

LIGHTWEIGHT VEHICLE TRACK SHUNTING



Prepared for
U.S. DEPARTMENT OF TRANSPORTATION
Federal Railroad Administration
Washington, D.C. 20590

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By: Thomas K. Dyer, Inc.
Lexington, Mass.

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16. Abstract The objective of this contract was to determine the extent of the shunting problem on lightweight rail vehicles and identify research recommendations to resolve it. This study discloses that special precautions must be taken before single-unit lightweight railroad cars can be operated on common carrier railroads. Such operation without special precautions introduces the likelihood of signal malfunctions in train protection systems and rail-highway grade crossing warning systems. Malfunctions of the signal system result from failure of the vehicle to make known its presence on a track by failing to pass sufficient current in a given time through its wheels and axles from one rail to the other. This is known as a shunt failure. This report is an effort to define the extent of the problem and possible avenues for solution. As such, it presents the following and is an excellent reference text: (1) Development of a clear statement of the problem; (2) Identification of applicable (government and industry) regulations and gathering of related data; (3) Assessment and documentation of industry developments and operational requirements, and (4) Formulation of R&D recommendations.					
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P R E F A C E

The material contained herein has been written in response to a standing need for a brief summary overview of the safety and reliability problems, applicable government regulations, and current status of industry developments associated with the operation of Lightweight Vehicles (LWV's) over U.S. railroad signal systems.

An effort has been made to treat the subject of track circuit shunting sensitivity in as concise a manner as practicable, consistent with the phenomena associated with rolling-wheel/rail-surface resistance of LWV operation.

The text describes the highly variable factors involved within wheel/rail shunting sensitivity, describes the current technological development status, and presents recommendations for technological research. It is believed that this can serve as introductory material for development of a program plan for needed FRA research aimed at economical and viable solutions to provide the level of signal system operational safety required for U.S. LWV passenger operation.

An Appendix has been included covering Reference Documents, Industry Developed Instruction Manuals, Contacts of recognized experts within the field, special AAR formulas, and related information.

TABLE OF CONTENTS

	<u>PAGE</u>
I INTRODUCTION	1
II BACKGROUND	2
III SUMMARY	7
IV DEFINITION OF TERMS	8
V TASK 1 - STATEMENT OF PROBLEM	10
VI TASK 2 - APPLICABLE REGULATIONS	18
VII TASK 3 - INDUSTRY DEVELOPMENTS	29
VIII TASK 4 - RESEARCH RECOMMENDATIONS	39

APPENDICES

A-I REFERENCE DOCUMENTS	43
A-II INDUSTRY DEVELOPED INSTRUCTION MANUALS	46
A-III CONTACTS	48
A-IV SPECIAL AAR FORMULAS	50
A-V "TRACK CIRCUITS AND TRAIN DETECTION" - (a reproduction of Chapter IV of "Principles of Electricity Applied to Railroad Signal and Train Control Systems" - for FRA, January 1977, by Thomas K. Dyer, Inc.)	53

I. INTRODUCTION

There is considerable interest and a public need in this country to provide means of transporting people from suburban areas to urban business centers, reliably, at minimum expense, and with a maximum efficient utilization of our energy resources.

It is anticipated that lightweight rail vehicles (LWV's) could greatly contribute to achieving this objective on a cost-effective basis, providing that they can be safely introduced into the U.S. rail network. To this end, the Federal Railroad Administration is engaged in conducting demonstration tests of lightweight rail vehicle operations over selected segments of U.S. railroads.

These demonstration operations (using British-European type equipment) are intended to identify and evaluate the feasibility and acceptability of this type of rail passenger service. However, these demonstrations are being conducted under certain operational constraints because current U.S. railroad signal systems will not reliably support such lightweight single-unit rail vehicle operations with the achievable degree of safety required.

II BACKGROUND

Some of the characteristic features of early U.S. railroad passenger service offer interesting similarities to those of today. Most early railroads were originally built to serve local needs in response to the desires of the people for improved transportation.

As the need to increase the capacity of rail lines evolved, the requirements for operationally safe and reliable signal systems became of paramount importance. Commuter rail passenger service was the primary mode of serving metropolitan business and industrial areas prior to and including the period ending with World War II.

Passenger Train equipment utilized during this era consisted of relatively heavy passenger coaches with steel underframes and all steel body construction. Train consists were normally made up of several coaches pulled by a passenger locomotive. Thus railroad signal system technology, while attaining a high degree of safety and reliability for heavy density conventional train movements, was not particularly concerned with single-unit self-propelled lightweight vehicle operation.

After World War II a dramatic decrease in commuter rail passenger service occurred. The use of private automobiles and bus transportation, with a cheap and plentiful supply of fuel,

over a rapidly expanded public highway network became the prime cost-effective-convenient, but not wholly efficient, method of moving people from suburban areas to urban business and work centers.

Advances in stainless steel, aluminum, and related light materials made possible the construction of lightweight self-propelled vehicles, such as the Rail Diesel Car (RDC). However, the commuter passenger market was not, at that time, sufficiently attracted back to rail transportation to reduce the mounting passenger train deficit operating costs. Therefore, with only a few notable exceptions, very little technological signal system research was performed after 1950 in relation to safe operation of single-unit lightweight passenger rail vehicles.

The signal industry (railroads and equipment manufacturers) has realized for years the problems presented by the operation of lightweight single-unit rail vehicles over existing U.S. signal systems, but the volume of such operations has generally been too small to justify any substantial private research and development.

During the 1930's a few self-propelled "Gas-Buggys" were operated over light density branch lines. For the most part these lines were not equipped with wayside signal systems and, therefore, such trains were operated either by Time Table and Train Order or under Manual Block rules. Some information was

obtained and corrective measures performed by individual railroads relative to train detection at automatic highway grade crossing protection devices.

One major resurgent thrust was made for about a decade, starting in the mid 1950's, to attract commuter rail passengers by introduction of self-propelled RDC cars manufactured by the Budd Company. The Boston and Maine Railroad purchased 130 of these units in an attempt to provide a cost-effective commuter rail service to the city of Boston. This was followed by introduction of lesser numbers of these vehicles by the Reading Railroad, the Baltimore and Ohio, the New York Central, and the Milwaukee, among others.

By far, the largest fleet number of these vehicles operated as single-units in revenue service occurred on the Boston and Maine. Consequently, the knowledge gained and methods implemented for improving detection of lightweight rail vehicles was greatest as a result of the B&M's work. A great deal of information was obtained, and some questions posed but not answered, as to the chemical composition of rail film build up, and the best means of "breaking-down" this wheel/rail electrical resistance.

Using the signal technology of the 1950's the B&M successfully operated single-unit RDC's in revenue service with an acceptable reliability of signal system safety. The modifications made by the railroad, at that time, were to both the vehicle and the wayside signal system. The majority of other

U.S. railroads operated single-unit RDC's on a manual block basis and generally only treated grade crossing protection circuits for improvement in train detection.

After this period, during the late 1960's, U.S. railroads substantially abandoned commuter rail passenger service and any further meaningful experimentation with technological signal system development for lightweight single-unit rail vehicle operation ceased.

In 1978, with a resurgent interest in rail passenger service, the Budd Company developed and demonstrated a new self-propelled vehicle, the SPV 2000. The SPV 2000 is essentially an improved version of the RDC utilizing 360 hp diesel truck engines as an improvement over the more sluggish performance of the 275 hp RDC engines. The SPV 2000 is available in two versions: one for commuter service, capable of speeds up to 100 mph; and an intercity high-performance version with a seat-per-mile fuel efficiency superior to that of an intercity bus.

In Europe, since World War II, passenger rail service experienced a rapid and continued growth. Resulting technological developments have been made in developing single-unit, lightweight, economical rail vehicles such as the British rail-bus --- a bus-type body mounted on railroad type axle/wheels.

Given the current need and interest in providing a more efficient, cost-effective, and a better utilization of energy method of transporting people from suburban areas to metropolitan centers, there exists a need for modern R&D aimed at safe and reliable operation of LWV's on U.S. signal systems.

The potential benefits of a fresh look at state-of-the-art improvements in vehicle detection should be closely allied with the promising benefits of LWV type passenger rail operation.

III SUMMARY

This investigation was conducted to identify, define, and summarize four work tasks relative to Lightweight Vehicle Track Shunting:

- . Task 1 - Statement of Problem
- . Task 2 - Applicable Regulations
- . Task 3 - Industry Developments
- . Task 4 - Research Recommendations

The remainder of this report is structured into five (5) sections. Section IV provides a Definition of Terms peculiar to semi-technical words and phrases as used in the successive sections of text. The remaining sections (V through VIII) are arranged in the order of the tasks listed above.

Since this is an information type document, no attempt has been made to form conclusions; the recommendations set forth within Section VIII (Task 4) are consistent with the "Statement of Goals and Implementation Policies of the Federal Railroad Administration" issued in 1977, following publication of the National Transportation Policy of 1976 by the Department of Transportation.

IV DEFINITION OF TERMS

The following definitions apply to terms used in the text of this report. Definitions listed by the Association of American Railroad shall also apply.

1. Block - A length of track of defined limits, the use of which by trains and engines is governed by block signals, cab signals or both. (Standard Code)
2. Circuit, Control - An electrical circuit between a source of electric energy and a device which it operates. (CFR)
3. Chucking - Lateral and vertical motion of rail vehicle axle due to track irregularities.
4. Circuit, Track - An electrical circuit of which the rails of the track form a part. (CFR)
5. Circuit, Trap - A term applied to a circuit used at locations where it is desirable to protect a section of track but where it is impracticable to maintain a track circuit.
6. Conductivity - The quality of power of conducting or giving passage to some molecular action, as of heat, light, or electricity.
7. Current, Foreign - A term applied to stray electric currents which may affect a signaling system, but which are not a part of the system. (CFR)
8. De-energize - To deprive an electro-receptive device of its operating current.
9. Joint, Rail, Insulated - A joint in which electrical insulation is provided between adjoining rails. (CFR)
10. Ionization - Condition of current flow resulting from breakdown of resistance by applied voltage.
11. Locking, Route - Electric locking, effective when a train passes a signal displaying an aspect for it to proceed, which prevents the movement of any switch, moveable point frog, or derail in advance of the train within the route

entered. It may be so arranged that as a train clears a track section of the route, the locking affecting that section is released. (CFR)

12. Point, Fouling - The location on a turnout back of the frog at which insulated joints or derails are placed at or beyond the clearance point.
13. Relay, Track - A relay receiving all or part of its operating energy through conductors of which the track rails are an essential part.
14. Resistance - The opposition offered by a substance or body to the passage through it of an electric current.
15. Section, Dead - A section of track, either within a track circuit or between two track circuits, the rails of which are not part of a track circuit. (CFR)
16. Shunt - A by-path in an electrical circuit. (CFR)
17. Speed, Restricted - Proceed prepared to stop short of train, obstruction, or switch not properly lined and to look out for broken rail, not exceeding 15 miles per hour. (Standard Code)

V TASK 1 - STATEMENT OF PROBLEM

I Problem Definition

The problems associated with Lightweight Vehicle Track Shunting may best be grouped into two separate, but related, categories:

- . Those due to train length.
- . Those due to the phenomena of track circuit shunting sensitivity inherent within the highly variable factors of individual rail/wheel electrical resistance.

The signal system problems attributable to the first category (train length) are not, in the strictest sense, a function of "shunting sensitivity"; the same safety problems can be experienced by operation of a single-unit locomotive at passenger timetable speeds. However, no treatment of lightweight vehicle operational problems would be complete without an understanding of the affects due to vehicle length.

The problems inherent within the second category (rail/wheel resistance) are not so easily definable, nor are the solutions so readily apparent, as those associated with train length. Therefore, prior to a discussion of the intrinsic factors involved, an understanding of track circuit theory is in order.

II Track Circuit Theory

Safety of train operation by wayside automatic block signal indication, interlocking protection, drawbridge locking, and reliable notice of a train's approach to a rail-highway grade crossing, is completely dependent on some form of track circuit.

The function of the track circuit is to detect the presence, or absence, of a train in an electrically defined or limited section of track, and subsequently enter such information into the signal network for the purpose of preventing train-train collisions, derailments, train-highway vehicle collisions at public grade crossings, and run offs at open movable bridges. While the track circuit is theoretically simple in design, and possesses acceptable reliability for common multi-unit train movements, it does not provide the same measure of train detection for lightweight single unit rail passenger vehicles.

Simply stated, the basic track circuit consists of an electrical source of energy, usually a battery, connected to a track relay through the two rails of a track as schematically illustrated in Figure 1.

It consists of:

1. A battery
2. A limiting resistance
3. Rail and rail bonds
4. Ties and ballast

5. Relay series resistance

6. Track relay

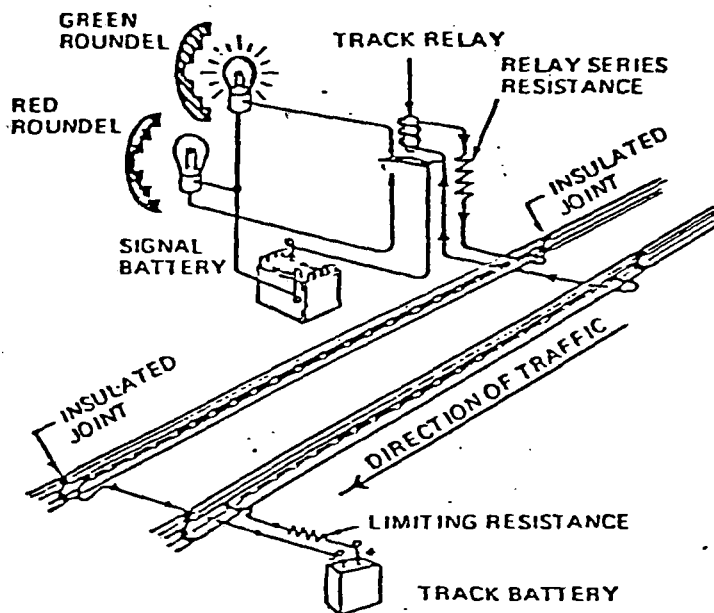


Figure 1. Simplified diagram of a track circuit, unoccupied.

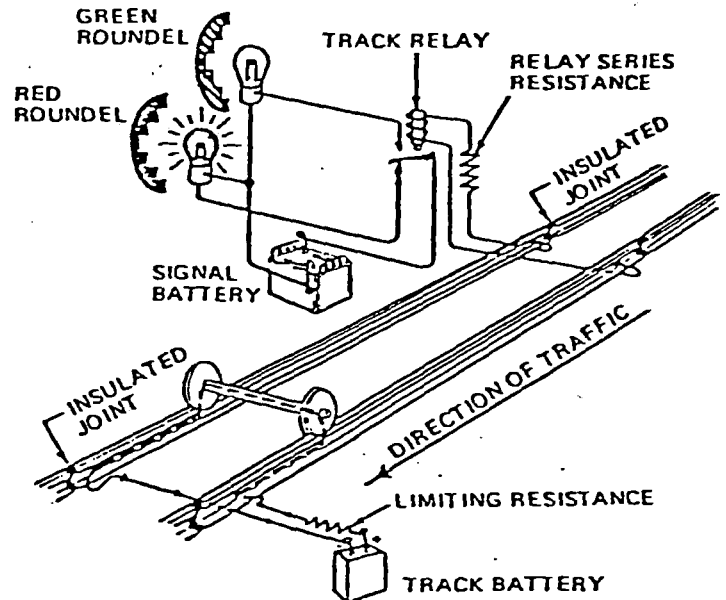


Figure 2. Simplified diagram of a track circuit, occupied.

The arrows show direction of current flow. Starting from the positive post of the battery, current flows through the limiting resistance, the one rail, through the relay winding, the relay series resistance and back through the other rail to the negative post of the battery. With the relay thus energized it closes a contact to provide a proceed aspect as illustrated. As the wheels and axles of a train move onto the track circuit as shown on Figure 2, they provide a path from rail to rail through which the track current flows, thus robbing the relay of its current and causing it to open the contact through which energy was feeding the lamps behind the green roundel and to close the contact to cause the lamp behind the red roundel to light.

There are many variations and degrees of sophistication in track circuits, but in every instance, the proper operation of the circuit is a function of electrical contact between the trains wheels and the rail. This wheel/rail contact must be of sufficient quality to cause de-energization of the relay by the resulting shunt path of track circuit current through the trains wheels and axles.

Various types of track circuits include:

Direct Current:

- . Steady Energy
- . Coded Energy

Alternating Current:

- . Steady Energy
- . Coded Energy
- . Phase Selective
- . Audio Frequency

III Shunting Sensitivity

Shunting sensitivity is highly dependent upon vehicle design characteristics, wayside track and signal configurations, and the environment.

A. Vehicle Design Factors

- . Weight
- . Wheelbase
- . Axles per car
- . Type of brake
- . Car frame to wheel/axle electrical resistance
- . Wheel contamination
- . Speed

Length of wheel base and vehicle speed are critical factors in maintaining a proper sequence of shunts when passing from one track section to another.

Vehicle weight, number of wheel/axle combinations, rolling resistance, and type of brake are highly influential factors regarding shunting sensitivity.

B. Wayside Configuration

- . Insulated joint stagger
- . Track Circuit length
- . Track circuit frequency (ac)
- . Power (track circuit voltage and adjustment)
- . Ballast resistance
- . Frequency of train movements

C. Environment

- . Humidity
- . Precipitation
- . Temperature
- . Salts
- . Rail contamination (oil film, rust, sand)

* * * *

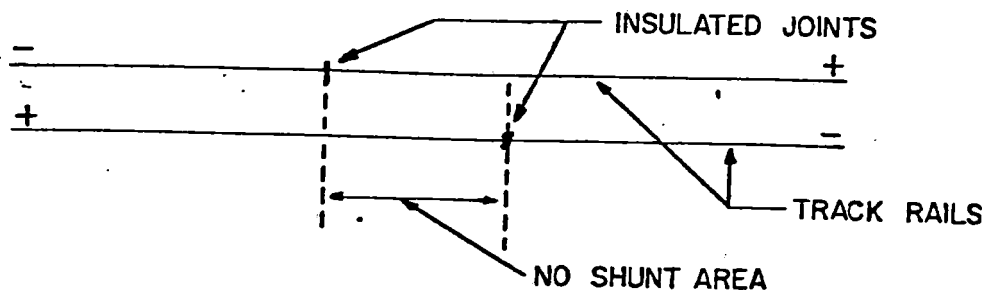
IV Shunting Problems

A. Due to Vehicle Length and Speed

The first aspect of the shunting problem results from the fact that track circuits comprising a wayside signal system are contiguous. Proper and safe operation of a signal system requires that track circuits be shunted in proper sequence as a train moves over the territory. Failure to shunt in proper sequence can result in

movement of track switches under a train, release of drawbridge locking, failure of grade crossing warning devices and falsely permitting following and/or opposing train movements.

- Two factors dependent upon vehicle speeds operate to preclude the desired results:
- (1) the rail distance between staggered insulated joints reduces the length and time available for adjacent track circuits to be simultaneously shunted, and
 - (2) the short wheel base of single unit vehicles further reduces the time and space combination to maintain a continuous detection of a moving rail vehicle. Simply put, potential safety malfunctions result when a track circuit which the train is leaving becomes energized before the track



circuit being entered is de-energized. The extremely short wheel base of a Lightweight Vehicle (LWV) (24 feet) illustrates the type of vehicle construction likely to cause this kind of safety problem, particularly if only one axle is available for shunting.

B. Due to Rail/wheel Resistance

In 1917, the Railway Signal Association, predecessor of the Communication and Signal Division, AAR, recommended that the maximum allowable Train-Shunt Resistance be 0.06 ohm. This 0.06 ohm recommendation is still recognized by the industry and is mandated by the FRA in their regulation 236.56 Shunting Sensitivity.

Past investigations have developed that two recognizable events take place over varying periods of time, each contributing to unreliable and potential unsafe shunting.

First, there is a continual build-up of microscopic contamination both on the wheel and on the rail. If the vehicle is equipped with off-tread brakes the contamination becomes more pronounced.

Secondly, on relatively little used tracks, such as crossovers, turnouts, and branch lines, the rails become coated with an oxidized film creating a barrier to electrical conductivity between the wheel and rail. The rate of rail film build-up is, of course, influenced by atmospheric conditions and frequency of train movements.

C. DC Shunting Sensitivity

Shunt resistance of a train is, to a considerable degree, inversely proportional to the number of pairs of wheels in a given track circuit. The individual rail/wheel resistance is a highly variable factor, especially if there is rust, oil, sand or other types of film on the rail surface. Coded or pulsed circuits and conventional low frequency ac track circuits are superior in shunting sensitivity to that of a continuous dc circuit. This is due to the fact that a fairly high peak voltage is required for each impulse in order to produce the necessary average operating voltage across the relay, and high voltage peaks are effective in breaking down most rail surface films.

However, regardless of the type track circuit, if the resistance of the multiple shunt paths afforded by the pairs of wheels exceeds the shunting sensitivity of the track circuit, a loss of shunt will occur. For a given ballast range, the longer the track circuit the lower will be the shunting sensitivity. In addition, the ratio of the highest ballast resistance to the lowest ballast resistance of a particular track circuit is a factor in shunting sensitivity.

Present FRA Rule, 236.56 provides that the track relay be in a de-energized position if, when the track circuit is dry, a shunt of 0.06 ohms is connected across the rails. This test is usually made with a firm connection between the rails, and does not take into account the rail surface condition with rolling wheels. To demonstrate the importance of proper shunting sensitivity adjustment, let us analyze the effects of ballast resistance, train shunt and maximum permissible relay current.

The current through a track relay increases as the ballast resistance increases. As the current through the relay increases, the permissible value of train shunt resistance decreases - the relay becomes more difficult to shunt. It is, therefore, important that sufficient resistance exists in series with the relay so that the relay current will not rise too high with dry ballast conditions. It is also of prime importance that upon train shunt the total current from the battery does not rise to such a level as to permit the parallel component of this current flowing through the relay to be at or near the drop-away value. AAR Signal Manual, Part 132 details formulas for calculating minimum allowable resistance between battery and track, to ensure maximum shunting sensitivity for various type relays and battery combinations.

The last and perhaps the most important factor in obtaining a low resistance rolling shunt is the required interrail voltage to break down (or ionize) the rail film. In other words, we wish to establish a wheel/rail contact by sufficient ionization voltage in order to reduce a potential rolling shunt of say 0.3 to 0.5 ohms to 0.06 or less ohms. Experiments with single unit equipment on glazed rails have determined that this minimum interrail ionization voltage should be in the range of 0.75 to 1.0 volts for steady dc track circuits.

VI TASK 2 - APPLICABLE REGULATIONS AND RELATED DATA

I Federal Rules and Regulations

The Federal Railroad Administration, Office of Safety, as part of its duties toward enhancement of railroad safety, has adopted several regulations applying specifically to track circuit operation. Those regulations were originally adopted and promulgated by the Interstate Commerce Commission (ICC) prior to creation of the FRA. In 1967, railroad safety functions were transferred from the ICC to the FRA, the signal system (RS&I) regulations were adopted without change by the FRA. These regulations may be found in Chapter 49, Code Federal Regulations, Part 236. They are generally applicable to all types of vital track circuits, although the 0.06 ohm shunt value requirement in Rule 236.56 is based on a formula using a single set of factors and assumptions representative of direct current operation only.

The following regulations appear in 49 CFR, Part 236 and relate to operation of the track circuit.

- 236.5 Design of control circuits on closed circuit principle
- 236.51 Track circuit requirements
- 236.54 Minimum length of track circuit
- 236.55 Dead section; maximum length
- 236.56 Shunting sensitivity

- 236.201 Track circuit control of signals
- 236.203 Hand operated crossover between main tracks; protection
- 236.205 Signal control circuits; requirements
- 236.302 Track circuits and route locking
- 236.309 Loss of shunt at automatic interlocking
- 236.311 Signal control circuits, selection through track relays, and through signal mechanism contacts and time releases at automatic interlocking.
- 236.405 Track signaled for movements in both directions, change of direction of traffic.
- 236.407 Approach or time locking; where required
- 236.408 Route locking

According to FRA records, there are approximately 98,000 miles of automatic block signal and traffic control systems utilizing track circuits.

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§ 236.5 Design of control circuits on closed circuit principle.

All control circuits the functioning of which affects safety on train operation shall be designed on the closed circuit principle, except circuits for roadway equipment of intermittent automatic trainstop system.

The safety of train operation is directly dependent upon the proper operation of track circuits. A literal interpretation of this rule would preclude use of any device, or combination of devices, not incorporating a normally energized track circuit that, upon being opened

or short circuited (shunted), will cause the device controlled by the circuit to indicate a STOP condition.

§ 236.51 Track circuit requirements.

Track relay shall be in deenergized position whenever any of the following conditions exists, and the track circuit of an automatic trainstop, train-control, or cab-signal system shall be deenergized in the rear of the point where any of the following conditions exists:

(a) When a rail is broken or a rail or switch-frog is removed except when a rail is broken or removed in the shunt fouling circuit of a turnout or crossover, provided, however, that shunt fouling circuit may not be used in a turnout through which permissible speed is greater than 45 miles per hour. It shall not be a violation of this requirement if a track circuit is energized: (1) When a break occurs between the end of a rail and track circuit connector; within the limits of rail-joint bond, applicance or other protective device, which provides a by-path for the electric current, or (2) as result of leakage current or foreign current in the rear of a point where a break occurs or a railroad is removed.

(b) When a train, locomotive, or car occupies any part of a track circuit, including fouling section of turnout except turnouts of hand-operated main track crossover. It shall not be a violation of this requirement where the presence of sand, rust, dirt, grease, or other foreign matter prevents effective shunting, except that where such conditions are known to exist adequate measures to safeguard train operation must be taken.

(c) Where switch shunting circuit is used:

(1) Switch point is not closed in normal position.

(2) A switch is not locked where facing-point lock with circuit controller is used.

(3) An independently operated fouling-point derail equipped with switch circuit controller is not in derailling position.

Note in subsection (b) the regulation requires (by shunting) de-energization of the track relay when a train, locomotive or car occupies any part of a track circuit and failure to comply constitutes a violation. The exception concerning presence of sand, rust, dirt, grease or other foreign matter generally covers conditions which are readily discernible, i.e., if sand prevents train shunt, the railroad is not in violation, if the railroad was unaware of such a condition.

§ 236.54 Minimum length of track circuit.

The length of any track circuit, except trap circuit or special circuit not used for control of signaling facilities, shall be greater than maximum inner wheel base of any locomotive or car.

The wheelbase of the LWV is approximately 24 feet; this should not present any problems insofar as this regulation is concerned since the minimum length of track circuits currently in use on U.S. railroads exceeds this vehicle length.

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§ 236.55 Dead section; maximum length.

Where dead section exceeds 35 feet, special circuit shall be installed. Where shortest outer wheel base of a locomotive operating over such dead section is less than 35 feet, the maximum length of the dead section shall not exceed the length of the outer wheel base of such locomotive unless special circuit is used.

This regulation prohibits use of a dead section where its length would exceed the length of the vehicle wheel base. Therefore, all dead track sections over which LWV vehicles operate, such as rail grade (diamond) crossings, must be less than 24 feet, or some type of accommodation must be made by means of special circuitry.

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§ 236.56 Shunting sensitivity.

Track circuit shall be so maintained that track relay will be in deenergized position if, when track circuit is dry, a shunt of 0.06 ohm resistance is connected across the track rails of the circuit, including fouling sections of turnouts.

This regulation specifies that 0.06 ohm be the maximum train shunt equivalent. Sensitivity is determined by measuring the maximum resistance that can be placed across

the rails to cause the track relay contacts to open. Thus high ballast resistance and low rail resistance will assist in proper track circuit shunting.

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§ 236.201 Track-circuit control of signals.

The control circuits for home signal aspects with indications more favorable than "proceed at restricted speed" shall be controlled automatically by track circuits extending through the entire block.

This regulation specifies that the track circuit must be used as the primary element in providing safety of train operation through automatic block signal systems.

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§ 236.203 Hand operated crossover between main tracks; protection.

At hand-operated crossover between main tracks, protection shall be provided by one of the following: (a) An arrangement of one or more track circuits and switch circuit controllers, (b) facing point locks on both switches of the crossover, with both locks operated by a single lever, or (c) electric locking of the switches of the crossover. Signals governing movements over either switch shall display their most restrictive aspect when any of the following conditions exist:

(1) Where protection is provided by one or more track circuits and switch circuit controllers, and either

switch is open or the crossover is occupied by a train, locomotive or car in such a manner as to foul the main track. It shall not be a violation of this requirement where the presence of sand, rust, dirt, grease or other foreign matter on the rail prevents effective shunting;

(2) Where facing locks with a single lever are provided, and either switch is unlocked;

(3) Where the switches are electrically locked, before the electric locking releases.

As stated, this regulation can be met using three different methods: (1) track circuits in combination with track switch point protection or (2) common

mechanically locked track switch points, or (3) individually electrical locking of each set of track switch points.

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§ 236.205 Signal control circuits; requirements.

The circuits shall be so installed that each signal governing train movements into a block will display its most restrictive aspect when any of the following conditions obtain within the block; (a) occupancy by a train, locomotive, or car, (b) when points of a switch are not closed in proper position, (c) when an independently operated fouling point derail equipped with switch circuit controller is not in derailing position, (d) when a track relay is in deenergized position; or when signal control circuit is deenergized.

This rule requires positive track circuit shunting in order to provide the most restrictive aspect when a train occupies a track section.

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§ 236.302 Track circuits and route locking.

Track circuits and route locking shall be provided. Route locking shall be effective when the first pair of wheels of a locomotive or car passes a point not more than 13 feet in advance of the signal governing its movement.

NOTE 1: Existing installations on each railroad, which do not conform to the requirements of this section shall be brought into conformity on or before December 31, 1970.

This regulation is intended to prevent a power-operated interlocked track switch from operating during the trains immediate approach to, and ensuing passage over, the track switch points. Failure to establish

shunt, or loss of shunt can cause misalignment of the intended route resulting in a possible derailment or collision.

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§ 236.309 Loss of shunt at automatic interlocking.

At automatic interlocking, a loss of shunt of 5 seconds or less shall not permit an established route to be changed.

This regulation is intended to provide for safety of train operation in event of momentary loss of shunt at an automatic interlocking.

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§ 236.311 Signal control circuits, selection through track relays, and through signal mechanism contacts and time releases at automatic interlocking.

The control circuits for aspects with indications more favorable than "proceed at restricted speed" shall be selected through track relays for all track circuits in the route governed, or through repeating relays for such track relays. At automatic interlocking, signal control circuit shall be selected (a) through track relays for all track circuits in the route governed and in all conflicting routes within interlocking limits or through repeating relays for such track relays; (b) through signal mechanism contacts or relay contacts closed when signals for such conflicting routes display stop aspects; and (c) through normal contacts of time releases for such conflicting routes or contacts of relays repeating the normal position of Contacts on such time releases.

This regulation requires that each signal, with a more favorable indication than restricted speed, must be checked by track circuits in the route protected by the wayside signal, in all conflicting routes. In effect, this rule requires that each track circuit in a route

must be determined to be energized before any wayside signal indication other than STOP can be displayed.

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§ 236.405 Track signaled for movements in both directions, change of direction of traffic.

On track signaled for movements in both directions, occupancy of the track between opposing signals at adjacent controlled points shall prevent changing the direction of traffic from that which obtained at the time the track became occupied, except that when a train having left one controlled point reaches a section of track immediately adjacent to the next controlled point at which switching is to be performed, an aspect permitting movement at not exceeding restricted speed may be displayed into the occupied block.

This regulation is intended to prevent the changing, or reversal, of traffic direction in TCS territory between adjacent control points once a train has established direction by entering the block under signal indication. A loss of shunt by such train could permit a reversal of traffic to allow an opposing train to enter the block.

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§ 236.407 Approach or time locking; where required.

Approach or time locking shall be provided for all controlled signals.

Where approach locking existing in the approach to an interlocking, the loss of an established shunt by an approaching train can cause the interlocked power track switches to be electrically unlocked and thrown immediately in front of an approaching train.

* * *

§ 236.408 Route locking.

Route locking shall be provided where switches are power operated. Route locking shall be effective when the first pair of wheels of a locomotive or car passes a point not more than 13 feet in advance of the signal governing its movement.

NOTE: 1.—Existing installations on each railroad, which do not conform to the requirements of the last sentence of this section shall be brought into conformity on or before December 31, 1970.

This regulation applies in Traffic Control territory and requires a track shunt to be effective, in order to lock the switches in the route, when the leading pair of wheels is within a distance not exceeding 13 feet in advance of the signal. This application is similar to that of Rule 236.302 for Interlockings.

II Other Rules and Regulations

In addition to the Federal Railroad Administration rules and regulations concerning use of track circuits for safe movement of trains, the Federal Highway Administration, through its Manual on "Uniform Traffic Control Devices for Streets and Highways" (MUTCD) generally requires some form of automatic train detection for control of warning devices.

A. Section 8C5 of the MUTCD is as follows:

1. "To serve their purpose of advising grade motorists and pedestrians of the approach or presence of trains, locomotives, or railroad cars on grade crossings, the devices employed in active traffic control systems shall

be actuated by some form of train detection. Generally, the method is automatic, requiring no personnel to operate it, although a small number of such installations are still operated under manual control. The automatic method currently uses the railroad circuit. Railroad circuits insofar as practical shall be designed on the fail-safe principle, which uses closed circuits.

B. Other Track Circuits:

1. Track circuits other than direct current type are often used in the control of grade crossing warning devices. They are:

a. Audio Frequency Overlay:

A circuit utilizing audio frequencies and which can be superimposed on circuits and which does not require use of insulated joints under normal conditions.

b. Motion Detectors:

A device to detect presence, motion and direction of a train, used to control rail-highway grade crossing warning devices.

c. Grade Crossing Predictor:

A device used to provide uniform warning time to accommodate varying speeds of approaching trains.

These devices function on the basis of the axle and wheel shunting the track similar to the dc track circuits. In addition to the existing 55,000 automatically track-circuit-controlled highway grade warning systems in the United States, additional new systems are continually being installed under Federal aid programs. It is significant that all these automatic highway-grade warning signaling systems depend on a train shunt of the track circuit.

This type control is the only recognized means of achieving safe and reliable highway-grade crossing warning operation.

VII TASK 3 - INDUSTRY DEVELOPMENTS

I PRIOR TO WORLD WAR II

Until the advent of the lightweight rail-car, it had been established empirically that a 0.06 ohm maximum shunt resistance valve provided an adequate factor of safety for all standard types of railway cars, both passenger and freight. The record of safety of railway signaling in this country over many years is proof that, except in very special circumstances, the 0.06 ohm train shunt valve is safe test parameter to use for track circuit operation.

The industry, consisting of the railroads with the cooperation of the major signal suppliers, investigated and reported on several early schemes to improve shunting characteristics of lightweight rail equipment. Starting in 1937 the Pennsylvania Railroad, with the cooperation of the Union Switch and Signal Company, conducted a series of tests of lightweight equipment on a given section of track. The resulting report detailed location, track circuit data, type of test vehicle, number and types of test runs, types of track circuits used, rail surface conditions, and instrumentation. Among the conclusions reached were:

"It should be clearly understood that the values obtained in these tests only apply to the particular circuit under test, subject to the physical conditions as existed at the time of tests". (1)*

* Number in parenthesis denotes reference in Appendix A-1.

II DEVELOPMENTS SINCE WORLD WAR II

The majority of railroad industry investigative research and development, aimed towards solutions of shunting problems introduced by lightweight rail vehicle operation, occurred during the period from about 1953 to 1964. After this period most railroads were abandoning single-unit lightweight vehicle operation on branch lines --- the market battle having been all but won by the private automobile, cheap fuel, and the federally funded highway program.

Today's resurgent interest in, and needs for, transporting people from suburban areas to urban business centers, at lower cost, and with a maximum efficient use of our energy resources dictates a fresh look at lightweight rail-vehicle operation. The following represents the history to date, of the development cycle for solutions to track circuit shunting problems:

- A. In 1946 the Signal Section, Association of American Railroads reported on the results of a questionnaire sent to member roads to obtain information on railroad use of schemes to promote improved shunting as described in the 1937 report. This report provides detailed information on different types of track circuits in use and the number of such circuits reported to be in use. The report includes descriptions of modifications by application of welded beads of stainless steel, bronze brazes and other non-ferrous corrosive-resistant metals to the rail head. While several methods are covered in the report, none go into an in-depth descriptive detail. (2)

- B. In 1948, a report was issued by the AAR describing the development of a new relay having increased efficiency factors for shunting. This report gives detailed descriptions. It also describes additional test of welded bead application to rail head surfaces and improvements minimizing the amount of sand deposited on the rail surface by locomotive sanding devices. This report covers the advantages of using a high efficiency track relay, but does not deal with fundamental causes of poor shunting. (3)
- C. The Electronic Track Circuit (ETC) was developed as an effort to increase sensitivity, maintain more uniform shunting, provide maximum broken rail protection, and to provide a means of inonization of the rust film between rail head and wheel surface. The ETC was initially applied at infrequently used crossover tracks to achieve train detection under rusty rail conditions. This development was reported by the AAR in 1949. While this report describes an electrical circuit developed for use on crossovers, particularly those with rust problems, it does not address mainline shunting difficulty. (4)
- D. In 1952, a report was issued by the AAR describing the results of stainless steel bead application; a listing of methods under consideration to assist in improving shunting of track circuits; and resulting advantages of using a higher track voltage for more effective shunting. While this report cites several methods to improve shunting, it also contains the caveat;

"Experience has determined that periodic checks of a car in any circuit, or number of circuits, is not conclusive evidence due to fact that shunting irregularities might occur on one track circuit at one time, while in another instance operation in this circuit would be satisfactory with shunting irregularities elsewhere".

However, there was no follow up to identify and determine the causes of such unpredictable irregularities. (5)

- E. Based on earlier reports that improved shunting of signal track circuits were needed for proper performance of the Rail Diesel Car (RDC) the AAR in 1953 published a report describing the effects of different schemes for improving shunting, and listed precautions that should be taken in operation of the RDC equipment. The report identifies such areas as sanding, conditioning shoes, truck-to-car frame bonding, disc brakes, etc.. Suggested steps are discussed to improve shunting, particularly as related to lightweight single unit rail vehicles. No attempt was made to explore the fundamental causes of poor shunting. (6)
- F. An additional factor to be considered in proving adequate shunting for lightweight cars concerns the oiling procedures used by railroads. An AAR report issued in 1955 presents the results of a survey made on the effects on track circuit shunting of oil and grease from journal boxes and rail flange lubricators. This report also includes an analysis of the composition of rail film build-up. coverage of this report was limited to effects of oil and grease on track and does not mention the problem of wheel-rail interface resistance. (7)
- G. In 1955, a U.S. railroad made available a report of their tests on the use of molybdenum disulfide as a lubricant to reduce wheel and rail wear. Tests were made to determine what effect molybdenum disulfide has on track circuit shunting. General observations made were that molybdenum disulfide did not prevent formation of rust on wheel and rails and secondly, it acted very much like rust and/or rail film build-up with respect to track circuit shunting. The report is similar in coverage as reference (7), except for the application of molybdenum. (8)
- H. In 1956, the industry (AAR) reported on a new "Check-in Check-out" type circuit used as a supplement to track circuit shunting for lightweight rail cars. This circuit utilizes elements of the intermittent inductive train control systems. The report does not deal with resistance variations in wheel-rail contact. (9)
- I. In the period 1956 through 1962 the Boston and Maine Railroad procured a fleet of 130 RDC cars from the Budd Company. This commuter rail fleet was the

largest amount of such units owned and operated by any single Class I U.S. railroad. A substantial number of these units were operated as single-units in revenue service. The following summarizes the modifications made to the wayside signal system and to the rail vehicle as a result of intensive field testing. Upon completion of these modifications RDC single-unit vehicles were successfully operated in revenue service on the routes so treated.

Modifications to the Wayside Signal System

1. All track circuits which had not previously been so designed were upgraded by the installation of resistors in relay end and had increased voltage applied to the rails.
2. Insulated joint stagger was decreased to 40 inches where cut sections came within operating limits of automatic highway crossing protection, especially gates.
3. Timing, utilizing 5 second thermal relays, was inserted in numerous track repeater relays and contain other relays at interlockings and in circuits operating automatic gates.

Number 1 above improved the shunting sensitivity of the track circuits. Numbers 2 and 3 were done to take care of the loss of shunt which occurs when a short wheel base car passes at high speed from one track circuit to the next. They also bridge over other momentary shunt losses. All track circuits so treated were found to shunt at a value well above the 0.06 ohm shunt required by FRA Rule 236.56.

Modifications to the Rail Vehicle

All cars operated as single units were equipped with an excitation circuit designed by the Budd Company. This circuit circulates a relatively high amperage 400 cycle current from wheel to rail and back to wheel on each truck. This breaks down the rail-wheel resistance and improves shunting very effectively. It does not have any adverse effects on conventional dc track circuits. However, it might be

undesirable to make use of this equipment with certain types of ac track circuits, especially those using dc relays and rectifiers..

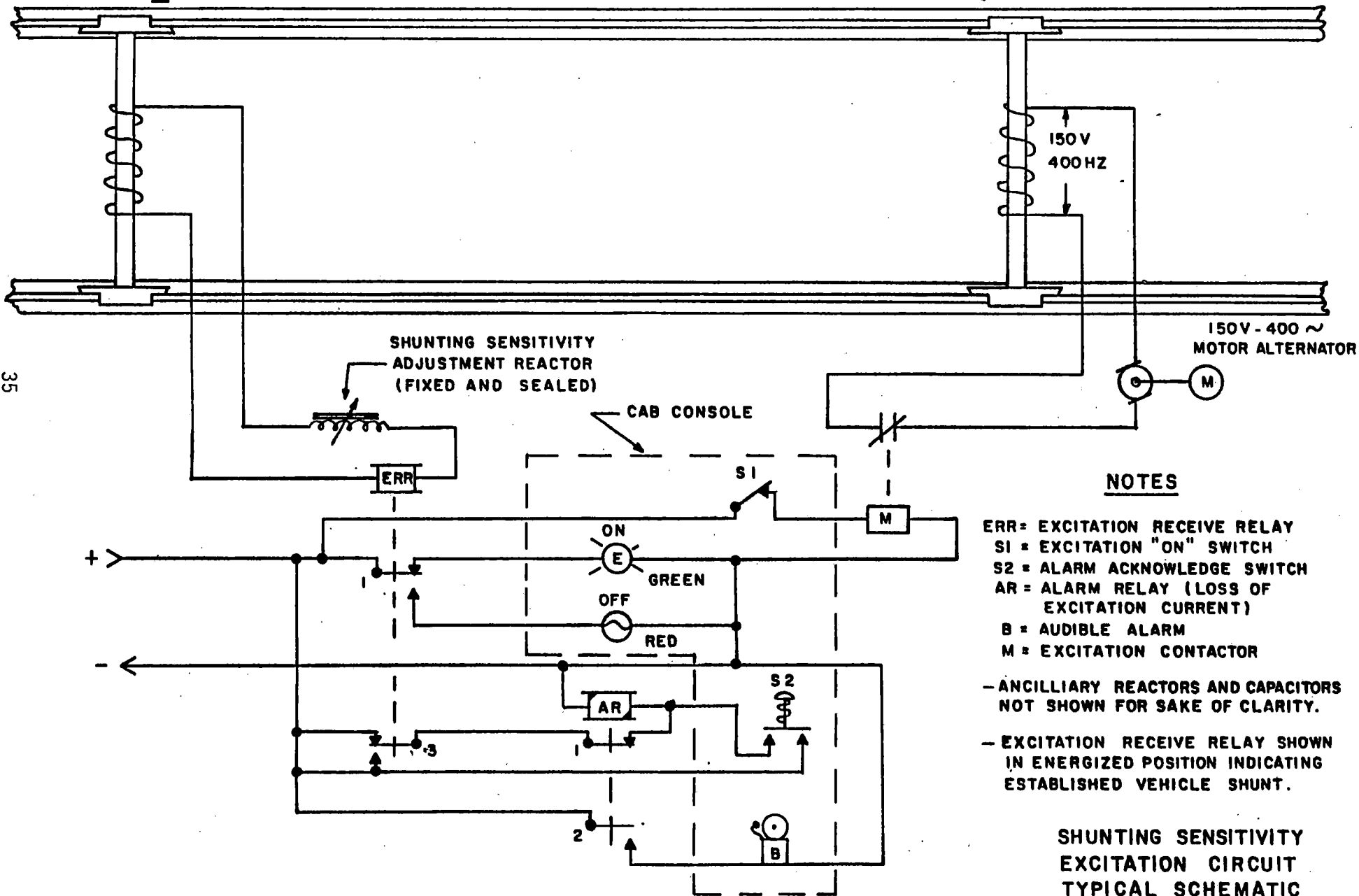
The excitation system was unique in that no "brushes", "additional wheel shoes", or similar mechanical parts, were required. The excitation system consisted basically of making the idler axle on each truck the secondary of a transformer. The axle transformer coils were suspended around each idler axle; power being supplied from a small on-board motor-alternator.

The combination of the: Lead-axle/both-running-rails/and rear-axle, acted as a one-turn transformer. The important development of this system, in addition to its success in ionizing the rail film, was that the engineer received a continual visual indication within his cab when he had an established shunt. If the vehicle/rail shunt dropped below a pre-determined safe limit, an audible alarm was effected that the engineer had to acknowledge. Usually a light braking action would quickly re-establish the train shunt. This cab-excitation-indication/alarm system was also effective if the on-board excitation equipment should malfunction.

Upon any sustained (over 5 seconds) malfunction of a rail vehicle's excitation, special railroad operating rules came into effect i.e., manual blocking, slow speed, reporting requirements etc..

It is evident, from a cost-effective viewpoint, that the cost of treating the vehicle(s) would usually be far less than that to treat all of the affected wayside signal track circuits, locking circuits, and associated apparatus and components. However, with this one notable exception, no other concentrated research and development has been done in an effort to solve the track shunting problem by treatment of the rail vehicle.

IDLER AXLES
LEAD & REAR TRUCKS
(INSULATED FROM CAR BODY)



- J. In 1958, an AAR report was issued on the effects of rail conditioner on track circuits. This report describes tests made on three railroads and the results obtained. While the effects of use of rail conditioner on track circuit shunting is discussed, there was no in depth study of the causes.(10)
- K. A new style track circuit, ET Hi - Shunt, was reported by the AAR in 1960. This circuit was developed to overcome shunting difficulties due to oil, grease, and wheel film on short detector track circuits as used in Classification Yards. The report describes its components and advantages but no attempt was made to analyze basic causes of poor track circuit shunting.(11)
- L. In 1962, a report was issued by the AAR which carried the results of a questionnaire to member roads in the matter of improved shunting of track circuits. This report covers, in detail, various applications of track circuit shunt improvement programs and the results obtained. Among the statements in this report is the following;
- "It is my belief that research would develop an economical arrangement to detect rapid fluctuations of a track circuit. In most instances moving equipment gives a partial shunt that fluctuates rapidly in value. This would be most useful as an adjunct to the standard neutral track arrangements".(12)
- M. As recently as 1978, special tests were conducted to determine shunting characteristics on a particular railroad. This report confirms that lightweight rail cars cannot be relied upon to shunt track circuits. It does not discuss the problem of electrical wheel-rail interface.(14) Again the results and conclusions are applicable only to the set of conditions at the particular test site. This emphasizes the requirement for basic research on the wheel-rail interface factors.
- N. A recent (1980) report, by a research group, (15) (Northrail Associates), generally concluded that little effort has been made in the last 20 years to improve shunting characteristics where lightweight single cars are used.

This report further concludes that there is no so-called "black box" available which would satisfy all the shunting requirements for single car operation.

III Summary

A review of industry developments, including efforts by individual railroads and other interested groups, does not disclose any scientific studies of the phenomena associated with current flow between the rail and the rolling wheel. A complete identification, analysis, and evaluation of all factors which contribute to an inadequate current flow between the rolling wheel and rail surface is necessary to develop methods to improve shunting sensitivity of lightweight rail vehicles. This can only be accomplished through adequate and documented research.

It is generally accepted practice to require special precautions in the operation of single lightweight rail vehicles in automatic signal territory, over interlocked track switches, in traffic control systems, and in approaches to automatic rail-highway grade crossing warning devices. Such precautions currently include absolute blocking and speed restrictions.

The significance of the track shunting problem is twofold;

1. The track circuit, because of its ability to detect the presence of a train is used to;
 - a. Retain switch points in proper position during approach and

passage of a train to prevent misrouting, collision or derailment of the train.

- b. Inform the engineer of the train whether he can proceed safely or should stop.
 - c. Control rail-highway grade crossing warning devices, i.e. activate the automatic flashing lights and lower gates at crossings to warn the highway traffic of immediate approach of a train and, after the train has cleared the crossing, place the devices in clear position to permit highway traffic to flow.
2. Secondly, the track circuit permits high speed operation, and real time control in centralized traffic train control applications and wayside signal automatic block territory thus becoming the single most important factor in efficiency of safe and train operation, an important factor in the competitive transportation picture.

Since the early 1970's, when the railroads were substantially relieved of the requirement to furnish passenger service, there has been no incentive within the industry to perform further research of track circuit shunting phenomena for the purpose of providing reliable and safe operation of lightweight single-unit rail vehicles.

VIII TASK 4 - RESEARCH RECOMMENDATIONS

I. Program Goals

It is a goal of the program to remove existing operational constraints for lightweight rail vehicle operation so that full benefits of this type of rail vehicle operation can be realized.

The intent is to develop, through research, an economical means of signal system and/or vehicle modifications to permit safe and reliable operation of lightweight, single-unit, rail vehicles over existing U.S. automatic block signaling systems.

II. Program Objective

The objective of this program will be to analyze and evaluate the barriers to compatibility of lightweight vehicle characteristics with those of the vehicle detecting portions of existing railway signal systems, and to outline suggested methods to achieve and establish such compatibility..

III. Recommendation for Suggested Research

In the majority of past cases, the lightweight rail vehicle has been introduced into the U.S. rail network without any structured technological consideration of its inherent deficiency to be reliably detected by the signal system. This deficiency resulted in permanent rule.

restrictions, by the carriers, being placed on such vehicle operation (in the interest of safety).

It is proposed that this analytical study be conducted in three distinct phases. The anticipated results of the study are expected to provide sufficient knowledge in establishing a tabulation of criteria for a given set of physical and electrical conditions.

PHASE I - Analyze Physical and Electrical Properties of the Wheel-Rail Interface.

1. Develop instrumentation and methods to determine the effects of wheel diameters, car weight, speeds, static, and dynamic resistances and similar factors.
2. Analyze the physical and chemical factors of the rail-wheel contact to determine those elements that tend to electrically isolate the wheel from the rail.
3. From the results obtained in (2) convert the identified barrier elements into electrical values from which basic design criteria for optimum track shunting sensitivity can be established.

PHASE II - Basic Electrical Design Criteria

The scope of this research is to establish minimum electrical values required for a sufficient track circuit shunt current flow.

1. The operation of the track circuit may be described as encompassing three states namely;
 - a) Unoccupied condition
 - b) Shunted condition
 - c) Fault condition

Abrupt temperature changes and effects of precipitation coupled with the quality of the road-bed directly influence the electrical values

of the track circuit components, and thus the track circuit operating current. Likewise, the composition and quality of the components affect the stability of the circuit.

1. Concerning the first condition, unoccupied, in order to derive research recommendations the following variables will require examination.
 - a) Define the unstable conditions which give rise to different electrical values, e.g. ballast conductivity.
 - b) Determine magnitude of such values and interactions resulting therefrom.
 - c) Determine range of adjustment values and limits of sensitivity.
 - d) Tabulate the results

From the tabulated results in d), determine ionization values (shunt) under variables defined. These values then can be adapted for nomographic presentation or for computer generated graphics. This information establishes the technological criteria for safe track circuit operation.

PHASE III - Research of Existing U.S. Rail Track Circuits

The purpose of this Phase is through research of devices and subsystems, remedial measures can be identified that could be applied to meet the technical criteria established in Phase II for:

1. Treatment of existing rail signal systems
2. Treatment of the vehicle

A considerable number of theoretical and empirical observations of existing track circuits in their natural environment have been made, but have stopped short of development, and research necessary to establish the design criteria as described in Phase II. Recognizing these studies were directed to the safe operation of single unit passenger vehicles, the problem becomes even more acute with the introduction of lightweight vehicles so equipped that attainment of a shunt is restricted to one axle. The LWV under demonstration is fitted with but one such axle.

Preliminary analysis reveals shunting is not compatible with existing U.S. signal systems. However, using the information gained from Phase II, the development of suitable corrective approaches for feasible solutions can be explored.

For example, vehicles equipped with excitation circuitry to achieve shunt current ionization (Black Box) may be one solution. On-board logic determination of an established shunt has already proven technically possible; an interface with the vehicles service braking system in case of sustained loss of shunt may be another viable safety solution.

To maintain this shunt (safe condition) research should identify one or more methods to restrict excessive chucking as well as necessary modification of lateral separation (stagger) of insulated joints to prevent joint hop. While it is expected that successful research will provide the necessary knowledge that will permit removal of operational constraints, the entire project and resulting findings must be progressed in accordance with established safeguards.

It is also recommended that applicable Federal regulations appearing in 49 CFR Part 236 be assessed as to their validity under the technical criteria developed under this project.

A P P E N D I X A - I

REFERENCE DOCUMENTS

APPENDIX A-I

REFERENCE DOCUMENTS

- (1) Necessary Modification of Direct Current Track Circuits in Detail or in Principle to Insure Reliable Protection of Rail Motor Cars of Passenger or Freight Carrying Type, AAR Signal Section Proceedings, April, 1938.
- (2) Methods in Use to Improve Shunting of Track Circuits, Progress Report, AAR Signal Section Proceedings, October, 1946.
- (3) New Developments in Methods of Improving Shunting of Track Circuits, Progress Report AAR Signal Section Proceedings, September, 1948.
- (4) Electronic Track Circuit, AAR Signal Section Proceedings, September, 1949.
- (5) Methods of Improving Shunting of Track Circuits, AAR Signal Section Proceedings, September, 1952.
- (6) Methods and Devices on Single Unit Self-Propelled Cars Equipped with Disc Brakes to Improve Shunting of Track Circuits, AAR Signal Section Proceedings, September, 1953.
- (7) Means and Devices Used in Oiling Procedures of Rolling Equipment to Improve Shunting of Track Circuits, AAR Signal Section Proceedings, October, 1955.
- (8) Effect of Molybdenum Disulfide Lubricant on Shunting Sensitivity of Track Circuits, AAR Signal Section Proceedings, October, 1955.
- (9) Improved Signal Protection for Lightweight Cars, AAR Signal Section Proceedings, September, 1956.
- (10) Rail Conditioner, AAR Signal Section Proceedings, September, 1958.
- (11) Style ET HI-SHUNT Track Circuit, AAR Signal Section Proceedings, October, 1960.
- (12) Report on Methods of Improving Shunting of Track Circuits, AAR Signal Section Proceedings, October, 1962.
- (13) R.B. Whalen letter July, 3, 1978 to Sam Maderia, The Budd Company, describing treatment of Wayside Signal System and Carborn Modifications to improve shunting sensitivity.

APPENDIX A-I (Con't)

- (14) Budd SPV 2000 Car Shunting Investigation, K. H. Frielinghaus, General Railway Signal Company, July, 1978.
- (15) Railroad Signal System Activation, by Budd Company RDC Units, North Rail Associates, March, 1980.
- (16) J.W. Hansen WABCO Letter, March 5, 1980 to Thomas P. Woll with attachments:
 - a) Engineering Letter #130, "Lightweight Railroad Equipment and Shunting of Track Circuits", September, 1954.
 - b) Supplement to Engineering Letter #130, March, 1955, Lightweight Trains with special reference to Operation of Signal System.
 - c) Supplement #2 to Engineering Letter #130, April 1955.
 - d) A Memorandum on Lightweight Trains, June, 1955.
 - e) Engineering Statement, Testing of Shunting of Lightweight Trains, Engineering Statement #43, December, 1956.

A P P E N D I X A-II

INDUSTRY DEVELOPED INSTRUCTION MANUALS

APPENDIX A-II

INDUSTRY DEVELOPED INSTRUCTION MANUALS

These instruction manuals concerning track circuits were developed by cooperative efforts of Railroad and Manufacturers of signal equipment as guidelines for employees.

1. Chapter 7, Non-Coded Direct Current Track Circuits, American Railway Signaling Principles and Practices, 1948.
2. Chapter XI, Coded Track circuits, American Railway Signaling Principles and Practices, 1951.
3. Chapter XXV, Coded Track Circuits, American Railway Signaling Principles and Practices, 1959.
4. Chapter XV, Block Signal Systems, American Railway Signaling Principles and Practices, 1955.
5. Manual Part 196, Train Shunt Resistance Test, Signal Manual, 1971.
6. Manual Part 132, Formula for Computing Minimum Allowable Resistance Between Track Battery and Track, and for Computing Related Current and Voltage Data, Signal Manual, 1951.
7. Manual Part 181, Adjusting ac Primary Battery Supply used with Non-Coded Track Circuits, Signal Manual, 1956.
8. Manual Part 59, Signal Requisites, Track Circuits, Signal Manual, 1967.

* Available from Communication & Signal Division, Association of American Railroads.

A P P E N D I X A-III

CONTACTS

APPENDIX A-III

CONTACTS

1. Mr. K.H. Frielinghaus
Senior Research Engineer
General Railway Signal Company
P.O. Box 600
Rochester, New York, 14624
2. Mr. R.B. Whalen
Vice President
Thomas K. Dyer, Inc.
1762 Massachusetts Avenue
Lexington, Massachusetts 02173
3. Mr. Ralph Horvath
District Manager
Thomas K. Dyer, Inc.
1901 L Street, N.W. -616
Washington, D.C. 20036
4. Mr. J. W. Hansen
Manager, Headquarter Sales
Union Switch & Signal Company
Westinghouse Air Brake Company
Swissvale, Pennsylvania 15218
5. Mr. Sam Maderia
The Budd Company
Red Lion & Verree Roads
Philadelphia, Pennsylvania 19115
6. Mr. J. W. Birkby
Commercial Manager
British Rail Research
Railway Technical Center
London Road
Derby, England DE 28UP

A P P E N D I X A-IV

SPECIAL AAR FORMULAS

APPENDIX

RAILWAY SIGNAL ASSOCIATION TRACK CIRCUIT STANDARD OF SAFETY 1917

Your Committee recommends that past practice of using a battery of three gravity cells in multiple (without added external resistance) and a 4-ohm R. S. A. relay be adopted as the basis of a standard of safety for track circuit operation.

The numerical value of this standard is represented by the maximum train-shunt resistance at battery end of track which will cause the 4-ohm relay to drop when the battery consists of three gravity cells in multiple.

Accordingly, your Committee recommends the following standard of safety for track circuit operation:

Maximum Train-shunt Resistance=0.06 ohm.

The recommended Standard of Safety was calculated by Formula I (the derivation of which is given below) making the following assumptions of the most adverse operating conditions:

Assumptions.

Ballast resistance=Infinity.

Resistance of wiring between battery and track=Zero.

Rail resistance=Zero.

Resistance of wiring between track and relay=Zero.

Drop-away current of 4-ohm, four-point relay=0.037 amp.

Instantaneous open-circuit voltage of one gravity cell, taken immediately after train shunt is removed=1.0 volt. (While the instantaneous open-circuit voltage of a gravity cell after a low discharge is 1.1 volts, a reasonable figure after the discharge caused by the train shunt is 1.0 volt. This value might be assumed as low as 0.92 volt or as high as 1.06 volts and still give a maximum train-shunt resistance of 0.06 ohm, when the gravity cell internal resistance is 1.0 ohm.)

Internal resistance of one gravity cell=1.0 ohm. (This value might be assumed as high as 1.10 ohms and still give a maximum train-shunt resistance of 0.06 ohm, when the gravity cell instantaneous open-circuit voltage is 1.0 volt.)

Symbols.

r = Relay resistance.

C_d = Drop-away current of relay.

g = Number of gravity cells in multiple.

r_g = Internal resistance of one gravity cell (when train is at battery end of track).

R = Resistance of complete divided circuit except battery and total resistance between battery and track.

R_c = Resistance of wiring between track and relay.

RR = Total resistance of both rails.

R_w = Resistance of wiring between battery and track.

S_s = Maximum train-shunt resistance at battery end of track to drop relay—Standard of Safety.

v_g = Instantaneous open-circuit voltage of each gravity cell taken immediately after train shunt is removed.

V_s = Voltage across train shunt when train is at battery end of track.

Derivation of Formula I.

Ballast resistance=Infinity.

(Assumption)

$$(1) V_s = (R_R + R_c + a) C_d.$$

(Ohm's Law.)

$$(2) V_s = \left(\frac{R}{r_g + R_w + R} \right) v_g.$$

(Fall of potential.)

$$(3) R = \frac{S_s (R_R + R_c + a)}{S_s + R_R + R_c + a}.$$

(Resistance of divided circuit.)

$$(4) C_d (R_R + R_c + a) = \frac{\frac{S_s v_g (R_R + R_c + a)}{S_s + R_R + R_c + a}}{\frac{r_g}{g} + R_w + \frac{S_s (R_R + R_c + a)}{S_s + R_R + R_c + a}}.$$

(Combining (1) and (2) and substituting (3).)

$$(5) = \frac{g S_s v_g (R_R + R_c + a)}{(r_g + g R_w) (S_s + R_R + R_c + a) + g S_s (R_R + R_c + a)}.$$

(Reducing (4).)

$$(6) g S_s v_g = C_d (r_g + g R_w) (S_s + R_R + R_c + a) + C_d g S_s (R_R + R_c + a).$$

(Reducing (5).)

$$(7) g v_g S_s - C_d (r_g + g R_w) S_s - C_d g (R_R + R_c + a) S_s = C_d (r_g + g R_w) (R_R + R_c + a).$$

(Collecting "S_s" terms.)

$$(8) S_s = \frac{C_d (r_g + g R_w) (R_R + R_c + a)}{g v_g - C_d (r_g + g R_w) - C_d g (R_R + R_c + a)}.$$

(Solving for "S_s".)

$$(I) S_s = \frac{(r_g + g R_w) (R_R + R_c + a)}{g \left(\frac{v_g}{C_d} - R_w - R_R - R_c - a \right) - r_g}.$$

(Simplifying (8).)

A P P E N D I X A-V

"TRACK CIRCUITS AND TRAIN DETECTION"

(A reprint of Chapter IV of "Principle of Electricity Applied to Signal and Train Control Systems" - prepared for FRA, January 1977 by Thomas K. Dyer, Inc./Author R.B. Whalen)

CHAPTER IV

TRACK CIRCUITS AND TRAIN DETECTION

Now that we have completed a review of basic dc and ac electrical theory, the next logical subject for consideration is the practical application of such theory to typical railroad and transit signal and train control circuits. An endeavor will be made to examine in more detail certain of the more common types of signal equipment and observe how these units are connected together to form working circuits. It is obviously impractical to consider all of the different kinds of apparatus used, or to analyze the varieties of circuit configurations required for successful railroad signal operation. We shall attempt, however, to cover typical safety circuits and concepts with which the F.R.A. Signal and Train Control Inspector is primarily concerned.

1. Track Circuits

As we all know, the track circuit forms the heart of any signal system. In the broadest sense, track circuits can be divided into two general classes - direct current and alternating current. Each of these families may be further sub-divided into numerous common sub-types with varying advantages, disadvantages and applications.

Before discussing track circuit types, it is advantageous to first investigate the physical parameters of a track circuit, regardless of what type power source is to be applied.

We know that any track circuit has a series rail resistance proportional to the size and length of rails between ends. A typical rail resistance, with good bonding, would be about 0.025 ohm per 1000 feet of track (2,000 feet of rail). We are also aware that all track circuits experience some leakage between rails, the value of which depends upon the resistance of the ballast and ties and atmospheric conditions. Ballast resistance is a constantly changing factor. During wet weather it may be as low as 2 ohms per thousand feet and during dry or frozen conditions it can range up to 30-40 or more ohms per thousand feet. Ballast leakage may be thought of as a sheet of electricity flowing between rails for the entire length of the track circuit.

If we were to impress an alternating power source, or a pulsed dc source, on a track circuit we would find that a series inductance is also present. An average value for this series inductance is about 0.5 henries per 1000 feet of track. With higher frequencies the

reactive component of track circuit impedance can be appreciable, consequently audio frequency track circuit receivers normally contain capacitive tuning units in order to tune the track circuit for resonance at the impressed frequency.

Thus, any track circuit has distributed along its entire length an infinitesimal number of series resistors and coils together with shunt resistors. The schematic representation of a track circuit with such an infinite number of components would be as shown in Figure 45, where the length of each section, 1 to 2, 2 to 3, 3 to 4, etc. is infinitesimally small.

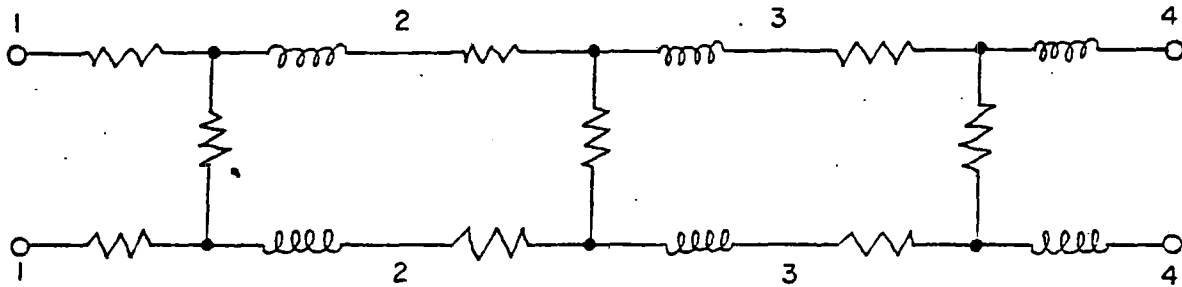


Figure 45

It is apparent that a diagram of a track circuit can not be drawn exactly correct and that for purposes of calculation, such a circuit would be exceptionally complicated. Since we are usually only concerned with values of current and voltage and shunting sensitivity, we can approximate a track circuit as shown in Figure 46. The convention, as used here, is to assume the ballast resistance as a lumped shunt resistor of a T - section network. For convenience all values are normally given, or calculated, on the basis of 1000 feet of track. For example, the total ballast resistance in parallel with the relay on a 6000 foot track circuit having a ballast resistance of 3 ohms per thousand feet would be $(3 \div 6) = 0.5$ ohm. The rail resistance or inductance would be the value per thousand feet multiplied by the length of the track circuit.

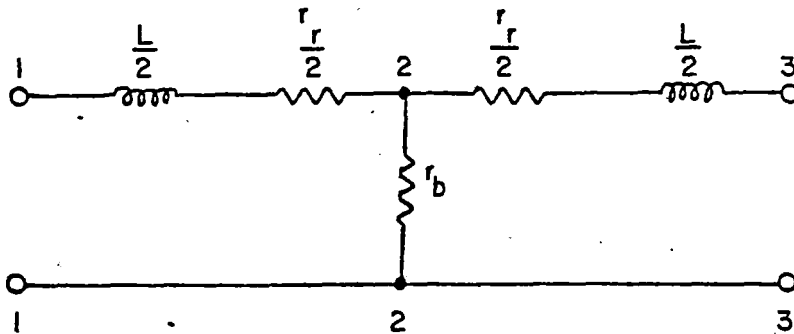


Figure 46

For a simple dc track circuit, the series rail inductance L can be neglected and the complete network would be as represented in Figure 47.

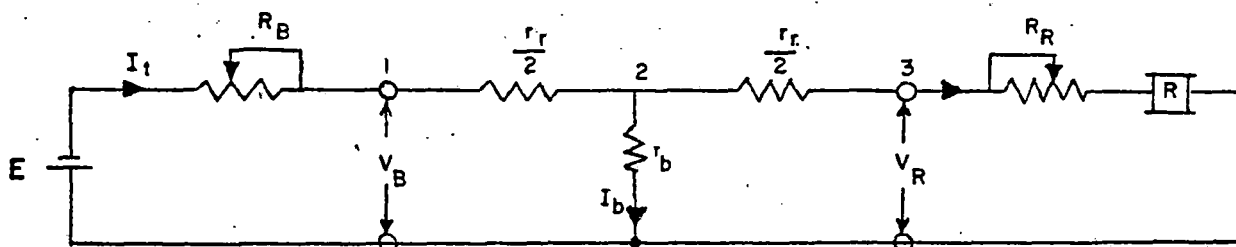


Figure 47

where:

V_B = Voltage across rails at battery end

V_R = Voltage across rails at relay end

r_r = Rail and bond resistance

r_b = Ballast resistance

R_B = Battery end limiting resistor

R_R = Relay end adjusting resistor

I_T = Total current to track circuit

I_b = Ballast leakage current

I_R = Relay current

E = Terminal voltage of battery

The voltage drop for the length of the track circuit is given by:

$$V_{1-3} = V_B - V_R$$

The average rail current is given by:

$$I_r = \frac{I_T + I_R}{2}$$

Therefore, for practical purposes, the formula for calculating Rail & Bond Resistance (r_r) is:

$$r_r = \frac{V_{1-3}}{I_r} = \frac{V_B - V_R}{\frac{I_T + I_R}{2}} = \frac{2(V_B - V_R)}{I_T + I_R} \quad (6.1)$$

In a similar manner, the distributed ballast resistance can be found by recognizing that the average voltage across the rails is:

$$V_b = \frac{V_B + V_R}{2}$$

and the ballast leakage current is:

$$I_b = I_T - I_R$$

Therefore, for practical purposes, the formula for calculating ballast resistance (r_b) is:

$$r_b = \frac{V_b}{I_b} = \frac{V_B + V_R}{2(I_T - I_R)} \quad (6.2)$$

These two equations (6.1 and 6.2) will be recognized as the two general equations for practical determinations of rail-bond resistance and ballast resistance.

In ac track circuits, the equation for rail-bond resistance (6.1) will be the series impedance of the track circuit (Z_r) and is equal to $r_r + j\omega L$. The dc component (r_r) is negligible in comparison to the inductive reactance and thus rail impedance for ac work can be considered as $X_L = 2\pi fL = Z \angle 90^\circ$.

2. DC Shunting Sensitivity

Shunt resistance of a train is, to a considerable degree, inversely proportional to the number of pairs of wheels in a given track circuit. The individual rail/wheel resistance is a highly variable factor, especially if there is rust, oil, sand or other types of film on the rail surface. Coded or pulsed circuits and conventional low frequency ac track circuits are superior in shunting sensitivity to a continuous dc circuit. This is due to the fact that a

fairly high peak voltage is required for each impulse in order to produce the necessary average operating voltage across the relay, and high voltage peaks are effective in breaking down most rail surface films.

However, regardless of the type track circuit, if the resistance of the multiple shunt paths afforded by the pairs of wheels exceeds the shunting sensitivity of the track circuit, a loss of shunt will occur. For a given ballast range, the longer the track circuit the lower will be the shunting sensitivity. In addition, the ratio of the highest ballast resistance to the lowest ballast resistance of a particular track circuit is a factor in shunting sensitivity.

Present FRA Rule 236.56 provides that the track relay be in a de-energized position if, when the track circuit is dry, a shunt of 0.06 ohms is connected across the rails. This test is usually made with a firm connection between the rails, and does not take into account the rail surface condition with rolling wheels. To demonstrate the importance of proper shunting sensitivity adjustment, let us analyze the effects of ballast resistance, train shunt and maximum permissible relay current.

The current through a track relay increases as the ballast resistance increases. As the current through the relay increases, the permissible value of train shunt resistance decreases - the relay becomes more difficult to shunt. It is, therefore, important that sufficient resistance exists in series with the relay so that the relay current will not rise too high with dry ballast conditions. It is also of prime importance that upon train shunt the total current from the battery does not rise to such a level as to permit the parallel component of this current flowing through the relay to be at or near the drop-away value. A portion of AAR Signal Manual Part 132 detailing formulas for calculating minimum allowable resistance between battery and track, to ensure maximum shunting sensitivity for various type relays and battery combinations, may be found in Appendix II.

The last and perhaps the most important factor in obtaining a low resistance rolling shunt is the required interrail voltage to break down (or ionize) the rail film. In other words, we wish to establish a wheel/rail contact by sufficient ionization voltage in order to reduce a potential rolling shunt of say 0.3 to 0.5 ohms to 0.06 or less ohms. Experiments with single unit equipment on glazed rails have determined that this minimum interrail ionization voltage should be in the range of 0.75 to 1.0 volts for steady dc track circuits.

3. Types of DC Track Circuits

DC track circuits are designed for a large number of uses and to operate under a variety of conditions. Some of the more common types and their characteristics may be briefly described as follows:

3.1 DC Neutral Track Circuits

This is the most common type track circuit encountered, and

with good ballast resistance may range up to about 6000 feet long. The source of EMF may be primary or storage cells or rectified ac, usually in the range of 0.6 to 2.2 volts. The neutral relay is normally 4 ohms and occasionally as low as 0.5, 1, or 2 ohms. The relay will pick up with either direction of applied track polarity. Track circuit rail polarities should be staggered at insulated joint locations in order to minimize the possibility of an adjacent track circuit battery falsely holding up a track relay in event of defective track circuit boundary insulated joints. With correctly adjusted track circuits the simultaneous bridging of a pair of insulated joints should cause both track relays to drop. A high-resistance bond wire in one track circuit could, however, defeat this feature with a train shunt between the battery and the high-resistance bond, if both insulated joints were broken down.

3.2 DC Biased-Neutral Track Circuits

This type track circuit is similar to a neutral dc track circuit except the relay is designed to only pick-up with proper track polarity. It's obvious advantage is in guarding against false pick-up from an adjacent track circuit battery if both insulated joints are electrically defective (provided a staggered track circuit polarity is maintained).

3.3 Center-Fed DC Track Circuits

This type track circuit is a modification of 3.1 or 3.2 in that the battery feed is located approximately midway of the track circuit with two track relays, one being connected at each end. Wayside control circuits are broken, in series, through contacts of each track relay. Progressive train movement shunts first one relay and then the other. The advantage over end-fed track circuits is that track circuit length can be approximately twice the former - an obvious advantage for long-block signaling in minimizing the number of insulated joints.

3.4 DC Polar Track Circuits

This type track circuit employs a pole-changing device (signal mechanism, relay or semaphore type pole changing contacts) on the feed end which can reverse direction of the track current. The relay arrangement consists of polar contacts in addition to neutral contacts. The polar contacts close in one direction or the other, dependent upon the direction of applied track current. The advantage of a polar track circuit lies in its inherent ability to provide 3-aspect signal control without the necessity of line control circuits. Polar track relays often include a retained feature (retained-neutral-polar "RNP") which prevents the neutral contacts from momentarily opening during a polarity change. If the RNP feature is not employed, usually a slow release neutral repeater relay is used to prevent "flipping" of signal aspects on signals to the rear of a particular track circuit.

3.5 Half-Wave Rectified Track Circuits

This type track circuit contains the disadvantage of not normally providing any track energy during ac power outages. The circuit

does provide better shunting characteristics than conventional dc track circuits for two interesting reasons. First, the voltage peaks are 2.82 times higher than the average dc level and thereby provide an excellent ionization voltage to break down rail film. Secondly, the induction of the relay induces a voltage opposite in polarity to the rectifier output. This negative track voltage acts between impulses of the rectifier output in an attempt to maintain current. As the ballast resistance increases the applied track voltage will, of course, increase but the negative track voltage incurred by the relay inductance will also increase. The net effect is that of almost automatic regulation so that with dry ballast the relay current will not be much higher than with minimum ballast resistance.

As shown in Figure 48, a bleeder resistor is required across the relay in order that at infinite ballast resistance the relay current will not drop below the working value.

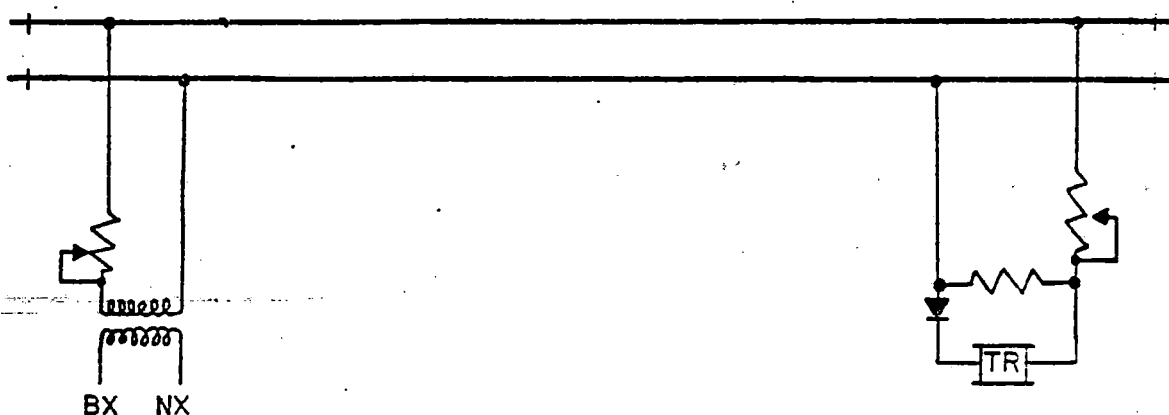


Figure 48

3.6 Coded DC Track Circuits (Non-Polarized)

Coded track circuits of any type have advantages over steady-energy track circuits in better shunting sensitivity, improved broken rail or poor-bonding detection, longer (up to 12,000 feet) track lengths and better protection against insulated joint failure and effects of foreign current.

With selective coding and de-coding apparatus, multiple signal aspects can be transmitted through the rails and thereby eliminate signal control line circuits. Coded track circuits can also form the command speed controls for continuous cab signal and train control systems with or without fixed wayside signals. Inverse coding can also be added to control vital circuits such as approach locking, block repeaters, etc.

Figure 49 on the following page illustrates a typical dc coded track circuit for a 2-block, 3-indication signal system without signal-control line wires. With track circuit 4 T and the next track circuit in advance of 4 T unoccupied, relay 4 HR is picked-up and will energize the 180-code rate transmitter. Code transmitter repeater relay, CTPR, will interrupt track current to the rails 180 times per minute.

At signal 2, code following track relay 2 TR will follow the code rate and code local energy to the decoding transformer which picks up relay 2 HR. This HR relay is made slow release in order to hold up during the off-time of the code-rate. The 180 coded energy from the output of the decoding transformer is also fed to the 180 decoding unit (180 DCU).

The 180 DCU is tuned for resonance at 180 pulses-per-minute (see Section 13 of Chapter III). If some other code rate were to be employed, say 120 pulses-per-minute, a similar decoding unit would be used except designed and tuned to only pass 120 pulses-per-minute.

With 180 energy, relay 2 DR will pick up from the current output of the 180 DCU. With both 2 HR and 2 DR UP, signal 2 will display a proceed aspect through local circuitry (not shown).

With 4 T occupied and 2 T unoccupied, relay 4 HR and repeater relay 4 YGPR will be down and apply local energy to the 75-code transmitter. The 75 code rate repeated by CTPR will feed a 75 code to the track rails. At signal 2, code-responsive relay 2 TR will follow the 75 code rate and through the decoding transformer will hold 2 HR in the up position.

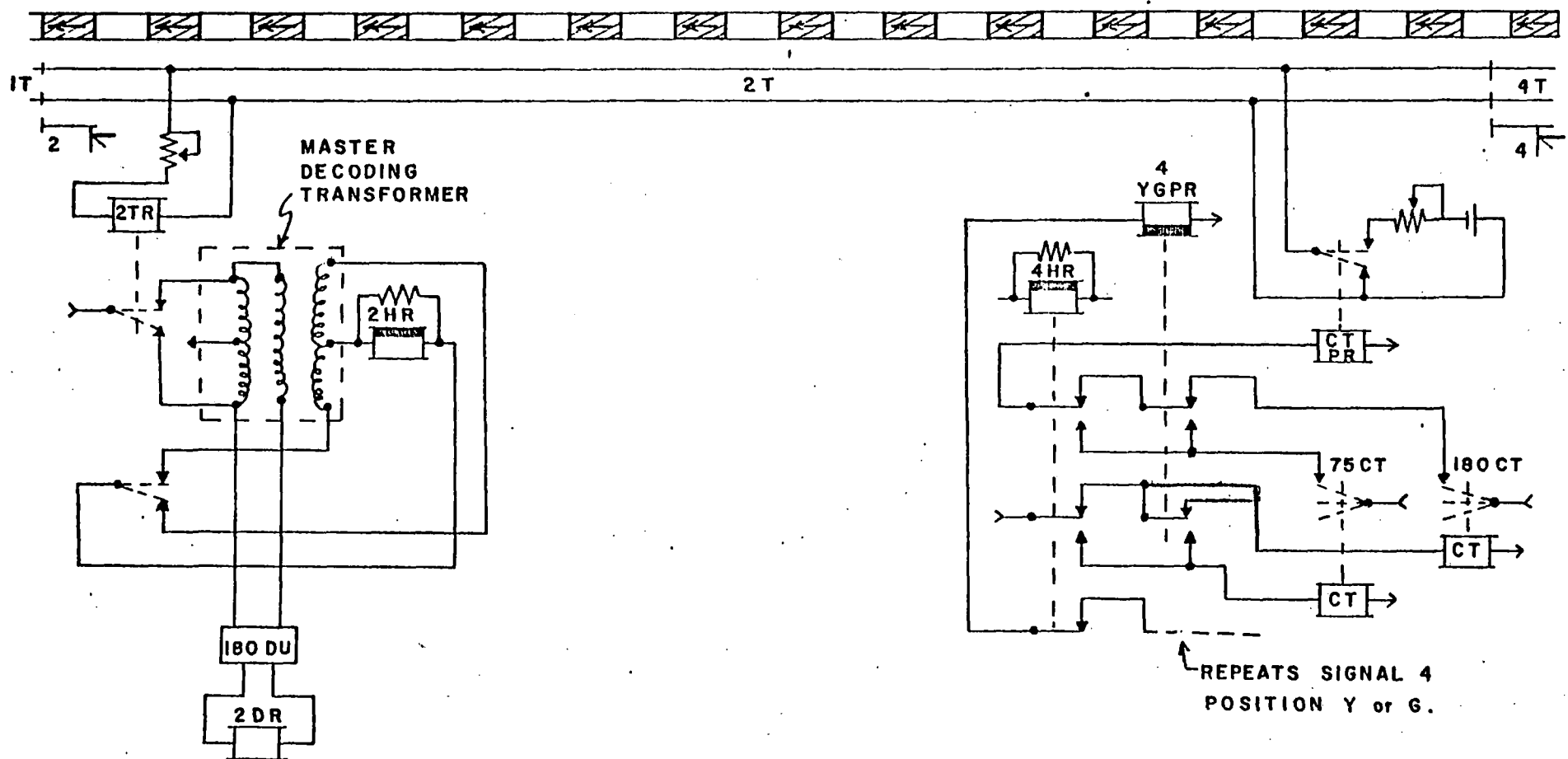
The 180 decoding unit (180 DCU) will not pass the 75 code rate and thus 2 DR will not pick up. With 2 DR down and 2 HR up, signal 2 will display an approach aspect.

With 2 T occupied no code-rated energy will reach 2 TR and both 2 HR and 2 DR will be down and signal 2 will display a stop aspect.

If we were to add a 120 code transmitter at Signal 4 together with local control circuitry, and a 120 de-coding unit together with a 2 BDR in multiple with 180 DCU, we could develop a fourth aspect for signal 2, such as an approach-medium, etc.

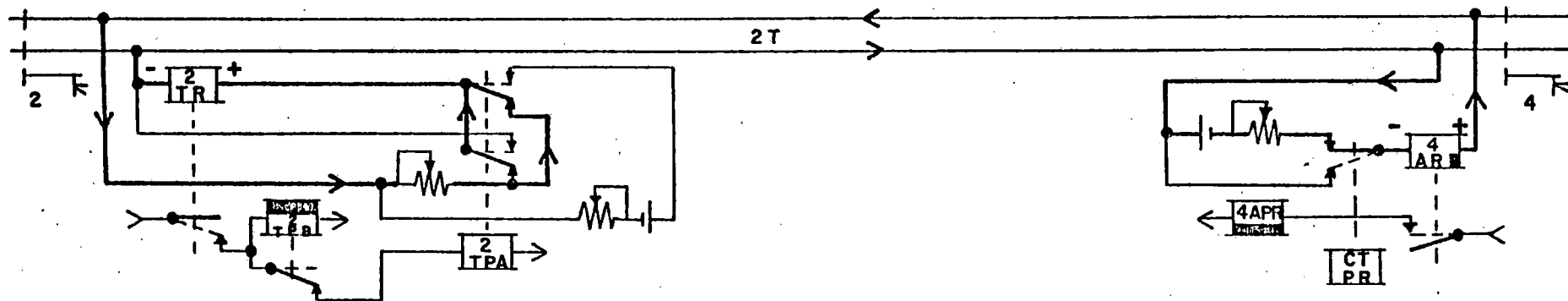
3.7 Inverse Coding

The foregoing description illustrated coded track theory for single-direction operation. In many cases it is desired to also have the train send information ahead of itself - in the opposite direction to the coded track circuit - without using line circuits. An example often encountered is block or approach indication and/or locking. This type is termed inverse coding. The "on" periods of such a code are transmitted during the "off" position of the direct (or independent) code. Figure 50 on page number 63 illustrates a typical circuit configuration for inverse coding. The top circuit shows the position of the relay contacts during the time of receipt of a direct code pulse,



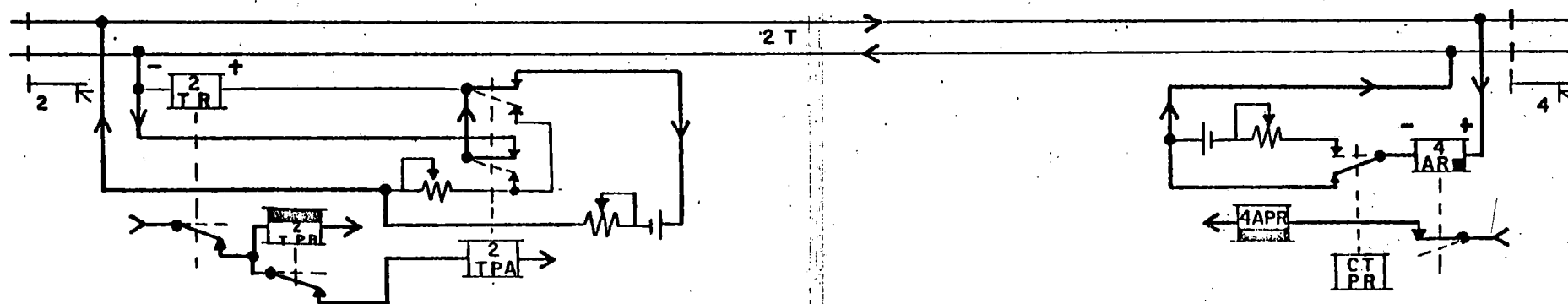
NOTE:
LOCAL CONTROL CIRCUITS
FOR SIGNAL 2 NOT SHOWN

TYPICAL DC CODED TRACK CIRCUIT
FOR
TWO-BLOCK, 3 INDICATION SIGNALING



TYPICAL INVERSE - CODE CIRCUIT
CURRENT PATH DURING A DIRECT - CODE PULSE

FIGURE 50-A



TYPICAL INVERSE - CODE CIRCUIT
CURRENT PATH DURING AN INVERSE - CODE PULSE

FIGURE 50-B

and the lower portion illustrates the same circuit with the relay contacts positioned during the generation of the inverse-code pulse. The heavy line indicates the portion of the circuit carrying current.

Referring to Figure 50-A, CTPR at the leaving end of the track circuit is picked up and allows current flow to the rails through series relay 4 AR. The 4 AR relay in this case is a polar stick relay, magnetically held in its last position dependent upon the last polarity direction.

At the entering end of the track circuit (signal 2), the direct codes pass through the back contacts of relay 2 TPA and picks up code-following relay 2 TR. With 2 TR up, a direct code impulse is applied to the master transformer and decoding units corresponding to the code rate being received. (These units are not shown for simplification, since their operation has been previously described.)

The lower circuit, Figure 50-B, is drawn to show the path of the inverse-code pulse. At signal 4, CTPR closes its back contacts thereby connecting the negative coil lead to the negative track lead.

Since the current of the direct-code impulse has ceased to flow, 2 TR will drop and apply current through its back contacts to both 2 TPB and 2 TPA. 2 TPA will pick up, but the slightly slow pick-up 2 TPB will not (during the time that 2 TPA is up).

During the short time that 2 TPA is up, a short impulse of inverse-code is applied to the rails governed by the time the 2 TPA front contacts are closed.

At Signal 4, the inverse-code pulse forces 4 AR to its normal position. 4 APR is thus picked up and is slightly slow to release so that the next inverse-code pulse will continue to hold it in the up position.

If a train passes Signal 2, 2 TR will be shunted 2 TPB will thus remain up, and 2 TA will stay down thereby stopping the generation of inverse-code pulses. Relay 4 AR will be driven to its reverse (down) position, and 4 APR will release. The release of 4 APR is then used for approach lighting, full block indication, approach indication, etc.

When inverse coding is employed to control approach locking, it is usually decoded at the interlocking by adding a decoding transformer with a slow-acting, vital relay connected to the output of the decoding transformer. With such an arrangement, the AR relay must be continuously pulsing in order to hold the vital APR relay energized.

Figure 51 illustrates the schematic wave shapes of direct and inverse coding. (See following page.)

Code-repeating cut-sections can be added to coded track circuits when required.

For single-track, double-direction operation, coded track circuits can be arranged to feed code impulses back and forth between head-blocks (ends of adjacent sidings). When traffic is initiated in one direction, all code transmission ceases at the entering end and all opposing signals will assume a stop position.

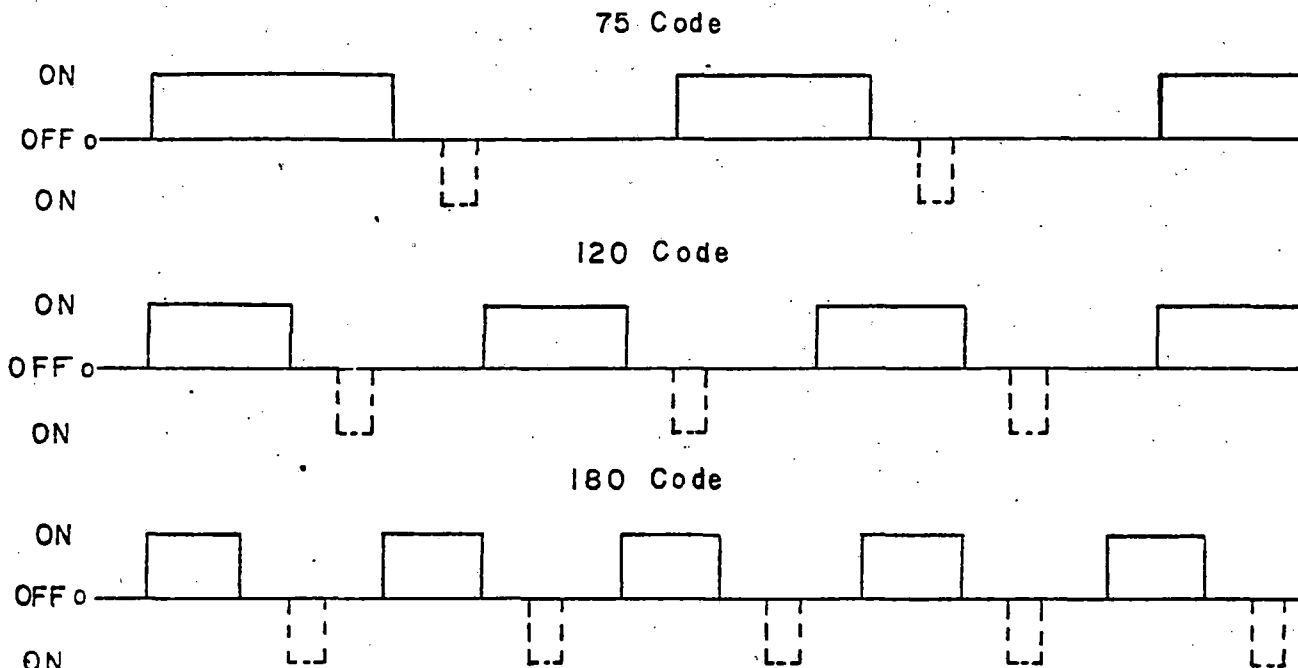


Figure 51

3.8 Polarized-Coded DC Track Circuits

This type of track circuit is somewhat similar to non-polarized dc coded track circuit theory, except that code pulse can be positive or negative and in addition can be paired. This results in four (4) possible characters that can be sent in each direction, i.e., a (+) code, a (-) code, a (+ -) code and a (- +) code. The code rate is slow, normally 33 per minute in one direction and 29 per minute in the other direction. Only one pulse is transmitted at a time in either direction. The "off" time between pulses is considerably longer than the "on" time (unlike conventional coded track circuits). This type of system finds application in both APB and TCS type signaling for full head-block to head-block-double-direction operation without signal-control line wires or line circuits for approach locking, etc. Track circuit length can be up to 12,000 feet long.

The polarity of a pulse is determined by conditions at one siding-end and transmitted via the rails to the first repeating cut section or wayside signal. At this point, the pulse is repeated, and may also be changed in character, to the next location, and so on, to the other end of the block at the next siding point (head block).

When the pulse is received at the second head block, a return pulse is automatically initiated to carry opposite-direction information back through the entire block. This type of code transmission is termed

independent coding for the first case, and dependent coding for the return code characters.

Codes received at intermediate signals are decoded and then position such signals to display the correct aspect. Any one of the four (4) codes may be used for this purpose.

A train entering (or the lining of a route into) a block prevents all transmission of code to the next headblock, thereby causing all opposing signals to assume a stop position.

The 33 rate is used for the "independent code," and the 29 rate for the "dependent," or follower, code. The rationale behind the use of two (2) different code rates is to prevent a "code-fight" somewhere within the block if both ends were to simultaneously transmit the same rate. With two different rates, the higher code rate dominates and the dependent code will be forced to follow receipt of the independent code.

4. Types of AC Track Circuits

Alternating current track circuits, or at least those that follow the laws of ac theory, can be broadly grouped into two general classes: Those using low frequency ac power and those that use a high frequency - usually in the voice range. The normal sub-divisions are as follows:

Low-Frequency AC Track Circuits (25, 60 and 100 hertz)

1. Non-coded using ac Track Relays
2. Non-coded using Rectifiers and dc Track Relays
3. Coded using Tuned Receiver units and dc Track Relays (for use with dc propulsion)

High-Frequency AC Track Circuits

1. Series Overlay Circuits, at fairly high (10,000 cps) frequencies used as a short track overlay circuit for automatic release section for electric locks, etc.
2. Approach Overlay Track Circuits, at voice frequency ranges (from about 900 to 5000 cps) used for approach warning for AHCP.
3. Audio-Frequency Track Circuits, at voice frequency ranges used for railroad and transit system wayside control. The AF track circuit is almost always coded and may also be a part of a stacked-group of coded frequencies applied to a common track circuit to generate wayside command speeds for automatic train control (ATC) systems, in addition to the train detection frequency.

4.1 Low Frequency AC Track Circuits

The applied current for low frequency ac power-type track circuits, in this country, is normally 25, 60 or 100 hertz obtained either from commercial power sources or manufactured by the carrier with motor-alternator sets or similar methods. AC track circuits were first necessitated by the advent of electrified propulsion, but are also used on steam railroads where a reliable source of ac power is available.

In electrified territory, whether alternating or direct propulsion, the traction-rail return power for double-rail ac track circuits must be allowed to flow around each insulated joint with a low resistance or impedance. The ends of each track circuit are therefore equipped with impedance bonds, consisting of a few turns of heavy copper wire wound around a laminated core, the terminals of which are connected to each rail, and the mid-point (center-tap) brought out for connection to a similar bond in the adjoining track circuit on the other side of the insulated joints.

Impedance bonds are designed so that traction power (direct current or low frequency ac), traveling in almost equal amounts in each rail, will pass through the coils of the impedance bond. This arrangement thus permits the flow of propulsion current between adjacent track circuits while at the same time retaining the ac signal current for operation of the track relay. In multiple track territory, cross-bonding is installed between impedance bonds in adjacent tracks to permit advantage to be taken of power return using the conductivity in all tracks. Such cross-bonding should only be done at intervals of 2000 feet or more, since too frequent cross-bonding could cause faulty signal operation (through leakage or run-around).

AC track circuits may be coded in a manner similar to dc track circuits. Some transit systems employ single-rail power-frequency track circuits in which case impedance bonds are not required since insulated joints are installed only in the "signal rail," the other rail being common for the signal frequency and the propulsion return current. Single rail track circuits are limited to short track circuits and find their widest application in interlocking plants in order to reduce bonding and insulated joints. The frequency used for the signal system should be as much higher than the propulsion frequency as economically feasible and not be a harmonic of the propulsion frequency.

AC track relays may be of the motor-driven type or of the vane type. The vane type may be either single-element or double-element. The motor-driven type is so constructed so that a small induction motor operates a contact bar with attached contact fingers. The operation is dependent upon two (2) separate stator windings, the currents in the two windings must be out of phase in order to produce rotation of the rotor. Maximum effect is obtained when the two currents are 90 degrees out of phase with each other.

A single-element vane type relay receives all of its current from the track circuit, while a two-element vane relay is constructed with both a track winding and a "local winding." The local winding is fed from a local ac source which supplies most of the energy required to operate the relay. Since the majority of the current required to operate a two-element vane relay is obtained through the local winding, track circuits employing such relays can be much longer than for single-element relays which must receive all of their current from the track circuit.

Single-element vane relays are always two-position type while two-element vane relays may be either two-position or three-position. For proper operation, the currents in the local winding and track winding of a three-position relay must be 90 degrees out of phase with each other. This phase displacement is obtained by adjusting the reactance of either the track or local control circuit. The third-position of a two-element three-position relay is obtained by a 180 degree phase displacement between the local and track currents thereby causing the relay to shift to its reverse position; this change in phase relationship is normally accomplished by pole changing the feed end of the track circuit.

Figure 52 illustrates a typical track circuit for use in dc propulsion territory. The tapped resistor is employed as a current limiter and for a method of achieving the phase displacement between the track and local currents in the two-element relay shown. This schematic also illustrates the use of impedance bonds for a double-rail propulsion return system.

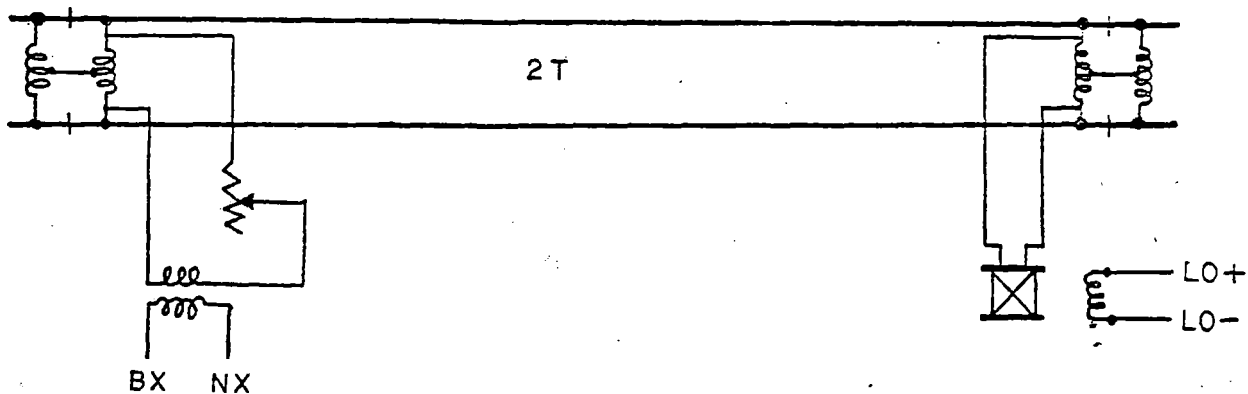


Figure 52

Figure 53 demonstrates the use of a three-position two-element relay with pole changing applied at the feed end and a common ac signal feed line in order to achieve proper phase relationship of the currents in the track relay windings. In electrified territory impedance bonds would be required at the track circuit boundaries.

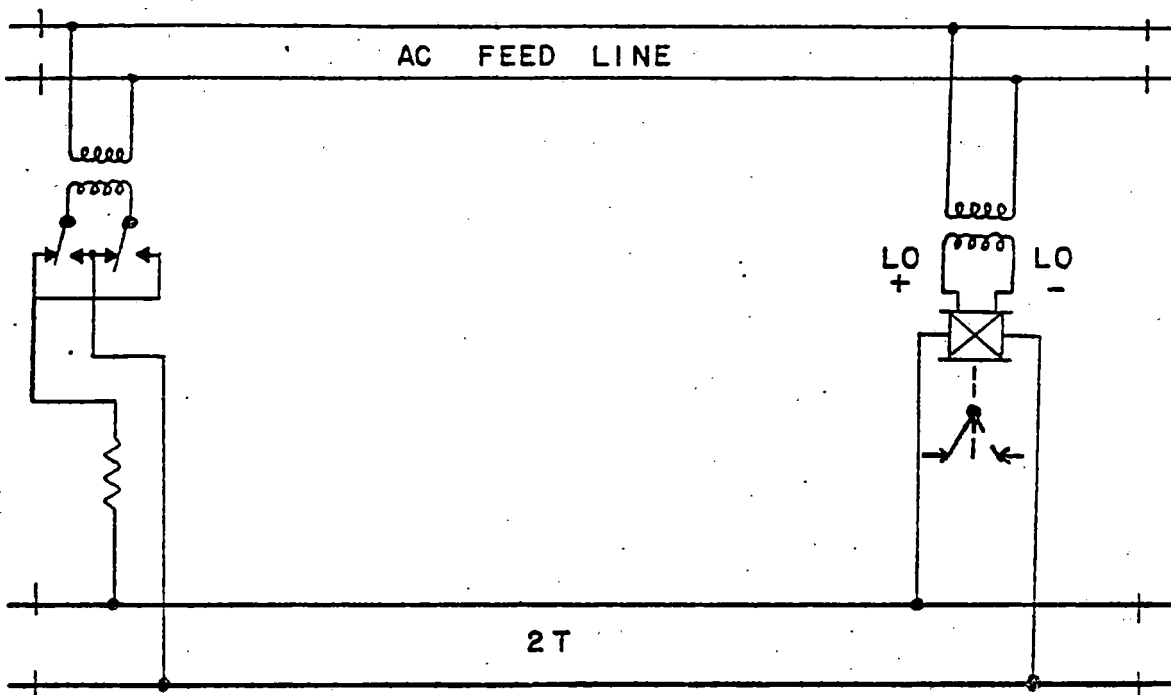


Figure 53

It is of prime importance in ac track circuit territory that the relative instantaneous polarities be staggered at insulated joint locations so that in event of a defective insulated joint the relay will not respond to the ac phase relationship from an adjacent track circuit. All ac track circuits should be fed from separate secondary windings because if two-track circuits were to be fed from a common transformer secondary winding, it would be possible that a broken rail would not be detected or that train occupying one circuit would affect the operation of another circuit.

4.2 High-Frequency AC Track Circuits

The low frequency track circuits previously described may be thought of as "power-frequency" track circuits basically following ac power theory. High-frequency AF track circuits, on the other hand, are more closely allied to communication or carrier circuit theory. With AF track circuits we are more interested in levels of power (in decibels) than we are in track voltage and current values. The other major consideration applicable to AF track circuits is based on the theory of tuned resonance for transmitter-receiver combinations.

4.2.1 Series Overlay Track Circuits

The series overlay track circuit is designed as a means to obtain release of an outlying electric lock with a short section of the main line occupied ahead of the switch points. The obvious advantage of such overlay circuits is the elimination of insulated joints required for conventional track circuit release sections. Series overlay track circuits consist of an oscillator and amplifier to generate the track frequency and a filter/receiver that can be tuned for resonance and peak current to pick-up a relay with a train shunting the track within the release section.

The impedance offered by the rails is, of course, directly proportional to the applied frequency ($Z = 2 \pi fL$). With a frequency normally in the 10,000 hertz range, the effective limits of such a track release section will not exceed about 200 feet, since the high rail impedance at high frequencies will sharply attenuate the signal level. Figure 54 schematically illustrates a series overlay track circuit. The tuner is adjustable in order that series resonance may be field adjusted for the particular track and ballast conditions. Occupancy, by a train, or by test shunt, will close points a and b resulting in circuit completion to pick up relay OLTR. Wayside signal circuits will open when OLTR contacts leave their back position and the electric lock will be energized with OLTR picked-up.

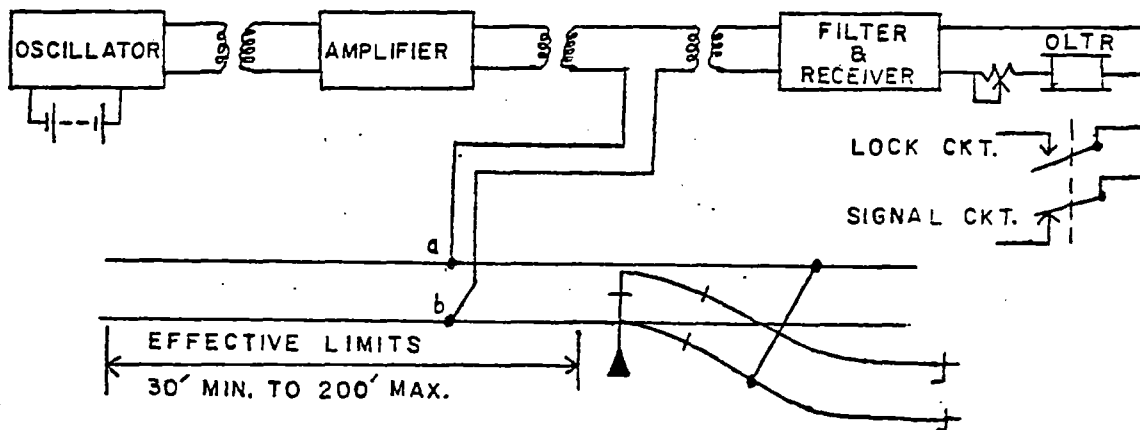


Figure 54

4.2.2 Approach Overlay Track Circuits

Approach overlay track circuits used for train detection to operate automatic highway crossing protection devices find a widespread application since such installations do not require insulated joints at track circuit boundaries. The approach overlay circuit is designed on a closed circuit principal, as opposed to the open circuit principal of the series overlay circuit. In order to obtain the distance required for advance AHCP warning time, the frequencies used are normally below 6 KHz, with the lower frequencies providing the greatest distance range.

Figure 55 (on the following page) illustrates a typical arrangement employing three (3) overlay track circuits. For proper operation, frequency interference between overlay track circuits within the same area must be avoided. A minimum separation of about 25,000 feet should be maintained between transmitters of the same frequency installed on the same track. Different frequencies should also be used on parallel tracks and care must be exercised in wiring to prevent crosstalk when a transmitter and receiver of the same frequency is installed within the same case. If a dc feed for an existing track circuit is within 300-400 feet of an overlay circuit a reactor must be added in the feed end of the dc track circuit to prevent the dc energy source from shunting the overlay circuit. The impedance of a relay is normally high enough to not require impedance compensation. In electrified territory and certain rectified ac track circuits, overlay frequencies must be chosen so as not to either interfere with the wayside signal system or to be susceptible to component frequencies or code rates generated by the wayside system.

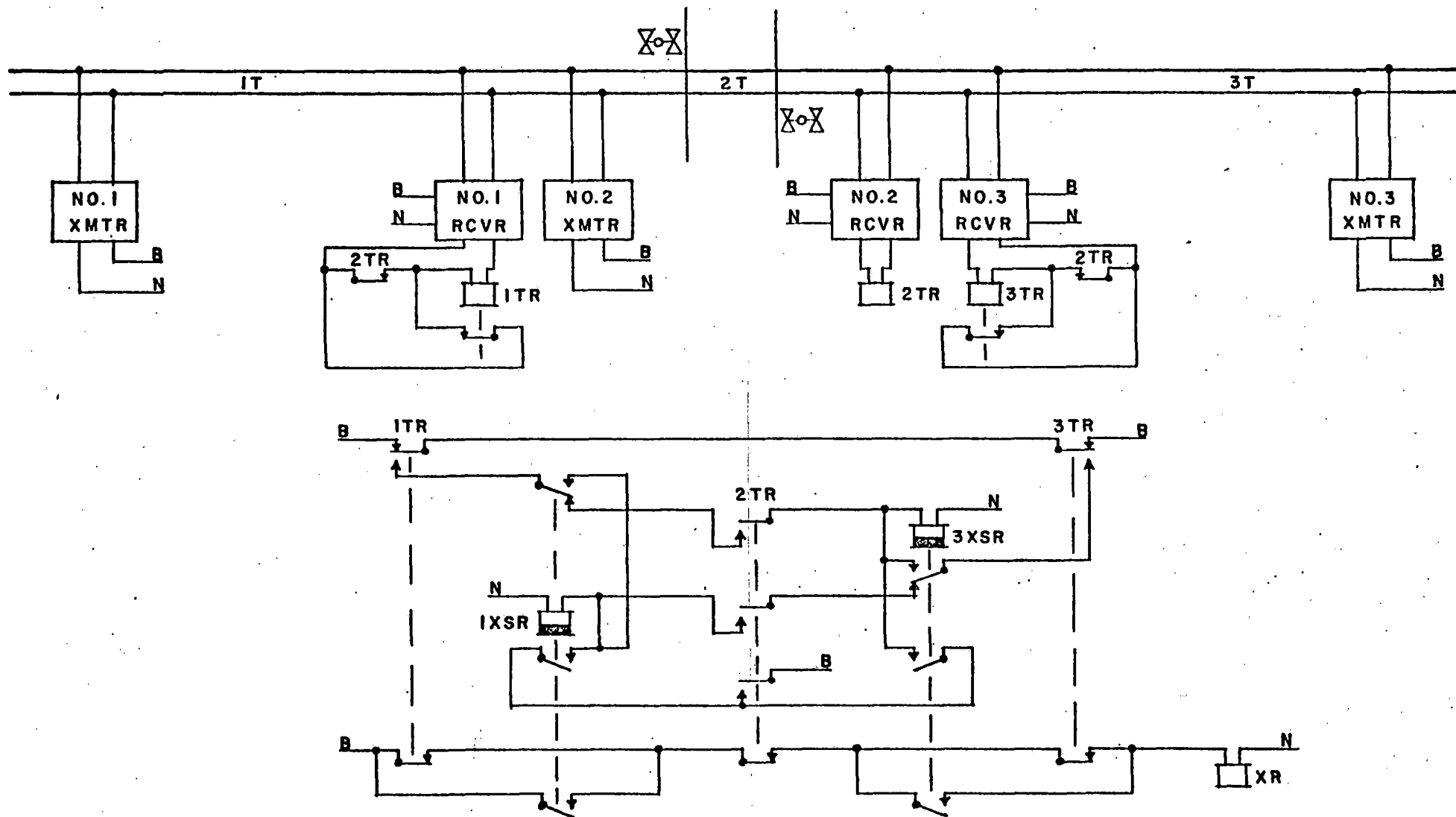
Figure 56 (on page 73) illustrates a block diagram for a typical frequency-modulated approach overlay track circuit consisting of a transistorized transmitter and receiver. The transmitter is composed of a high-frequency carrier oscillator, a low-frequency tone oscillator, modulator, filter, and amplifiers. The receiver consists of a tuned filter resonant at the carrier frequency, an amplifier, a demodulator, a tone-frequency selector and a full-wave rectifier to feed the resulting dc output to the overlay track relay.

4.2.3 Audio-Frequency Track Circuits

Within the past decade the advances in transistorized technology and printed circuit board manufacture have been responsible for the introduction of a virtual revolution in the type apparatus available for wayside signaling, automatic train control and automatic train operation. Transit systems, by virtue of heavy capital grant funding, have been the major recipients of these new systems. As in any new family of prototypes, some systems or component subsystems, are subject to reliability and safety problems, while others are already delivering results in system safety and high-speed close-headway operation beyond the capabilities of all-relay type conventional systems. Unquestionably, the experience gained in modern transit system train-control technology will rapidly find its way into signal and train control systems for steam-railroads, and thus present new problems and apparatus for the signal and train control inspector. For this reason, a typical solid-state automatic train control type transit system will be described.

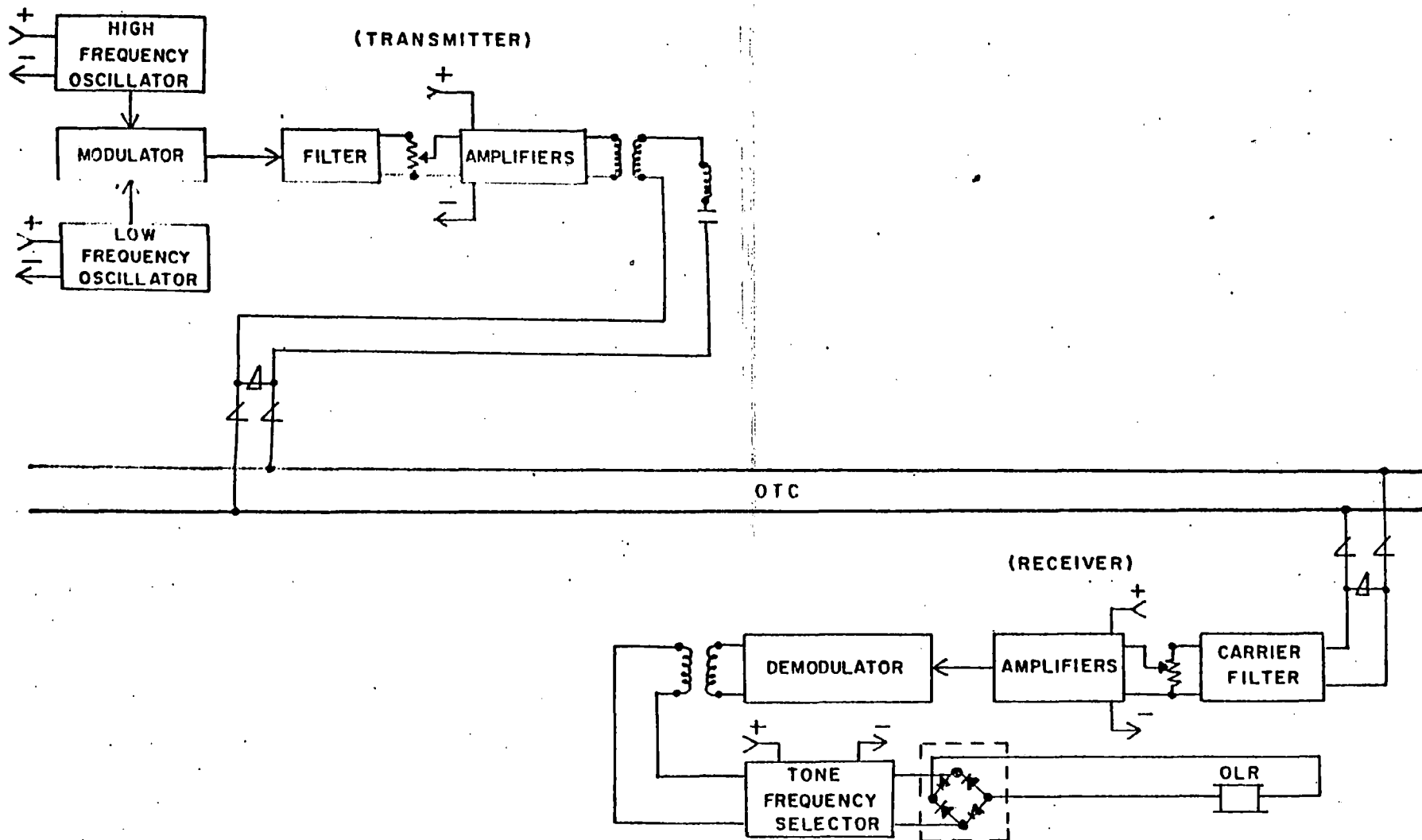
It should be borne in mind that the AF track circuit, forming the heart of such modern systems, is only a very distant relative of the AF overlay circuits for crossing protection with which the signal and train control inspector may be familiar.

The description herein is for electrified territory utilizing tuned miniature impedance bonds at track circuit boundaries without insulated joints, or wayside signals, except at interlockings. The maximum



TYPICAL CIRCUITS FOR AUTOMATIC HIGHWAY CROSSING PROTECTION
USING FREQUENCY OVERLAY TRACK CIRCUITS FOR APPROACH CONTROL AND ISLAND CIRCUIT

FIGURE 55



SCHEMATIC BLOCK DIAGRAM - APPROACH OVERLAY TRACK CIRCUIT

FIGURE 56

length of such an AF track circuit is about 1800 to 2400 feet at frequency ranges from 1000 to 6000 hertz. Within this frequency range, the rail impedance is sufficiently high to confine the overlap (or "slop-over") of adjacent track circuits within satisfactory boundary limits, insure a 0.06 ohm shunting sensitivity, and provide broken rail protection. To obtain the desired reliability and safety parameters, proper design and adjustment are of paramount importance - equal or exceeding that required for conventional signal/train control systems.

4.2.3.1 AF Track Circuit Boundary Definition

Figure 57-A, on page 75, shows a simplified track layout. Points A and B are the points at which a train shunt will be effective. The distances L_a and L_b between the rail connections and A or B is the overlap. An overlap occurs at each end of the track circuit, beyond which a track relay will not drop with a shunt applied between A and B.

The point of overlap (track circuit boundary) is primarily determined by: (1) The amount of over energization, (2) changes in ballast impedance, (3) the track circuit frequency, and (4) the impedance resulting from the parallel combination of a shunt and that of the impedance bond.

It would be possible to completely eliminate boundary overlap by over-powering the track circuit and making the impedance - bond impedance small in comparison to the desired 0.06 ohm shunt. Energization over about 200%, however, may defeat broken rail protection, while too low a bond impedance can cause a negative overlap which would result in a dead zone - an especially detrimental effect for continuous cab-signaling type automatic train control or detection of short trains.

The graph shown in Figure 57-B, on page 75, demonstrates the relationship between frequency, ballast impedance and over-energization. For example, the curve illustrates that at 2000 hertz, with infinite ballast impedance, and 100% over energization the overlap will be approximately 15 feet beyond the rail connection point. With the ballast impedance decreased to 5 ohms, the overdrive will reduce to about 60% and the overlap will increase to about 22 feet.

For a 5000 hertz circuit of the same length, the overlap would range from 12 feet at infinite ballast impedance to about 30 feet at 5 ohms for the same initial adjustment parameters.

Obviously, some over-energization is necessary to prevent the relay dropping out at low ballast impedance. Shunting sensitivity also depends upon the ratio of the resistance of the train shunt to that of the impedance bond. To provide a margin for changes in ballast and insure shunting sensitivity up to 200% overdrive, the resistance of the impedance bond should be at least three (3) times the shunt, or about 0.18 ohms. Within this balanced range, a properly adjusted AF track

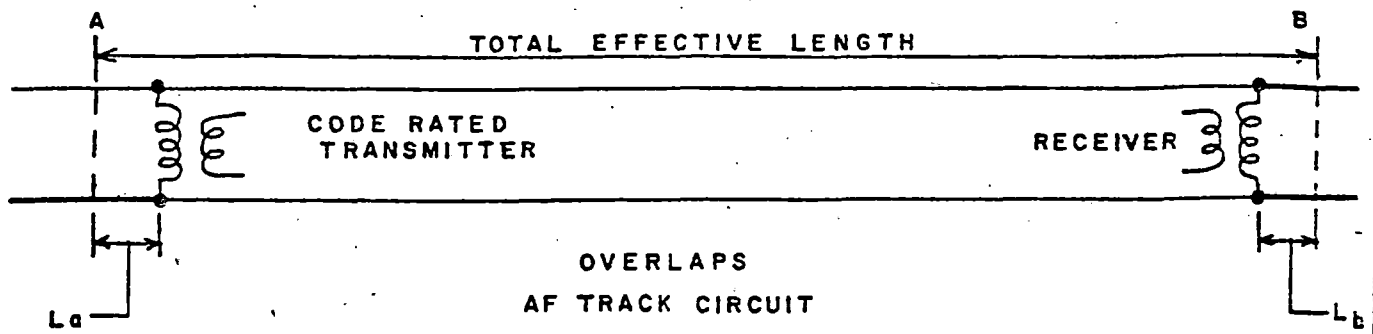
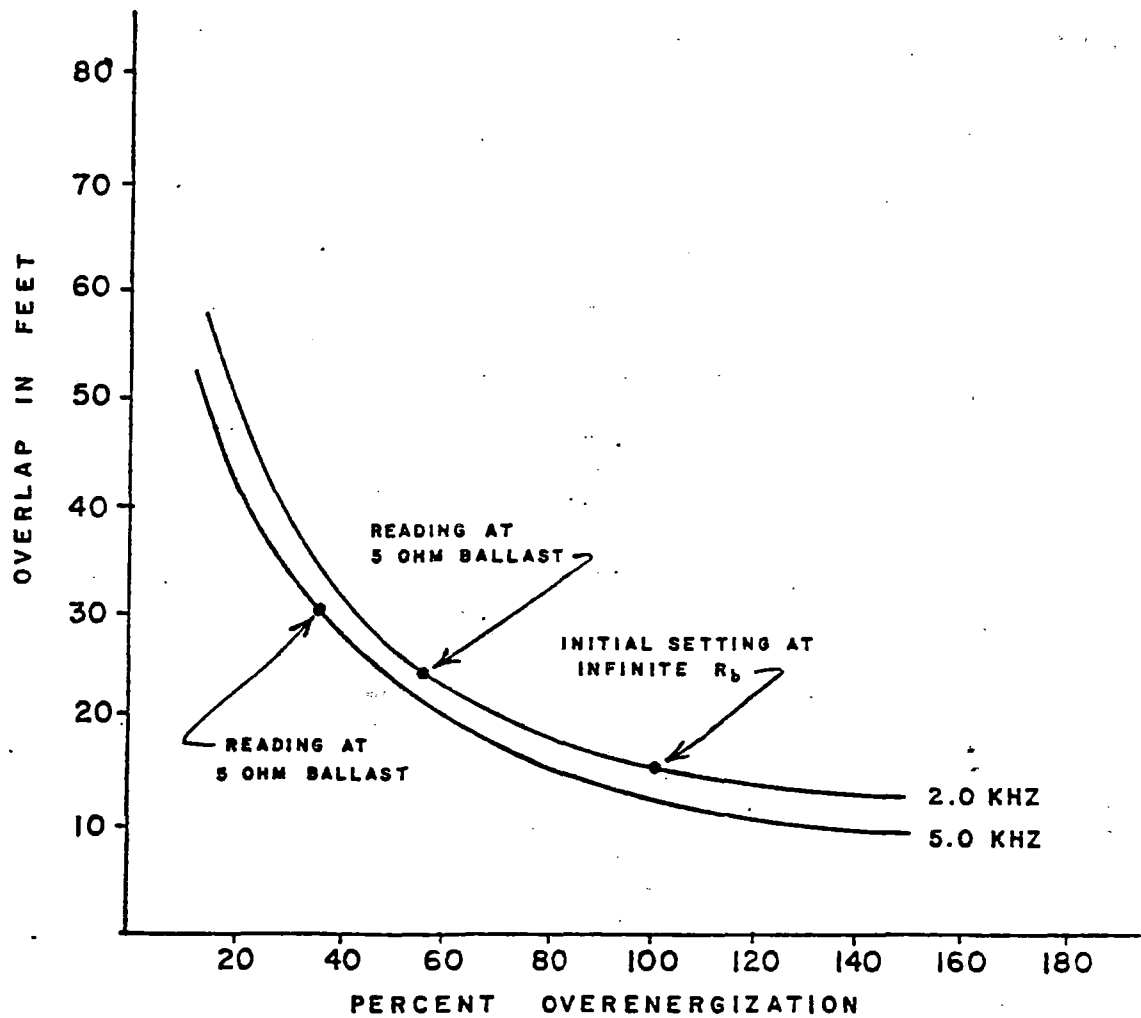


FIGURE 57-A



TYPICAL 2000 FT. AF TRACK CIRCUIT

FIGURE 57-B

circuit should provide an overlap range between 10 and 30 feet beyond the rail connections. With shorter track circuits and/or at lower frequencies, the overlap range will not vary much above the 10-foot mark, but for longer track circuits where the effects of ballast changes become more pronounced, the overlap range can be as much as 30 feet during low ballast impedance conditions.

4.2.3.2 Typical ATC - AF Track Circuit Operation

A typical transit-type ATC system employs a base group of train detection frequencies, such as f_1 , f_2 , f_3 , etc., applied to successive track circuits spaced so that a second f_1 transmitter is well beyond, or separated from, any other track circuit containing a f_1 receiver. These train detection frequencies are code-rated so that their receivers respond only to coded signals of the correct carrier frequency, and code rate. A typical system could be one utilizing ten (10) train detection frequencies with five (5) assigned to Track 1 and five (5) to Track 2. On each track, the five frequencies would be assigned to five contiguous track circuits in a sequential manner, and then repeated for the next five (5) circuits, etc.

A group of cab signal frequencies, separate and non-interfering with the main detection frequencies, is used to simultaneously send speed commands to an approaching train. The cab signal frequency is also code-rated and the combination of the cab signal frequency and code rates can provide a large number of speed commands. Normally six (6) to eight (8) speed commands will suffice for train speeds up to 80 mph. The wayside code selection for speed control is determined by the area of track occupancy ahead, safe braking distance, condition of the next interlocking, defined speed restrictions, automatic station stops (if used), and related input information.

The train-detection code-rated frequency is applied only to an unoccupied AF track circuit. Usually this rate is a low code rate such as 75 cpm. Upon train entrance, the dropping of the track relay turns on (or "gates") the speed command frequency and corresponding correct code rate. These code rates will range to higher assigned code rates dependent upon conditions ahead as determined by the wayside selection logic. AF track circuit boundaries, in transit terminology, are often called "gate locations".

Lightweight Vehicle Track Shunting, 1981
US DOT, FRA, Thomas K Dyer, Inc.

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