LIMITED SPEED MAY RANGE FROM 45 MPH TO AS HIGH AS 70 MPH.

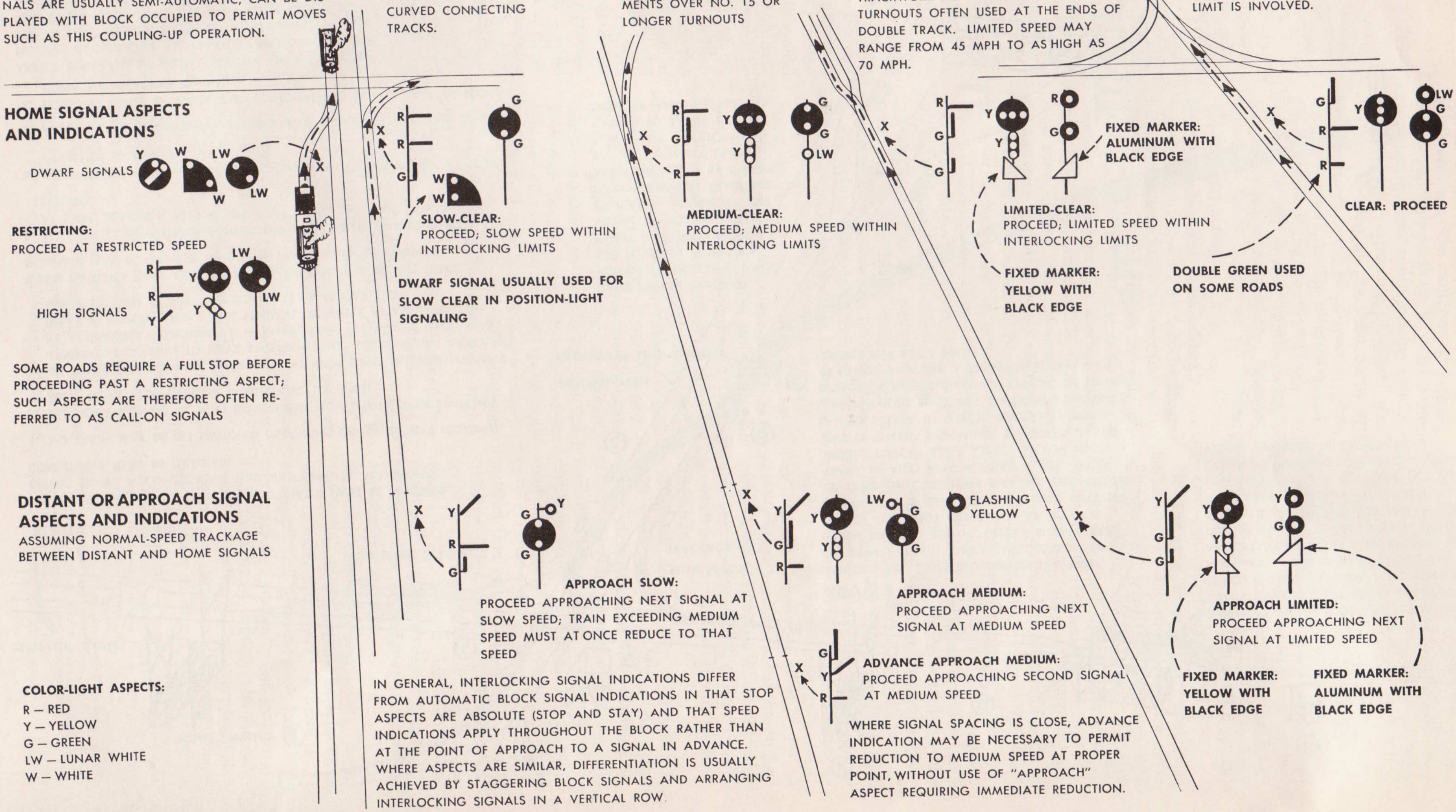
NORMAL-SPEED ASPECTS

NORMAL SPEED IS THE AUTHORIZED MAXIMUM SPEED IN THE TERRITORY INVOLVED; IT MAY APPLY TO DIVERGING ROUTES IF NO RESTRICTION BELOW THE TERRITORY'S SPEED LIMIT IS INVOLVED.

HOME SIGNAL ASPECTS AND INDICATIONS

DISTANT OR APPROACH SIGNAL ASPECTS AND INDICATIONS

ASSUMING NORMAL-SPEED TRACKAGE BETWEEN DISTANT AND HOME SIGNALS



IN GENERAL, INTERLOCKING SIGNAL INDICATIONS DIFFER FROM AUTOMATIC BLOCK SIGNAL INDICATIONS IN THAT STOP ASPECTS ARE ABSOLUTE (STOP AND STAY) AND THAT SPEED INDICATIONS APPLY THROUGHOUT THE BLOCK RATHER THAN AT THE POINT OF APPROACH TO A SIGNAL IN ADVANCE. WHERE ASPECTS ARE SIMILAR, DIFFERENTIATION IS USUALLY ACHIEVED BY STAGGERING BLOCK SIGNALS AND ARRANGING INTERLOCKING SIGNALS IN A VERTICAL ROW.

COLOR-LIGHT ASPECTS:

R — RED
Y — YELLOW
G — GREEN
LW — LUNAR WHITE
W — WHITE

may be fully justified economically by the elimination of the otherwise-required full stop by each approaching train. Both these extreme situations have been open invitations to automation, and the railroads and manufacturers started doing something about it long before the word was coined.

In the case of the isolated crossing the answer is automatic interlocking, first applied in 1909 but reaching full acceptance only in the last 30 years, during which nearly 600 installations have been made, 24 of them in 1955. Its principle is simple: the presence of a train on an approach circuit takes the place of an operator in initiating clearing of the signal for that route. If all conflicting routes are clear, the train gets a green board and clatters through without interruption; if another movement is in progress, it must stop and wait its turn. Directional circuits release the crossing as soon as the caboose clears the diamond. Automatic interlocking also finds application in protecting movements on gantlet tracks in tunnels and on bridges, but until recently was limited to such cases where no selection of route was involved.

Now, developments in electronics point the way toward a vastly more flexible use of automatic interlocking in the future. In 1954 the first application of Union Switch & Signal's Identra train identification system to automatic routing of trains was made on the Chicago Transit Authority. The Identra system comprises an inert coil on the train which will actuate a matched wayside circuit (from whose receiving coil it may be separated by as much as 30 inches) as it passes by at any speed. Since several tuned frequencies are available, it is not hard to see many ways in which this flexible means for indicating to an interlocking which route is desired can automatize more complex layouts.*

Route interlocking

When the territory logically controlled from one interlocking is too much for one operator, on the other hand, it's time to think about ways to further simplify the setting up of routes. Since the first installation in 1937 the answer has been route interlocking, called NX (eNtrance-eXit) by General Railway Signal and UR (Union Route) by US&S. A compact machine of the all-relay type is equipped with an illuminated track diagram on which are mounted push-buttons at the beginning and end of each route through the controlled territory.

Pushing the entrance button for the track upon which a train is arriving energizes a stick circuit which locks out other routes conflicting with this track. Another push on a smaller button at the desired point of exit starts an electrical search within the machine for the best available route connecting with the entrance point. When this has been found the machine then positions all track switches for the route and clears the signal. The established route is indicated on the panel by switch-point position indicators or by lights in the lines of the track diagram. A train passing through the interlocking shows up as a procession of white lights; red switch-lock lights go out behind it as sectional-route locking releases the vacated track.

The most striking advantages of route interlocking show up in the more complex plants where one-man operation eliminates the problem of co-ordination among several towers and dispatchers. At Fostoria, O., for example, there's a dilly of a junction at which New York Central, Chesapeake & Ohio, Baltimore & Ohio, and two Nickel Plate routes cross each other in a triangular pattern. Prior to 1949 and the installation of an NX machine this network was under the control of three widely separated dispatchers, with 32 passenger, 130 freight and 200 switching moves a day to be worked through the tangle. It was entirely possible for the individual crossings to be cleared in such a way that three trains could get into a triangle tieup in which no one could move until someone backed out of the mess. One operator now controls the whole complex; the simplicity of setting up routes gives him time to plan movements so that no such impasses result. The return on investment realized from this installation is figured at 42.3 per cent.

Interlocking signal aspects

The route-interlocking circuits, while including all the safety locking of conventional systems, position all switches in a route at once, far more rapidly than an operator could work individual levers for each. The machine is capable of a limited amount of thinking, selecting an alternate route if the most direct one is occupied and infallibly sending trains via the highest-speed lineup if there's a choice between crossovers of different angles. In common with the more venerable interlockings, the signal indications are automatically matched to the alignment and occupancy status of the route; Fig. 12 (page 20) shows some of the aspects used in interlocking to indicate clear routes. As in block signaling, no brief compendium can begin to cover all the variations in use. The searchlight aspects most frequently seen in modern interlockings are the same as the night indications for the semaphores shown in the figure.

A common problem has been that of differentiating between stop-and-stay indications (necessary where the signal is at stop because a conflicting move has been cleared) and stop-and-proceed aspects (appropriate where the interlocking signal is functioning as a block signal and a train can properly enter an occupied block). The usual stop-and-proceed equivalent is the restricting aspect given by dwarf or lower-arm units. In position-light and color-position-light signaling, marker lights may be illuminated along with the stop aspect to indicate stop-and-proceed. Similarly, in its fabulously busy three-track territory from Chicago to Aurora, which has so often in the past been a proving ground for signaling advances, Burlington has introduced a special indication to tell whether a home signal is at stop because of an occupied block or a conflicting route; if a commuter train making a station stop up ahead is the cause, a lunar-white marker to the left of the top red searchlight head converts the aspect to stop-and-proceed, expediting following moves.

Another problem is distinguishing interlocking signals from automatic blocks. As a much-violated rule, square-end semaphore blades and light signals arranged in a vertical row are interlocking aspects, while staggered lights and pointed-end blades denote permissive block signals. New Haven likes round-end semaphores for everything (and has many left-handed ones to boot, presumably because of contemplated extensions of electrification where the catenary supports would have blocked the view of right-handers); Santa Fe likes them all square.

Two trends may be noted. One is toward the increasing use of limited-speed aspects (Fig. 12) to take full advantage of better trackwork. A second is the use of dwarf signals (often of two-head type) capable of giving indications authorizing the full speeds appropriate to the trackage in con-

*In 1952 Erie placed in service an automatic OS system at a remote-controlled interlocking at Waterboro, N. Y. The direction and number of a passing train is indicated to the dispatcher 22 miles away, an interesting extension of the capabilities of unmanned interlockings.

gested areas. In such complex layouts as those in the Syracuse and Los Angeles station throats this eliminates the expensive overhead signal bridge with its limited flexibility of signal location.

Regulating opposing movements

Creeping along at restricted speed to the next open block station is tedious and making a statutory stop before crossing another railroad at grade in the absence of interlocking may cost a few minutes, but the most serious delays can occur in meeting opposing trains on single track, particularly in the face of off-schedule conditions. Since 86 per cent of U. S. route-mileage is single track, most of the spectacular advance in average train speed must come from improvements in handling meets and passes.

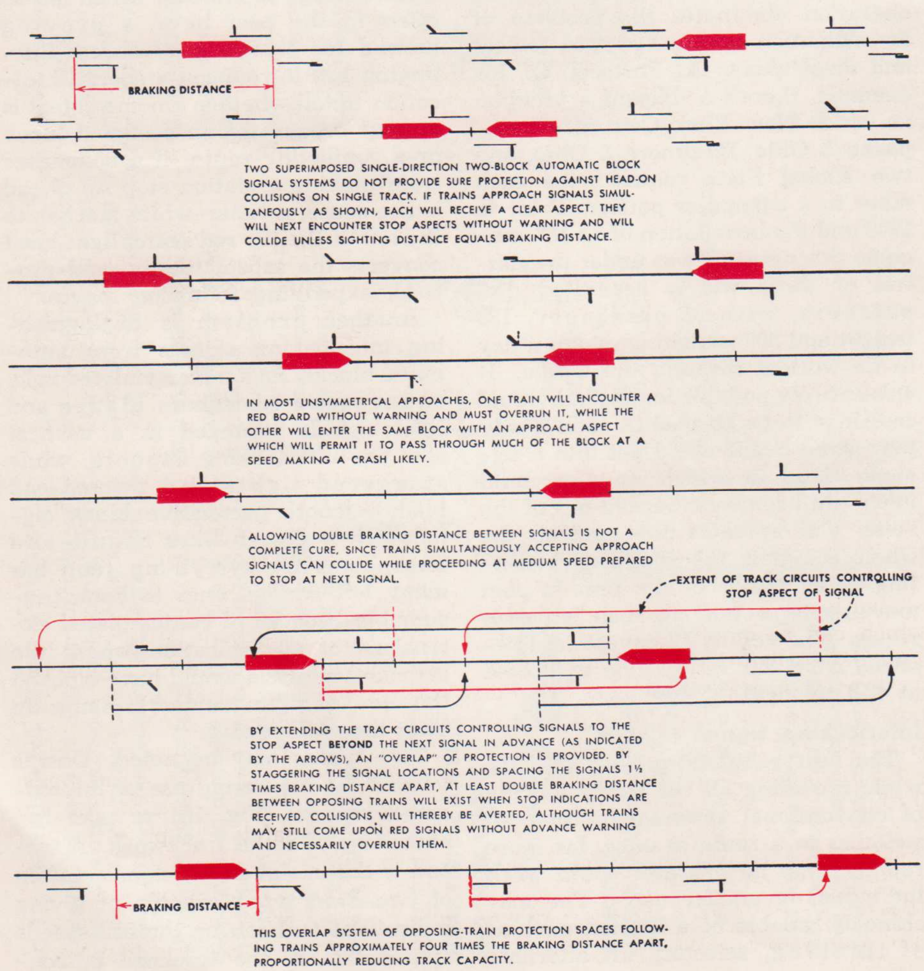
The first advance beyond literal adherence to a timetable took place on that famous day in 1851 when Erie Superintendent Charles Minot took advantage of the capabilities of the new-fangled telegraph and issued the first train order, holding a delayed train to allow another to advance to a meeting point beyond that set forth in the schedule.

Over the years detailed standard rules for operation by timetable and train order have developed. They allow the dispatcher to keep trains moving fairly well, with a remarkably high degree of safety considering the long series of human actions involved in even such a simple process as determining the point where an extra will go in the hole for a scheduled train. The rules are designed to be as specific and unequivocal as possible; by the same token they are so complicated that many editions of Peter Josserand's book *Rights of Trains* sold out in providing answers to the trickier questions, and rules-interpretation columns have been staple fare in the operating Brotherhoods' magazines. Each procedure specified is in there to prevent a lapse that sometime, somewhere has been disastrous, and most of them take precious time to carry out, as the meet sequence in Fig. 1 (page 4) shows.

Head-on collisions are still possible. Less often in fact than in fiction, the dispatcher may actually issue a "lap order" advancing one train past the point to which an opposing train is authorized to proceed. A crew may have many orders in its possession at one time, some of which will not be acted upon until hours after receipt; under these circumstances it is no wonder that one order may be disregarded. There may be an error in the transmission of an order, or it may be misunderstood or misinterpreted.

As a *supplement* to timetable and train-order operation, therefore, block signaling on single track enters the picture purely as a safety device, and some 42 per cent of this line mileage is so protected. Twenty-eight thousand miles of this signaling is manual, with blocks generally extending from station to station. As in multiple-track manual block signaling, before authorizing entry the operator must verify from his block register and communication with the operator at the other end that there are no opposing trains in the block and that the opposing signal is at stop.

FIG 13 OPPOSING-TRAIN PROTECTION ON SINGLE TRACK

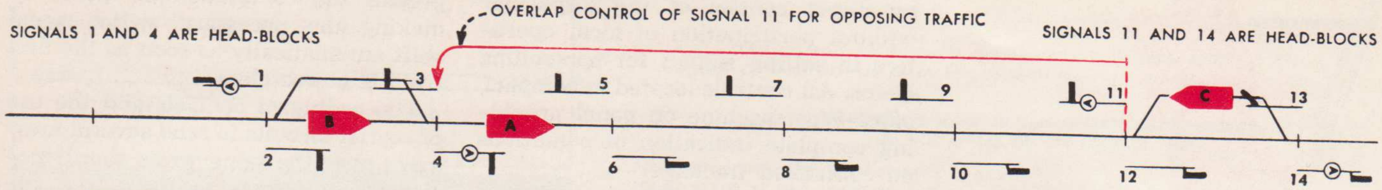


Controlled manual block

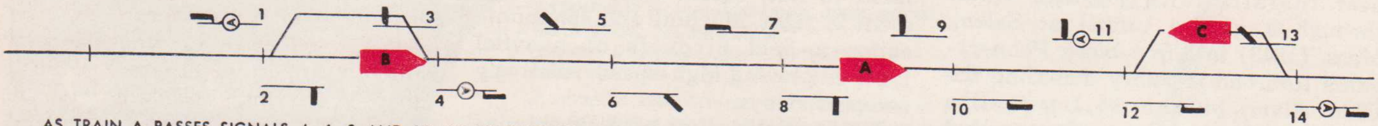
Manual block is manifestly a potent safeguard against lap orders and overlooked meets. Further assurances are provided in controlled manual block, often referred to as "lock and block." Here the signals are electrically interconnected so that the co-operation of both operators is required to clear a signal. Track circuits insure that stop signals are properly displayed and that block occupancy is taken into account. In England especially, where efficient operation of the road is largely in the hands of the individual operators working with a minutely detailed timetable and there is no dispatcher in the American sense, special systems are in widespread use in which possession of a staff or token is the key to allow a train access to a single-track section. A machine (in effect a spread-out interlocker) will not permit more than one staff to be out at a time.

In the United States with its high wage rates and fewer, longer trains, controlled manual block has never fit in too well and has not been extensively used. Automatic block, on the other hand, has been applied to 55,000 miles of single track and continues to be added at a rate of several hundred miles a year, exclusive of that added in new C.T.C. installations. It might appear that merely superimposing two

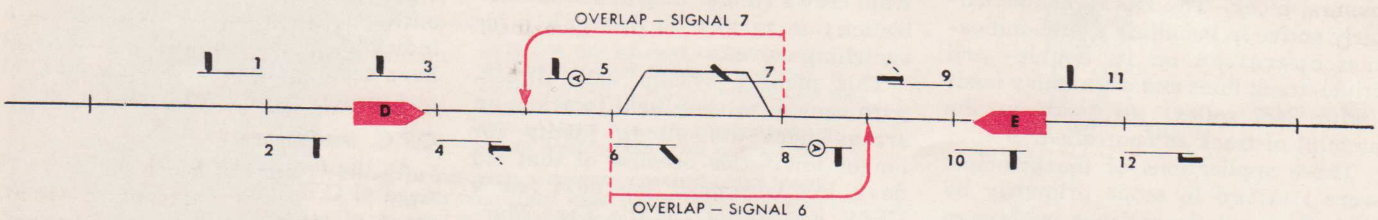
FIG 14 ABSOLUTE PERMISSIVE BLOCK SIGNALING



IN ABSOLUTE PERMISSIVE BLOCK ("APB") SIGNALING, OVERLAP AGAINST OPPOSING TRAINS IS EXTENDED FOR THE ENTIRE DISTANCE BETWEEN PASSING TRACKS. WHEN TRAIN A PASSES THE "HEAD-BLOCK" SIGNAL (4), SIGNALS 5, 7, 9 AND 11 "TUMBLE DOWN" SUCCESSIVELY TO STOP. THIS PROVIDES "ABSOLUTE" PROTECTION AGAINST ANY OPPOSING TRAIN'S ENTERING THE SINGLE-TRACK SECTION, SINCE HEAD-BLOCK SIGNALS SUCH AS 11 ARE ABSOLUTE (STOP AND STAY) SIGNALS. THIS EXTENDED OVERLAP IS PROVIDED BY HAVING SIGNALS IN THE REAR OF SIGNAL 5 (NOS. 7, 9 AND 11) NORMALLY CONTROLLED BY THE POSITION OF SIGNAL 5. SIMILARLY, SIGNALS 4, 6 AND 8 WILL GO TO STOP IF TRAIN C SHOULD PASS HEAD-BLOCK SIGNAL 12 AND THUS PLACE SIGNAL 10 AT STOP.



AS TRAIN A PASSES SIGNALS 4, 6, 8 AND 10, RELAY CIRCUITS AT EACH SIGNAL LOCATION DETERMINE (FROM THE SEQUENCE IN WHICH THE ADJACENT TRACK CIRCUITS ARE SHUNTED) THE DIRECTION IN WHICH THE TRAIN IS TRAVELING AND PERMIT THE SIGNALS IN THE REAR OF THE TRAIN TO CLEAR FOR FOLLOWING TRAIN B. SIGNALS 6, 8 AND 10 ARE PERMISSIVE (STOP AND PROCEED) BLOCK SIGNALS, HENCE THE NAME "ABSOLUTE PERMISSIVE BLOCK" FOR THIS DIRECTIONAL SYSTEM. AS COMPARED WITH OVERLAP SIGNALING, TRACK CAPACITY IS ENHANCED SINCE A FOLLOWING TRAIN CAN PROCEED AT TWICE BRAKING DISTANCE IN THE REAR OF THE PRECEDING TRAIN WITHOUT ENCOUNTERING APPROACH ASPECTS.



SINCE THE APB OPPOSING-TRAIN PROTECTION EXTENDS ONLY TO THE HEAD-BLOCK SIGNALS AT THE NEXT PASSING TRACK, OVERLAP IS PROVIDED ON THE STATION-ENTERING SIGNAL CONTROL CIRCUITS, AS SHOWN FOR SIGNALS 6 AND 7. SHOULD TRAINS D AND E PASS SIGNALS 4 AND 9 SIMULTANEOUSLY, ACCEPTING CLEAR INDICATIONS, THEY WOULD THEN ENCOUNTER STOP INDICATIONS (ON SIGNALS 6 AND 7) WITHOUT WARNING. TO PREVENT THIS, A "DOUBLE-CAUTION" SYSTEM IS USED WHEREBY SIGNALS 4 AND 9, AS WELL AS SIGNALS 6 AND 7, DISPLAY THE CAUTION (APPROACH) ASPECT WHEN CORRESPONDING HEAD-BLOCK SIGNALS 8 AND 5 GO TO STOP IN THE FACE OF OPPOSING MOVEMENT.

single-direction block signal systems would keep opposing trains apart in the rare cases where timetables and train orders do not suffice. As Fig. 13 (page 22) shows, more is needed.

Overlap and absolute permissive block

The first method for providing genuine opposing-train protection in automatic signaling is the overlap scheme, shown in one typical form in Fig. 13. Overlap requires little special circuitry, but does space trains much farther apart than necessary for following moves, a considerable time handicap when one train is following another and is kept back two blocks while its predecessor is clearing the main track.

One of the triumphs, significant but little heralded, of the "standard railroading" era of the 1920's was A.P.B. signaling, shown in principle in Fig. 14 on this page. At the expense of some tricky relay circuits the presence or absence of overlap is made dependent upon whether an opposing or following movement is involved; following trains can run as close together as they could on multiple track. With its dual promise of increased safety and enhanced track capacity, A.P.B. accounted in large part for the bulge in block signal installations in that period, and it forms the basis for most of today's C.T.C. It is particularly well handled by the various types of coded track circuits most commonly used for new automatic block installations (as shown in Fig. 10 on pages 14 and 15), which can accomplish all the necessary directional discrimination and extended overlap functions without line wires between headblocks.*

Train operation by signal indication

A symphony orchestra might get through a number somehow using only the music and a metronome, but for real music it needs a conductor. And when the conductor wants a cymbal crash at a crescendo, he gets it by pointing his baton at the cymbal player, not by sending him a telegram calling for a big one at 8:42:37 p.m. Similarly, ideal train dispatching calls for the most instantaneous, continuous and direct system of communication from the DS to the engineer, subject to the requirement for preventing hazardous combinations of instructions. For over a hundred years it has been realized that a fixed signal giving a specific indication requiring action right at the time and place that it is observed is a far closer approach to this ideal than the schedule, timepiece or message methods. The delay has been in doing the job with absolute safety at a price making it profitable.

Train operation by signal indication without train orders is a development that sprang up rapidly (perhaps earli-

*A typical code system for non-cab-signaled territory (GRS's Trakode) uses short pulses at a single slow repetition rate (30 per minute), conveys various messages by sending pulses of positive, negative, positive followed by negative, or negative followed by positive nature in such a manner that the direction from which they come can be identified by a signal.

er than generally realized) wherever congestion was critical, operators or interlocking plants were available at close intervals, and officials anxious to railroad better were in charge. Pioneer installations governed traffic through a gantlet tunnel at Salem, Mass. (1843) in a five-block Pennsylvania Railroad territory including the Ohio River bridge at Louisville (1881),* and on the heavily traveled section of the Burlington west of Chicago (1888). By 1903 the American Railway Association had adopted rules permitting operation by signal indication on two or more tracks, and by 1915 for single track with controlled manual block. The B&O was particularly active in installing signal-indication operation on its double- and triple-track lines and even today leads (with 2487 miles) all roads in the amount of track so controlled.

These applications of the principle were limited in scope primarily by their frequent dependence on human operators, which in turn raised the cost to the point where only heavily traveled (and hence usually multi-tracked) territories could pay the price. Since operation on multiple track inherently requires relatively fewer train orders and suffers less obvious delays, the advantages of signal-indication operation were also less attractive and so it languished until reliable, economical components for the over-all job became available one by one after World War I.

Centralized traffic control

The I.C.C. officially designates C.T.C. as the "traffic control system," defining it as "a block system under which train movements are authorized by block signals whose indications supersede the superiority of trains for both opposing and following movements on the same track."

The first one-man machine providing the essentials of such operation went into service on the New York Central between Stanley and Berwick, O. (40 miles) in 1927. This GRS system included the following features:

1. All direction of train movements by direct control of the dispatcher without participation of local operators in setting signals for controlling trains. All controls located in compact, office-type machine on panel providing complete indication of conditions on controlled trackage.
2. Signals and switches at the ends of passing tracks arranged as route-type interlockings with all necessary forms of locking provided locally by relay circuits and supervisory control from the C.T.C. machine by instructions of simplest type: switch normal; switch reversed; signal clear for movement to left; signal clear for movement to right. Machine and communication-to-field circuits of nonvital type, employing high-speed, relatively compact relays.
3. Automatic absolute permissive block signaling between sidings, forbidding opposing movements but permitting following moves.
4. Track switches at ends of sidings controlled by dispatcher, but of dual-control type permitting operation by train crews (under dispatcher authorization) as might be desirable for switching moves.

This pioneer system used direct-wire control to each field location, an arrangement difficult to justify for longer territories because of that old devil, line wire cost. The next year a US&S installation on the Pere Marquette completed the picture by using a selector-type control doing the job over just two line wires. By 1937 code systems were improved to the extent that whole engine districts could be controlled from one machine and C.T.C. was ready to leap from 150-mile-per-year growth to the 1000-mile rate of World War II, when it made single track do the work of double in critical territories from the N&W's Shenandoah Valley route to the Santa Fe's San Diego line.

C.T.C. operation is (to the operator and trainman, if not to the circuit designer) so logical and straightforward that there is really little to explain about it. Fig. 15 (page 25), a segment of a GRS-manufactured control panel,* gives an idea of the way in which an operator can manipulate trains like chessmen. Because the information on train location is relatively complete and up to the minute, and because so little time is used in actually authorizing movements, the operator can plan his moves effectively, even perhaps sneaking in a bit of luxury: thinking ahead. This particular machine, presumably for fairly heavy traffic, includes the optional refinement of "preconditioning," which expedites the completion of meets by making the necessary switch-signal shift automatically as soon as the first train is in the clear.

The coding of controls and the use of carrier circuits to send several messages over the same wires simultaneously is a subject in itself, and advances in techniques have been so rapid recently that almost every installation — whether the little table-model machine on the Q used by the woman station agent at Old Monroe, Mo., to guide traffic through the bottleneck between there and West Alton or the Seaboard's triple-horseshoe job at Raleigh forming part of an unbroken C.T.C. route 1045 miles in length — has some unique feature.

In brief, coded control can be visualized as a completely automatic telegraph system in which the office machine translates the turning of a lever into a code addressed to the proper location by its first few characters. At the field station the short and long pulses are translated into the desired switch and signal actions and a transmitter at the location sends back an indication to the office that the changes have been made. This is then decoded and presented on the panel.

C.T.C. variations

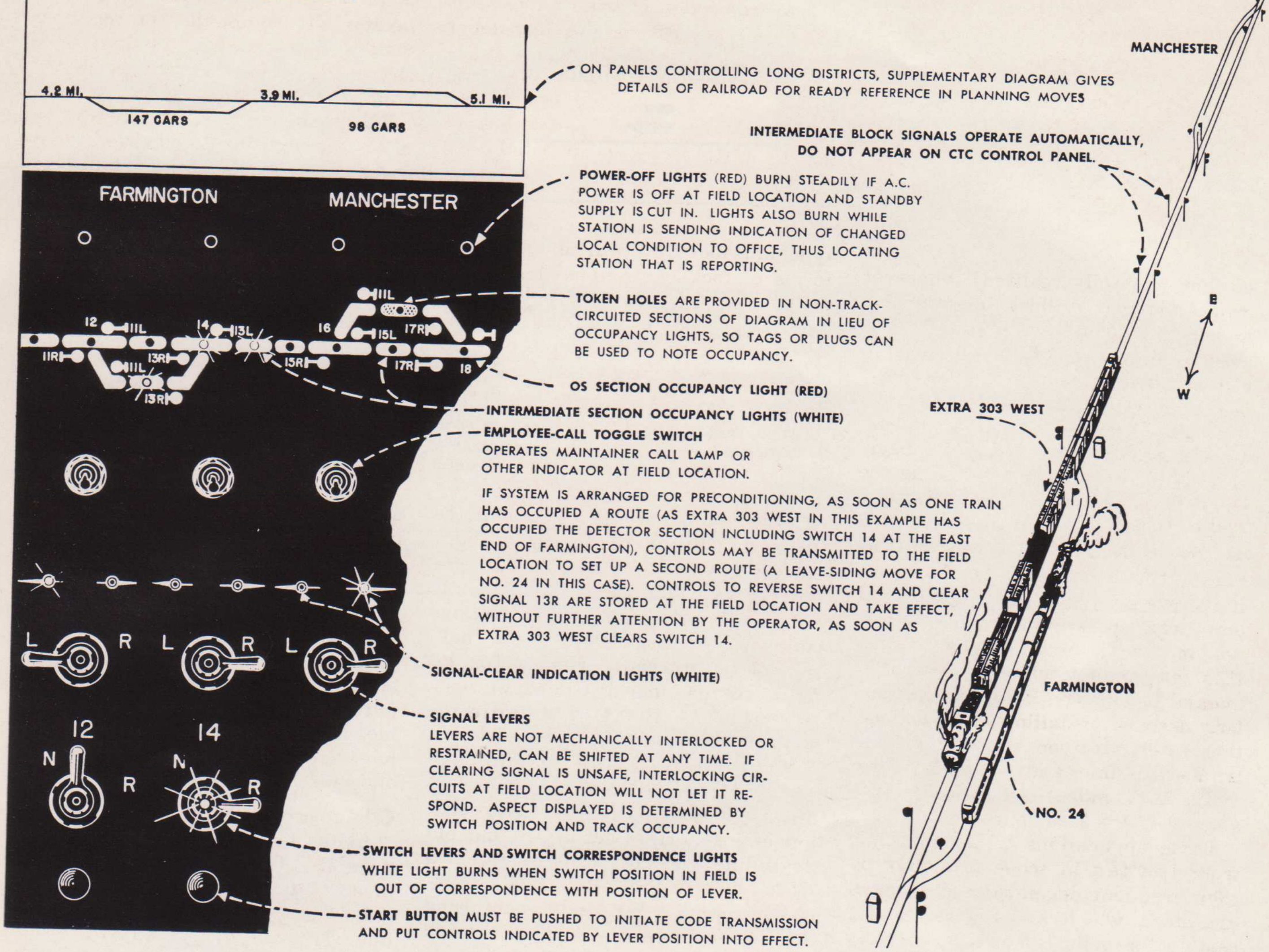
As the territories most obviously in need of C.T.C. are equipped, development of schemes for the more marginal cases becomes the order of the day. Fig. 16 (page 26) illustrates how the basic controls, such as those on the Western Pacific or the Nickel Plate main lines, may be simplified to provide much of the benefit at a price justifying the investment for a line with fewer trains. The complete installation on the 336-mile Quebec North Shore & Labrador is of this "light traffic" type, although this paragon of modernity moves over 100,000 tons of ore a day. With trains carrying one commodity in one direction in uniform consists spaced evenly around the clock, following trains move along about 3 hours apart, so block signal protection between sidings is unnecessary. On the other hand, with some 80 meets to be made per day, the savings from keeping the 16,000-ton trains moving will pay for this installation quickly.

For very heavily traveled lines, additional refinements provide extra capacity as shown in Fig. 16. Sixty to 80 trains a day, a number that would have very seriously taxed double track 20 years ago, can be handled with little delay. A prime example of this type of installation is the Santa Fe's southern main line from Wellington, Kans., to Belen, N. Mex., on which

*An important characteristic of signal-indication operation is the way in which it greatly reduces the dependence of safety upon exact time synchronization, since a movement is then authorized on the basis of where a train actually is, rather than on the basis of where it is supposed to be at a certain moment. One of the factors making the Louisville installation so desirable: the four railroads involved each operated on a different brand of solar time in that pre-Standard Time era.

*A US&S panel, essentially similar, uses a slightly different arrangement of switch and signal indication lights, and levers that turn through a smaller arc. Individual roads naturally insist on their own variations in light colors, etc.

FIG 15 CTC PANEL OPERATION



over 80 per cent of the meets are non-stop. Even the passenger in a San Francisco *Chief* Big Dome is likely to be unaware that the line is single track as freight after freight rolls by.

It should by no means be assumed that C.T.C. is limited to single track, though the conversion of the Boston & Albany and much of the Erie main line to single is a most conspicuous example of what it can mean. Forty-nine hundred of the 23,600 miles* of line operated by signal indication is multiple track, and C.T.C. set up for either-direction running on one or both tracks has eliminated many a need for third track, chiefly by reducing the delays associated with passing movements.

The C&O recently applied C.T.C. to its double-track Columbus-Toledo line to meet an awkward situation: this segment's traffic in coal and ore to and from the lake boats is necessarily seasonal, and track maintenance to keep up with the wear and tear of the heavy trains can't well be done in the winter, either. C.T.C. allows one track to be kept free for a whole shift with little penalty to traffic — maximum efficiency for both roller-bearing hoppers and the mechanized successor to the gandy dancer.

Control centers

The Long Island is installing either-direction control on its 15.7-mile two- and four-track main line from Jamaica to Hicksville, primarily to allow true express runs over the reverse-main trackage. At the same time the locals will do better by the people closer in, since at present the number of local stops that can be made is limited by the effect on express schedules. For such complex, dense-traffic installations which are not exactly glorified C.T.C. and yet go beyond the scope of the ordinary consolidation of interlockings, a new pattern of control center is evolving.

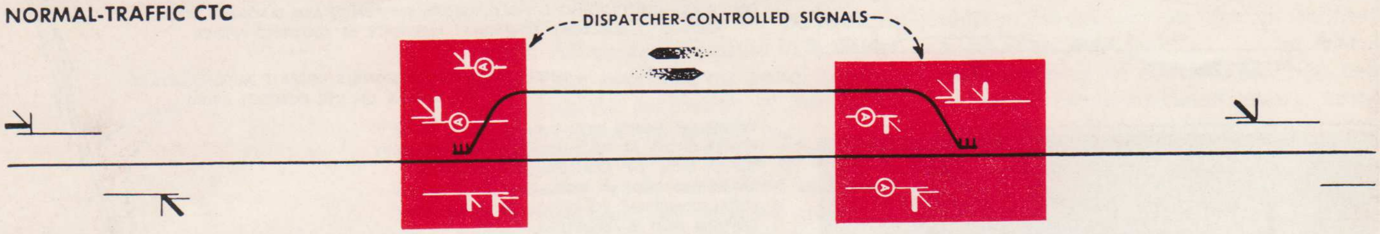
Route-type interlocking allows an operator to set up routes so fast that he can control a large territory, and the push-buttons for control take up little space. The track diagram with its many lights to indicate the position of the trains and its details of all controlled trackage rapidly expands beyond arm's reach, even with the now-familiar U-shaped machine. A solution might be to hire long-armed orangutan operators, but instead the newest installations favor a compact operating console with the entrance-exit knobs on a simplified diagram. Up above, somewhat similar to the old track model boards in electromechanical interlocking towers, is a separate, expanded track diagram with the occupancy lights.

To back up this control-center concept, new and faster communication with the field locations is needed; the now-conventional two-wire time code for C.T.C. use takes about 4 seconds per control or indication and is ordinarily limited to 35 stations or fewer per carrier channel. The Lackawanna in consolidating three busy interlockings in the Newark area used a US&S multiplex system which sends out controls and receives indications at 25 and 50 per second respectively. The GRS system governing the 163 miles

*January 1, 1956, figures; C.T.C. is being installed currently at the rate of about 1500 miles of line per year.

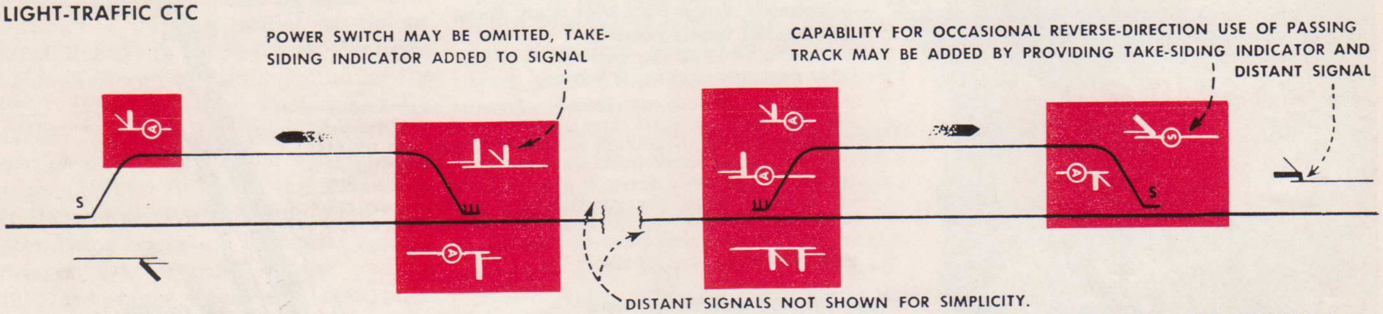
FIG 16 CTC FOR VARYING TRAFFIC DENSITIES

NORMAL-TRAFFIC CTC



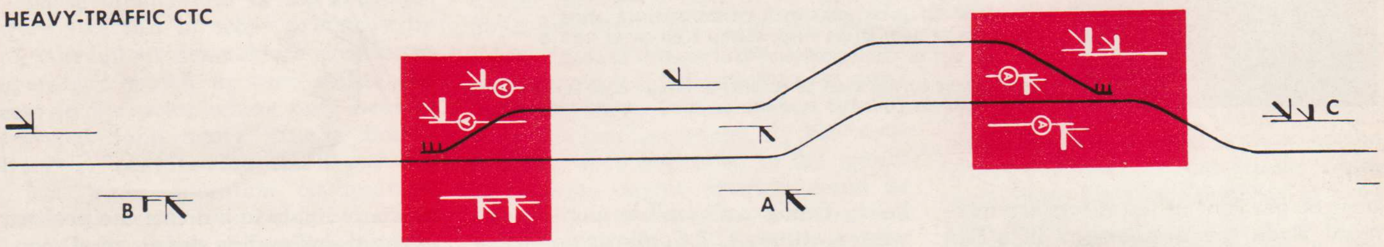
FOR NORMALLY HEAVY TRAFFIC ON SINGLE TRACK, A CTC INSTALLATION PROVIDES DISPATCHER CONTROL OVER POWER SWITCHES AT BOTH ENDS OF CONTROLLED SIDINGS, WITH A FULL COMPLEMENT OF CONTROLLED SIGNALS GOVERNING MOVES THROUGH PASSING TRACKS IN EITHER DIRECTION. INTERMEDIATE AUTOMATIC BLOCK SIGNALS OPERATING ON THE APB SYSTEM EXPEDITE FOLLOWING MOVES BETWEEN SIDINGS.

LIGHT-TRAFFIC CTC



FOR LIGHT-TRAFFIC TERRITORY NOT ECONOMICALLY JUSTIFYING FULL-DRESS TREATMENT, MOST OF THE ADVANTAGES CAN BE OBTAINED WITH A MINIMUM INSTALLATION PROVIDING FOR BASICALLY SINGLE-DIRECTION OPERATION OF PASSING TRACKS. A POWER SWITCH (OR A HAND-THROWN SWITCH AND A TAKE-SIDING SIGNAL) IS PROVIDED AT THE ENTERING END, WHILE A SPRING SWITCH ELIMINATES TRAIN STOPS AT EXIT END. TRACKAGE BETWEEN SIDINGS MAY OR MAY NOT BE SIGNALED, DEPENDING ON VOLUME AND NATURE OF TRAFFIC.

HEAVY-TRAFFIC CTC



EXTREMELY HEAVY SINGLE-TRACK TRAFFIC CAN BE FURTHER EXPEDITED BY PROVIDING SIDINGS TWO TRAIN LENGTHS OR MORE LONG, WITH HIGH-SPEED TURNOUTS AND THREE-INDICATION LOWER ARMS ON THE STATION-ENTERING SIGNALS. TRAINS CAN ENTER SIDINGS AT MEDIUM SPEED AND RE-ENTER THE MAIN TRACK AT SIMILAR SPEED UNDER THE CONTROL OF THREE-POSITION DWARF SIGNALS. INTERMEDIATE BLOCK SIGNALS ON PASSING TRACKS ALLOW FOLLOWING TRAINS TO DOUBLE UP IN THE SAME SIDING, WHILE SPECIAL DISTANT SIGNALS (SUCH AS A) AT POINTS WHERE VISIBILITY OF SIDING-END SIGNALS IS OBSTRUCTED ALLOW TRAINS ON THE MAIN TRACK TO RESUME SPEED PROMPTLY WHEN THE TRAIN BEING MET GETS INTO THE CLEAR. FOURTH ASPECTS (APPROACH MEDIUM) ON SIGNALS SUCH AS B AND C PERMIT MOVEMENTS UP TO REVERSED PASSING TRACK SWITCHES AT MEDIUM SPEED.

of NYC main line from Buffalo to Cleveland which has been reduced from four tracks to two sends its controls out by a synchronized high-speed relay system but obtains indications electronically at a speed of 100 a second, in effect scanning the whole line for changes at rapid intervals.

What next?

Any broad-brush discussion of signaling must slight dozens of auxiliary developments that solve pesky though lesser sources of danger, delay and expense — dragging equipment detectors, for example, 692 of which in one year caught 5768 potentially disastrous conditions. But where can all this lead? Union Switch officials, observing that it is being found desirable and, with coding, inexpensive to locate the C.T.C. machines for different divisions of a railroad in the same or adjoining rooms so that co-ordination can be direct and immediate, envision a single center right in the road's headquarters from which all control will emanate and in which the entire story of the status of the line will be available at every moment. Noting that they already make all components necessary for unmanned operation of trains and have in fact controlled a New Haven M.U. train with no one in the cab, they further foresee an automatic railroad snaking cars from any origin to any destination, virtually in one smooth motion. We'll have to hope that some future Harry Bedwell can build up tension over an electronically lost spent-fission-products local and that he can impart the same fascination found in the old Morse key to the blinking lights of the master panel.