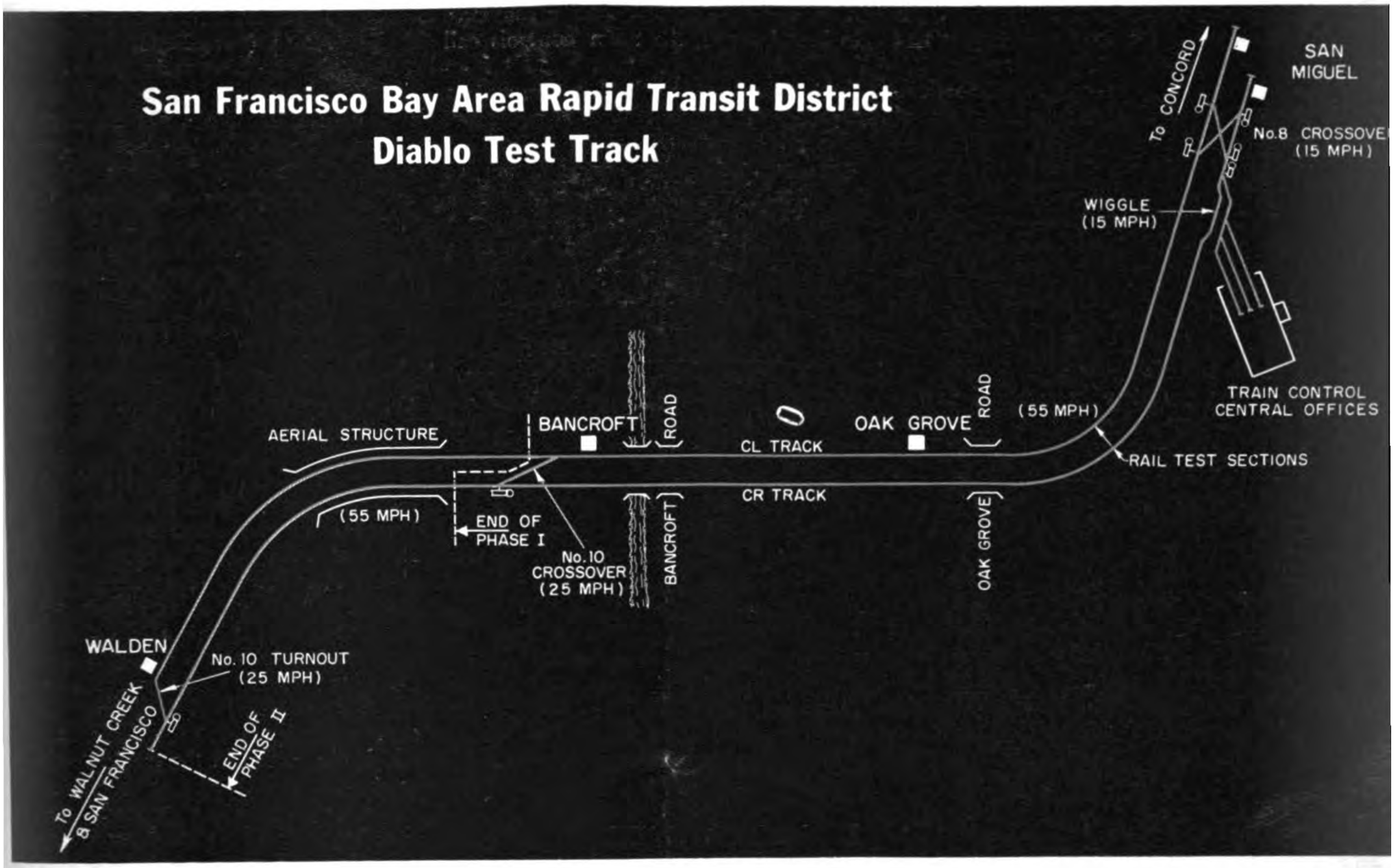
Railway
Signaling &
Communications



San Francisco will test four ATO systems

Robert J. Barber
Senior Electrical Engineer
Parsons Brinckerhoff-Tudor-Bechtel

Thirty miles east of San Francisco a section of the once-electrified Sacramento Northern is giving way to four miles of double track on which will be tested the latest in rapid transit equipment and controls. New cars for existing systems have not departed radically from Frank Sprague's multiple-unit controls installed in 1897 on the Chicago South Side Elevated Railway. Thus the many recent technological developments, particularly in the field of automatic controls, need to be tested to find the features of automatic train controls which will best suit SFBARTD's needs. The Federal Government is participating in the test program through a grant from the Housing and Home Finance Administration; thus the results of the tests will have national significance. The joint venture firm of Parsons Brinckerhoff-Tudor-Bechtel are the consulting engineers to SFBARTD.

The initial study of automatic train control by PB-T-B resulted in a set of general functional requirements. These functional requirements determined that automatic train control consists of three thoroughly-integrated sections:

- Train protection—which automatically maintains the complete safety of operation and the separation of trains running on the same track and over interlocked routes.
- Line supervision—which automatically directs train operations to provide scheduled service, routes, and alterations in the load capacity of the train service.
- Automatic train operation (ATO)—which automatically performs those functions traditionally assigned to the motorman and door guard.

In a recent speech before an IEEE section, chief electrical engineer John Asmus said: "It is essential that a highly refined and fully integrated automatic train control system be proved for the efficient operation of the San Francisco Bay Area Rapid Transit system. This system will provide all aspects of control and operation which heretofore have been considered separate functions in transit operations. Their integration into a single system may be one of the more significant developments of this rapid transit system."

Automatic train control is not intended as a substitute for manpower. Indeed, an attendant will be aboard every train to oversee the comfort of passengers. But the final system will require 10-car trains moving at 80 mph on 90-sec headways with an exacting degree of control that is beyond the capabilities of even the most skilled motorman.

In the test program, three laboratory cars will each be equipped with different trucks and different traction systems. Integration of functions always in mind, the term "traction" includes both *positive* traction (the propulsion system), and *negative* traction (the braking system). Four train control systems will be installed on each of the three cars. However, at any one time only one train control system will actually be operating the three cars.

A major problem currently being resolved by the engineers is the interface between the train control and traction systems. Each of the four train control systems must interface with the three different traction systems. Across this interface—which generally represents the trainline in multiple-unit operation—signals are transmitted from the train controls commanding positive and negative tractive effort. The train control system is responsible for delivering fail-safe commands to the traction system; the traction system is responsible for fail-safe following of those commands. In broad scope, the train controls call for a certain torque (not speed) from the traction system; the traction system sees to it that this torque is provided. The train controls measure the resulting speed and adjust the torque command as necessary.

The duties assigned to the train control and traction systems have been carefully evaluated. Fully automatic train control could not be merely a "black box" hooked up to the present type of propulsion and brake systems. The absence of a man in the control loop has eased the problem of obtaining intended performance, but it has been necessary to assign revised responsibilities to the traction system.

Traction must take on safety functions it never had before. For example, the lack of an input signal must cause a full-service brake application. Emergency braking in the traditional sense has no meaning here: a permissible braking effort can be determined based on wheel-to-rail adhesion and equipment capabilities. Calling for a greater braking effort would engender a slide, putting the train dangerously out of control.

NO WHEEL SLIDE

Wheel slide is intolerable. Consequently it is essential that the traction system sense the car weight (with lightweight vehicles the passenger load is significant) and adjust brake effort accordingly. Successful automatic train control will depend upon obtaining consistent performance from the traction system.

In addition to safety, smooth handling of the train is a responsibility of both the train control and traction systems. Starts, stops, and speed changes must be free of jerks; similarly, smooth transitions between positive and negative tractive effort are required to maintain a constant speed on an undulating grade. Though the train controls should not call for sudden transitions in tractive effort, a jerk-limiting stage in the traction system will prevent uncomfortable rates of change in acceleration by limiting this change to 2.0 mph-per-sec.

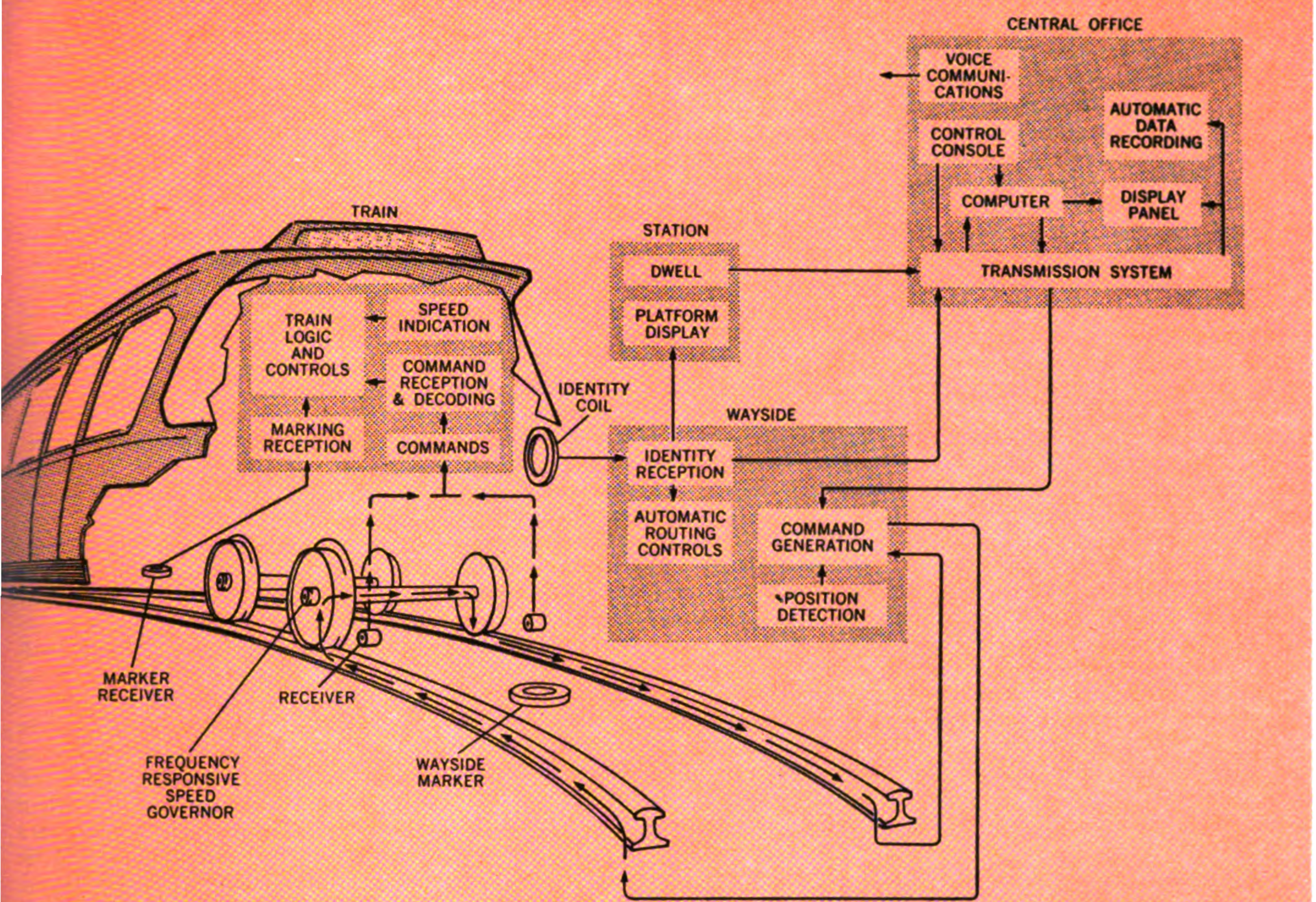
In mid-1963 Parsons Brinckerhoff-Tudor-Bechtel invited interested firms to submit automatic train control concepts to them for evaluation. Only four were complete enough to warrant testing. The manufacturers who have contracted with SFBARTD to demonstrate their concepts of automatic train controls are the General Electric Co., General Railway Signal Co., Westinghouse Air Brake Co., and Westinghouse Electric Corp. (see RS&C, April 1964, page 40). The four train control concepts are considered proprietary, therefore only a thumbnail sketch is given.

- The General Electric Company's automatic train control system is highly vehicle-oriented and decentralized. Through the use of "guided radar", their train protection system embodies the "moving block" principle, by which the speed of a following train is made a function of the distance and relative speed between it and the train ahead.

The lead car of a train sends a radar signal down a waveguide mounted alongside the track and detects a returning signal, reflected either from a train ahead or from a reflector inserted into the waveguide. As long as conditions are safe, each inserted reflector is removed before the train approaches close enough to require a speed reduction. The waveguide is also used to transmit operating data and voice communications to the train. To enable precision station stops, variations in wheel diameters, brake response times, etc., are compensated for by inert coils which are placed in the track structure to provide exact location to the train.

Train operation is regulated by GE's Directo-Matic II Control and a new GE/PAC-4000 computer in the central office. This equipment dispatches trains, monitors their operation, compares their performance with programmed schedules, and initiates corrective action.

- The General Railway Signal Company's automatic train control system gives the track circuit a new twist. Audio-frequency track-circuit transmitters are located at intervals along the track, but instead of wayside track receivers and relays, the signals are picked up and interpreted on the train. The frequencies are assigned to the transmitters in a repeating sequence, as f_1, f_2, f_3, . . . f_1, etc. A train must pick up three different frequencies in order to receive a valid full-speed signal. As a train closes in on a leading train, it picks up less than three frequencies because the lead train is shunting, or "covering", transmitters. In addition, these frequencies are modulated to transmit control signals—such as speed limits and, at stations, door commands—to the train. Precision station stops are assisted by coils located in the track structure in the approach to stations to give exact location data to sensors on the train.



GRS system, train picks up audio frequencies from the track circuit and interprets them in lieu of wayside receivers.

- The WABCO automatic train control system uses audio-frequency track circuits, with different frequencies assigned in a repeating sequence. A wayside receiver located within the track-circuit limits detects a train's shunt in essentially the traditional manner. Speed limit commands are transmitted to the train by modulating the track circuit signals. The central-office computer tracks the train via indications received from these train detection circuits.

The speed limit commands are controlled by wayside safety circuits; unless a train picks up this signal its controls will call for a full-service brake application. Precision station stops are assisted by coils located in the track structure in the approach to stations to give exact location data to sensors on the train. Within the station-stop area is a wayside wire transmission line by which door and train performance controls are exchanged between the train and the wayside.

- The Westinghouse Electric Corporation's automatic train control system is a wayside-oriented system using a Greek-square wire structure to communicate with the train. This is a wire laid in a square-wave pattern, alternating on either side of the track centerline. Transmitters with off-center antennas on the lead and tail car of each train induce pulses in the wire as they pass over one side of the Greek-square wire. Shift registers in wayside controllers track the train by counting the pulses received; the frequency of the pulses is a measure of train speed. The wayside controllers issue train-operating commands which are transmitted to the train via the same Greek-square wire. At approaches to stations, a more closely spaced wire pattern is employed to assist in the precision stopping of the train.

TEST TRACK CONSTRUCTION

The earthwork, structures, and track for the test program are now under construction and will be completed about the middle of January, 1965, by which time installation of wayside train control equipment will be underway. For the test program, the building which is to house the servicing facilities for this branch of the final transit system will be partitioned to provide central offices for the four train control suppliers and their equipment; the building is expected to be completed near the end of January. Control cables will be laid directly on the ground for the length of the test track, making connections to wayside equipment and tracks as required. Operation begins early in March.

Track structure will generally be on timber ties, similar to traditional construction. However, around the curve east of Oak Grove station various types of concrete ties and concrete slab construction will be tested. Aerial structures of new design will carry the tracks over Walnut Creek, Bancroft Road, Oak Grove Road, and over several roads west of Bancroft. Sound control tests will be carried out at a number of places along the test track.

Two interlockings are needed to enable safe operation, but these interlockings are not themselves being tested. They will be standard plug-in DC-relay route interlockings, with a switch to select the train control system providing inputs to and receiving outputs from the interlocking. (The engineers received no proposals for interlockings of other than traditional design.) Also as a support to the test program, a train phone system will be installed, and this is likewise not a subject of test. The train phone will provide voice communications between the central office, all three cars, and one wayside point. Transmission will be via carrier on the contact rails. The train control manufacturer actually operating the trains at any given time will have exclusive use of the train phone. The interlockings and train phone are being supplied by WABCO.

Because of the short length of the test track, a meaningful test of automatic line supervision was deemed not feasible. Therefore, most line supervision functions will be simulated manually from the central offices. However, two of the train control suppliers will have automatic line supervision.

The three laboratory carbodies, being fabricated by the Budd Company, will be assembled in the Western Pacific's shop at Sacramento. Trucks, propulsion, brakes, and car-carried portions of train controls will be installed on the cars there, with the cars shipped essentially ready-to-run. The three carbodies will be 70-ft long, 10½-ft high, and 10½-ft wide. The term "laboratory cars", rather than "test cars", is used because the vehicles do not in any way resemble the final cars, but are in fact rolling laboratories for train controls, traction, and trucks.

Each car will have four train control compartments, plus an area on each end for propulsion and truck instrumentation and manual controls. With all four train control systems aboard the cars will weigh in the neighborhood of 80,000 pounds. The cars have been designated A, B, and C.

Propulsion power will be 4,160 volts 3-phase AC and 1,000 volts DC. The three AC contact rails, mounted in a vertical plane to receive a side-bearing set of shoes, will be located only on the south side of all tracks; the DC contact rail, of more or less conventional overrunning design, will be located only on the north side of all tracks. Initially, car A will pick up power from the AC rails, with cars B and C contacting the DC rail. Later in the test program one or more of the cars will have the power-modulating ("front end") of the traction system changed to the other type of current. It is not presently contemplated to run the cars in multiple-unit. If that is done, for reasons other than train control tests, the train control systems will be temporarily train-lined between cars.

Generally the test program will simulate a prolonged peak period operation. This dense pattern will operate 16 hours per day, six days per week from March until the end of 1965. Operations are divided into three parts:

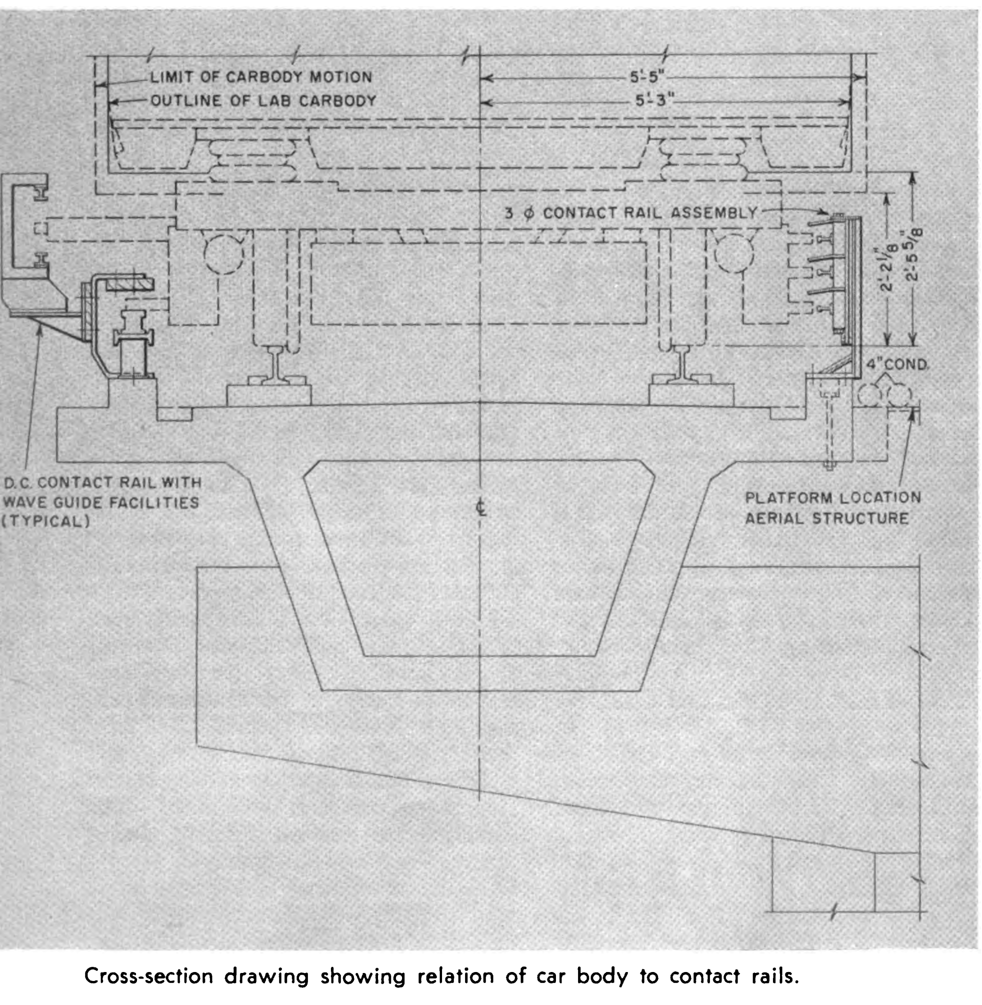
● **Part I,** normal circulation, tests are intended to confirm normal and continuous operational ability. Specific examination will include (a) safety of train protection, (b) consistency of train performance, (c) smoothness of station stops from high, medium, and low speeds, (d) accuracy of platform spotting, (e) conformance to speed restrictions, (f) quickness of turnback, and (g) track capacity as a function of headway interval.

The operating pattern in Part I tests will be a continuous circulation of the three laboratory cars. The first car will operate at a normal performance level between stations, a 20-sec dwell time at all stations, and prompt turnback at Bancroft (and later at Walden). This car will pace the pattern. The second car will follow the first car at an interval of 90 sec. It will dwell at all stations for 20 sec and make a prompt turnback at Bancroft. The second car's performance between stations will be adjusted to maintain the 90-sec interval. The third car will follow the second car on a controlled, but variable, interval which may be more or less than 90 sec. Its dwell time will be variable to the extent its performance adjustment cannot achieve the required separation interval from the second car. Any of the three trains may be represented by any of the three laboratory cars.

At Bancroft (and later at Walden) trains will turn back (reverse) on the single-track stub as quickly as possible. At San Miguel the first and third cars will turn back on the CR stub; the second car will turn back on the CL stub. At each platform stop the car door on the platform side will be operated. The platform for the CR track at San Miguel may have a door whose operation will be coordinated with the car door (similar to the wall-door for an elevator); this feature is being considered for use in the final system.

The trains will be automatically received onto the main tracks and returned to the yard track at least once each eight hours. The changeover from manual to automatic operation takes place on the section of the yard lead called a "transfer track".

● **Part 2** tests are disruptions of the normal circulation pattern and are intended to test the protection against willfull safety violations and failures

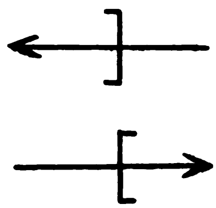


Cross-section drawing showing relation of car body to contact rails.

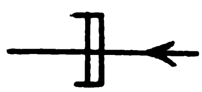
ATO for rapid transit introduces new terms and symbols

Because the automatic train control systems being tested by SFBARTD, are a complete departure from anything that has been done before, it has been necessary to invent new terms and symbols. For example, the home signal would have no meaning on an automatic railroad, yet its function is still required; hence "gate" was coined. This glossary and symbol list define a few of the new terms and symbols.

GATE, CONTROLLED The limit of an interlocked route at which point entry to that route is governed. An "open" gate permits automatic trains to pass; a "closed" gate ensures an absolute stop. (Top symbol is for trains moving from right to left, bottom symbol is for trains moving from left to right. Gates have no effect on trains moving contrariwise.)



GATE, FIXED The limit of an interlocked route, past which trains in automatic operation are never permitted. No effect on trains moving contrariwise or under manual control.



ZONE, RESTRICTED SPEED A zone for which a maximum authorized speed is established; a nomenclature suffix will indicate that speed.

ZONE, STATION STOP A zone in proximity to a station platform in which a precision platform stop is completed, and in which controls and indications are exchanged between a train and the station program and Line Supervision systems.

ZONE A length of track, comprised of one or more train detection loops, over which a selected operating mode governs train movements.

ZONE, APPROACH A zone in which a train's operation is preconditioned for that required by the next zone in advance.

ZONE, INTERLOCKED A zone, comprising all or part of an interlocked route and containing one or more track switches, in which train occupancy must be detected to effect detector locking of those switches.

ZONE, TERMINAL An interlocked route of one zone in which the prescribed direction of running can be reversed while the zone is occupied by a train.

LOOP, TRAIN DETECTION A circuit which detects the presence of one, and only one, train between the limits it defines.

TRANSFER TRACK A track in a yard of sufficient length to hold the longest train, on which the transfer between manual and automatic modes takes place.

due to damage. These tests may be called for at any time without advance notice to the train control manufacturer then operating. Whenever a failure due to damage is called for, the manufacturer will simulate or effect the damage. The principal feature being tested here is the fail-safety of the system.

• **Part 3** tests are the manufacturer's special tests and are intended to examine the singular features and claims each manufacturer has made for his system—in effect his "day in court".

The test program is divided into two phases. In Phase I the test track will be only about 2½ miles long, extending from San Miguel to Bancroft (named after local streets). This section will go into operation early in March. Construction will continue, however, and by mid-summer the test track will extend to Walden, approximately 1½ miles further, at which time Phase II operation will be inaugurated.

On a typical run, trains will leave San Miguel (considered the starting point) and accelerate to about 80 mph; trains from the CR stub will be restricted to 15 mph through the No. 8 crossover. They will maintain 80 mph until they begin to decelerate to 55 mph to meet the artificially imposed speed limit around the curve east of Oak Grove (it can take 70 mph). Coming out of the curve the trains will decelerate to a precision stop at the Oak Grove station platform. After dwelling here for the nominal 20 seconds, the train will again accelerate to maximum speed, then decelerate to a precision stop at the Bancroft station. Leaving here the trains move through the No. 10 crossover, not exceeding 25 mph, and stop on the turnback track. The interlocking will reverse the switch and the train will immediately start a non-stop run back to San Miguel. For this run, the trains will accelerate to maximum speed and maintain it until they slow to 15 mph to traverse the "wiggle track". This double reverse curve, one of 300-ft radius and one of 500-ft radius, is intended to test truck qualities. Past the wiggle, the trains will continue at 15 mph to a precision stop at one of the San Miguel station platforms. Thus precision stops are made from a low speed at San Miguel, from a medium speed at Oak Grove, and from a high speed at Bancroft.

When the track for Phase II of the test program is completed, the stop at Bancroft will be eliminated; the operation at Walden will then resemble the former operation at Bancroft. The switches at Bancroft will be spiked and the interlocking there will be moved to Walden. RS&C