American Railway Signaling Principles and Practices

CHAPTER VII

Direct Current Track Circuits

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The Signal Section, American Railway Association, defines Track Circuit as: An electrical circuit of which the rails of the track form a part.

The track circuit is the most important link in the signal system. It is the medium of connection between the moving train and the signal or other device provided for its protection.

Its importance is attested to by the following excerpt from the Third Annual Report of The Block Signal and Train Control Board to the Interstate Commerce Commission, dated November 22, 1910:

> "Perhaps no single invention in the history of the development of railway transportation has contributed more toward safety and dispatch in that field than the track circuit. By this invention, simple in itself, the foundation was obtained for the development of practically every one of the intricate systems of railway block signaling in use today wherein the train is, under all conditions, continuously active in maintaining its own protection.
>
> "In other words, the track circuit is today the only medium recognized as fundamentally safe by experts in railway signaling whereby a train or any part thereof may retain continuous and direct control of a block signal while occupying any portion of the track guarded by the signal."

The essential parts of a direct current track circuit are the battery, rails, bonding, relay and insulated rail joints.

Various types and arrangements of batteries are used to provide the necessary energy or current to operate the track circuit and this feature will be dealt with more fully later in this chapter.

The rails of a track circuit provide an easy path for the flow of current from the battery, but this flow would be greatly retarded if it was necessary to depend entirely on the splice plates joining the rails together, hence, bond wires are applied to insure a path of low resistance from one rail to the other.

These bond wires are of different types, probably the most generally used being two or more No. 6 A.W.G. galvanized iron wires driven into the web of each rail by channel pins. Frequently, copper, copper-clad or copperweld wires are used instead of galvanized iron wires. These are used for either increased conductivity or due to local conditions where the bonds are subject to salt brine, gases, etc. Another type of bond used extensively is known as the stranded bond, being made up of several strands of galvanized iron, copper, copper-clad, copperweld or a combination of them welded to a steel terminal or pin which is driven into the web of rail after drilling a ⅜ inch hole. Another type bond uses two sets of several strands of the above welded to the same pin. Still another is a short copper bond welded directly to the head of rail. In fact, the method of bonding track circuits has and is receiving a very large amount of attention and study, and experiments are being made with several other types of bonds.

The relay used is fully described in Chapter VI and the resistances recommended for track relays are 2 and 4 ohms.

Insulated rail joints are applied at the limits of each track circuit, also at turnouts, crossovers, etc., to restrict the flow of current to certain predetermined limits. These joints are applied to the rails in place of the regular splice bars. Fibre, bakelite or other insulating material is used in these joints to insulate one rail from the other.

Historical.

As a result of certain railroad accidents, the desirability of providing a definite means to indicate the presence of a train to a following one began to receive very serious consideration, and about the year 1867, William Robinson, then a recent graduate from college, entered actively upon the development of an automatic signal system for preventing these accidents.

In 1869 he developed an elaborate model which he exhibited at the American Institute Fair in New York City, 1870.

This system was what is now known as a "wire" or "open circuit" system, that is, there were circuit instruments in proximity to the track which were actuated by the wheels of a car. The action of the wheels on an instrument at one point closed the circuit through a relay whose magnet was so arranged that the instant it was magnetized it attracted its armature and kept its own circuit closed. The circuit of the magnet which directly actuated or controlled the signal was under control of the relay which operated to open and close the signal circuit directly.

When the train or car proceeded to the proper point beyond, it actuated a reversing lever, thus opening the relay circuit and reversing the signals.

In the model described the reversing lever operated to open the relay circuit by cutting off the battery therefrom by short circuiting.

A short time after this exhibition an installation of the system was made at Kinzua, Pa., on the Philadelphia & Erie Railroad, now a part of the Pennsylvania Railroad. This was in 1870.

This installation performed satisfactorily after being placed in working order. It was, however, a normally open circuit wire system as described above in connection with the model.

Shortly after this system was placed in operation and accomplishing all claimed for it, Mr. Robinson, who aimed to be the most severe critic of his own work, entered systematically into a deeper study of the system from the standpoint of a railroad man with a view of finding the weak points, if any existed.

He soon discovered there were serious defects which, without exception, are inherent in all normally open circuit or wire systems of automatic signaling.

He found after a train had entered the section and set the signal behind it at "stop," that if the train broke in two and the forward part passed out of the section, the signal in the rear would clear and a following train would be given false information as to the actual condition of the track. A train might enter the section from the opposite end or from a siding, thus blocking the track, while the signal, not having been affected, would continue to show "proceed" as before. If a line wire broke or other connection be interfered with accidentally or maliciously, or the battery failed from any cause, the signal would invariably show "proceed" behind every train passing through the section.

Mr. Robinson at this early date recognized the above serious objection as inseparable from open circuit system of signaling, apparently, before these defects were recognized by any one else and at once entered upon the solution of the problem presented of eliminating these objections by producing a signal system which would meet all the requirements of safe and efficient railroading.

He reasoned that the first thing to do to accomplish this result should be to insure that every pair of wheels in the train must have controlling power over the signal throughout every inch of the block section.

He realized this could not be accomplished by any open circuit arrangement on the track and having used the short circuiting principle in his model of 1869-70, he concluded that this principle presented the only possible solution of the problem.

He then made drawings of the closed rail circuit system substantially as it is used today and in 1871 applied for a patent thereon, broadly covering the closed rail circuit system.

In 1872 he made an exhibition of this system at the State Fair held at Erie, Pa. When a car entered the closed rail circuit section it short circuited the current from the relay, releasing its armature. On running the car out of the section the current returned to the relay energizing the same.

The whole operation was perfect, demonstrating the successful operation of the closed circuit system and attracting great crowds of people as well as the marked attention of practical railroad men.

Mr. Robinson was requested to install this new arrangement at Kinzua, Pa., where he had already installed the open circuit wire system, and as all the apparatus was already in operation it took but a short time to convert this open wire system into a closed rail circuit system.

The first experiments proved conclusively that the system would work. The track, however, was in a very unsuitable condition for the purpose. The light rails were connected together by a 4 foot wooden bar on the outside and a 12 inch fish plate on the inside. There were two holes through the iron fish plate allowing one bolt for each rail and four holes through the wooden bar, two for each rail. However, with a little care he managed to get the current working through the whole length of the section, which was about 1¼ miles in length.

It was evident, however, that on such a section as this a rail bond of some kind would be necessary for reliable, continuous service, and here, at this time, in 1872, Mr. Robinson conceived the invention of the bond wire, or its equivalent, method of electrically connecting the rails as now in universal use on every electric railway throughout the world using the rails for a return.

The Robinson closed rail circuit which now forms the basis of every efficient automatic electric, electro-pneumatic and electrically-controlled fluid pressure system throughout the world, is illustrated in its typical form in Fig. 1.

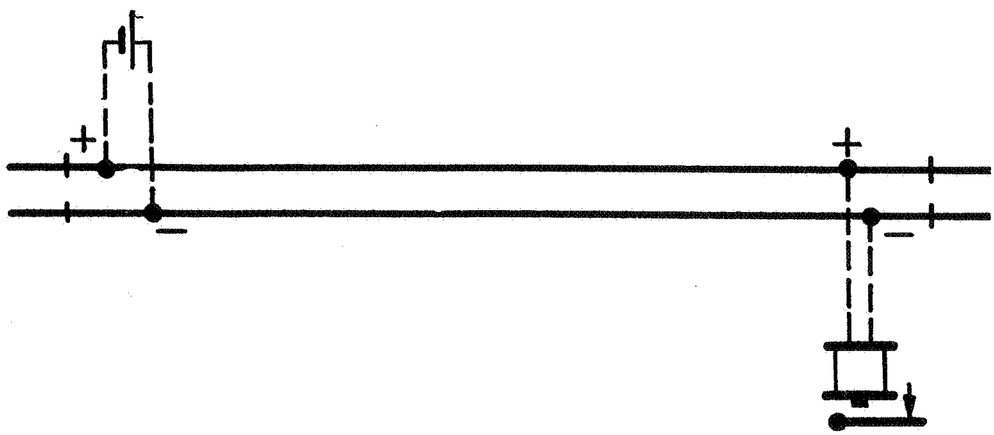


Fig. 1.
Typical Track Circuit.

Mr. Robinson obtained the patent on his track circuit in France, February 29, 1872, and in the United States on August 20, 1872, reissued July 7, 1874, No. 5958.

Operation.

The track is divided into sections, each section being insulated from the adjoining section by insulated joints. The sections vary in length as required, a typical section being shown in Fig. 1.

A battery has its terminals connected to opposite rails at one end of the section and at the other end a relay magnet has its terminals connected to opposite rails. Thus, the current passes through the whole length of the section keeping the relay on continuously closed circuit and magnetized as its normal condition. The relay thus keeps the secondary circuit, which directly controls the signal, normally closed.

When a train enters the track section the wheels and axles connecting the opposite rails thereof short circuit the current from the relay, which promptly releases its armature, thus opening the secondary circuit. As soon as the last pair of wheels passes out of the track section, the current will again flow through the magnet coils of the relay, causing the front contacts to close.

Figures 2 to 7 inclusive, represent other typical track circuit layouts, the symbols used being in accordance with those shown in Chapter II.

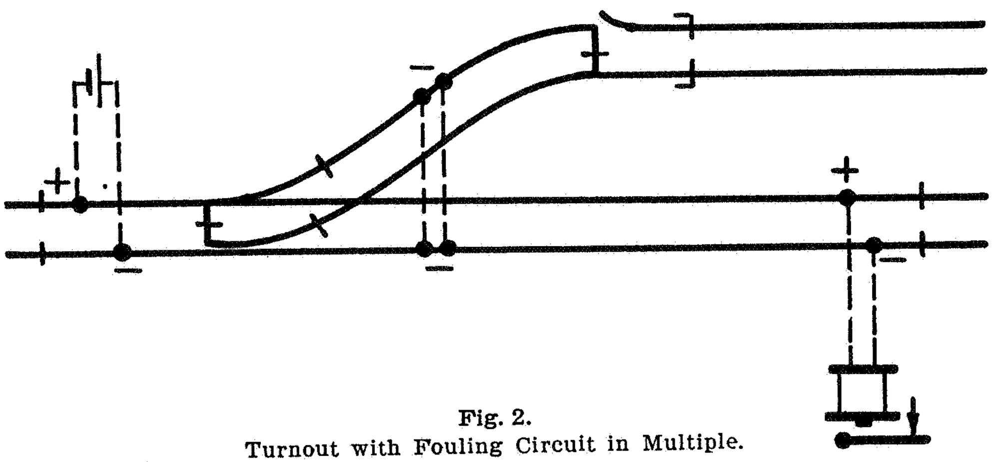


Fig. 2.
Turnout with Fouling Circuit in Multiple.

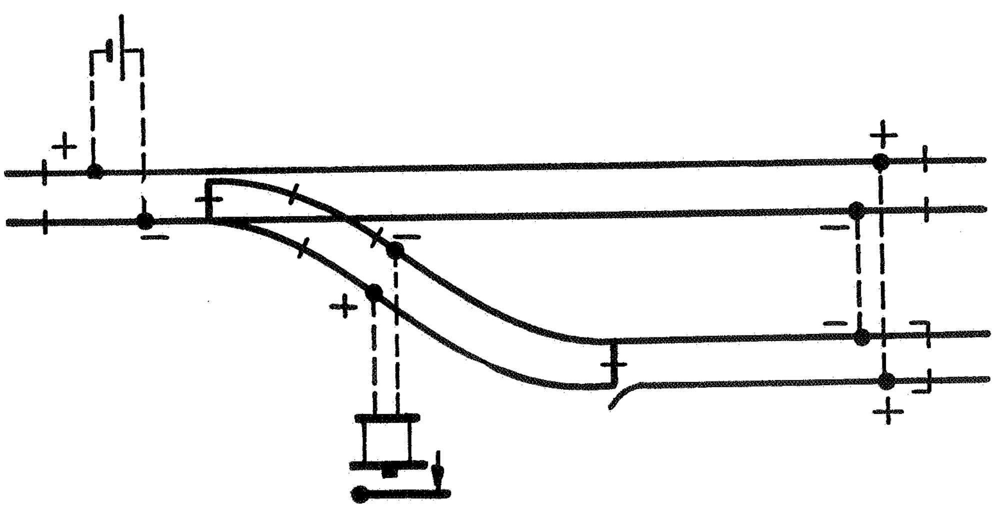


Fig. 3.
Turnout with Fouling Circuit in Series.

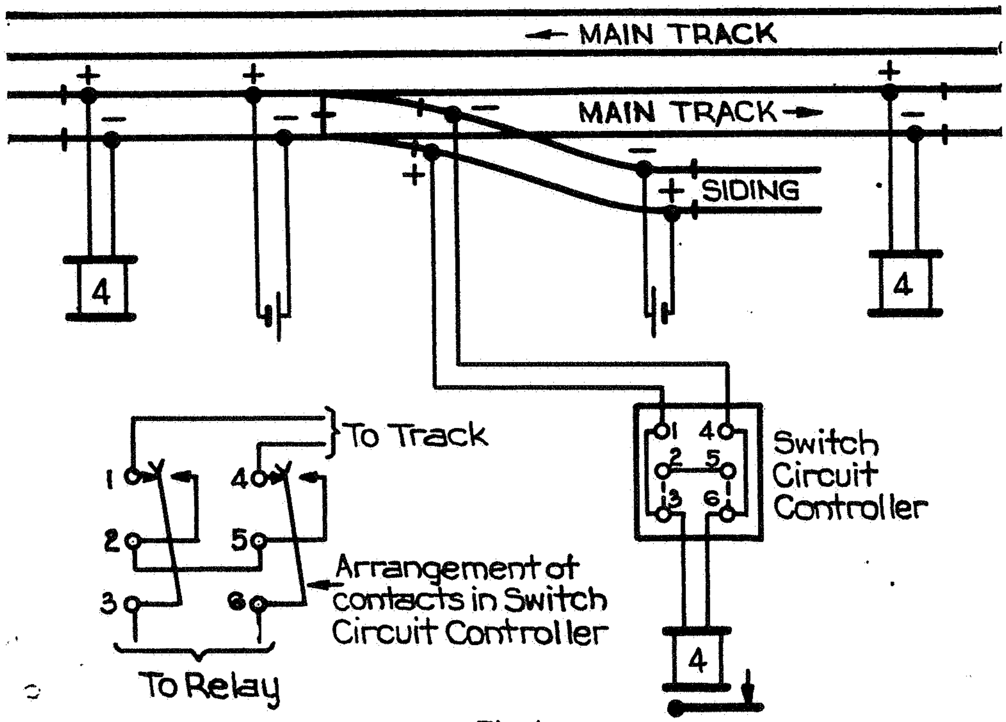


Fig. 4.
Turnout with Independent Track Circuit.

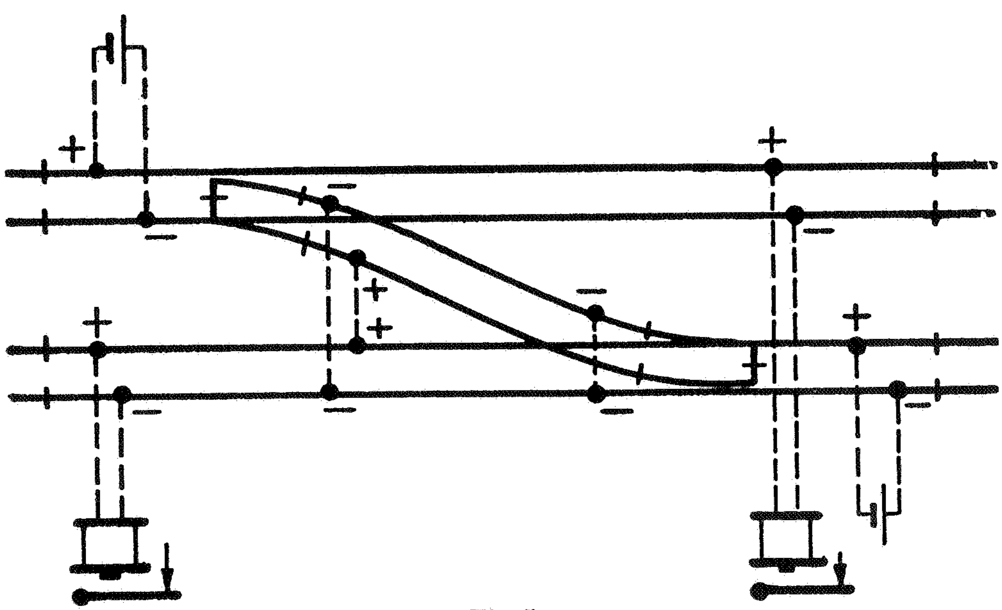


Fig. 5.
Crossover Between Main Tracks with Fouling Wires at Each End.

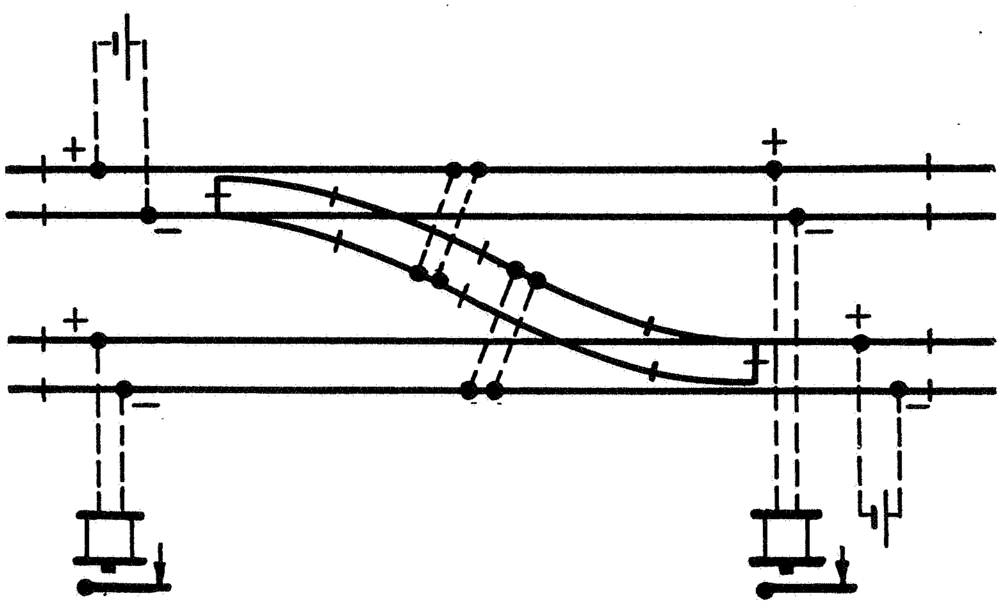


Fig. 6.
Crossover Between Main Tracks with Insulating Joints in Center.

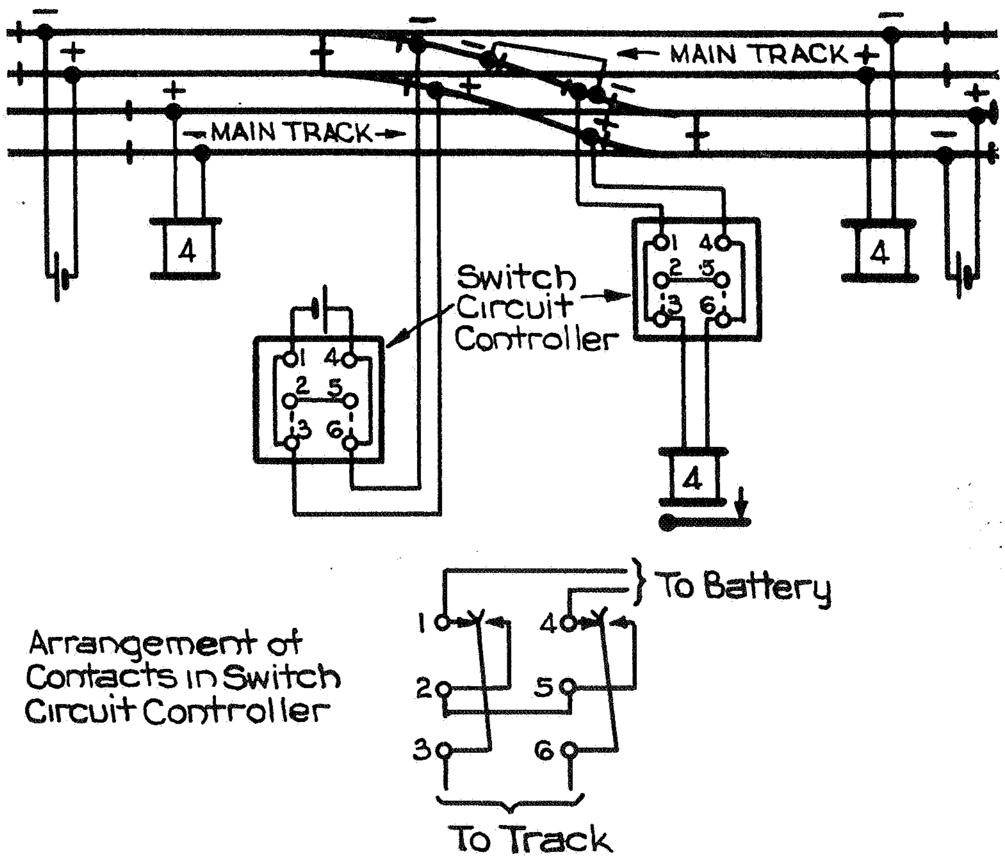


Fig. 7.
Crossover with Independent Track Circuit.

It will be noted that in Fig. 5 the fouling wires are arranged in such a way that a broken rail could occur or several rails could be removed between the limits of the fouling wires and the track relay remain picked up by the current following the fouling wires around the break or removed rails. While there were and possibly are many crossovers wired this way, the latest method of fouling is similar to that shown in Fig. 6 where broken-rail protection on the main rails is provided.

The ideal track circuit is one which has a minimum rail resistance and maximum ballast resistance. Very few track circuits, however, measure up to the ideal in the matter of ballast resistance.

Ballast resistance.

Ballast resistance is the resistance of the ballast, ties, etc., to leakage of current from one rail of a circuit to the other. Innumerable leakage paths exist, due to cinders, dirt, etc., touching base of rails and filling cracks in the ties. This resistance is constantly changing and may vary in dirty track circuits from 2 ohms per 1000 feet when wet to 80 or 100 ohms when frozen. It is this wide variation which causes most all the complications and makes it difficult to so adjust the track circuit that it will operate satisfactorily when the ballast is wet and not over-energize the relay when the ballast is dry or frozen.

It is frequently quite desirable to determine the ballast resistance of a certain track circuit. For all practical purposes the following method can be used: Take an ammeter reading in the positive lead from the battery, also an ammeter reading in the relay lead, then take a voltmeter reading on the track at the feed end, and a voltmeter reading on the track at the relay end. The reading of the ammeter and voltmeter readings should be taken simultaneously, if practicable, or at least within a few minutes of each other, and without the track being occupied between the readings.

The formula for obtaining the ballast resistance by the above method is:

$$R_b = \frac{\frac{1}{2}(E_1 + E_2)}{I - I''}$$

E_1 represents the voltage reading at the rails feed end
E_2 the voltage reading at rails relay end
I the amperes flowing from the battery
I'' the amperes flowing through the relay
R_b the ballast resistance.

As an example, assume that the meters indicated

0.8 volt at E_1
0.5 volt at E_2
0.300 ampere at I
0.115 ampere at I''

Then

$$R_b = \frac{\frac{1}{2}(E_1 + E_2)}{I - I''} - \frac{\frac{1}{2}(0.8 + 0.5)}{0.300 - 0.115} = 3.51$$

The ballast resistance for the entire circuit is therefore 3.51 ohms To determine the resistance per 1000 feet of track, multiply the resistance in ohms for the entire circuit by the length of the circuit in thousand feet. Thus, if the circuit in the above example is 4900 feet long, the ballast resistance per 1000 feet of track would be $3.51 \times 4.9 = 17.199$ ohms.

To determine the minimum ballast resistance of any particular track circuit, the measurements should be made immediately after a shower or late in the Winter or early Spring when ballast is wet from rain or melting snow.

Under the most adverse conditions the minimum ballast resistance should not be less than 4 ohms per 1000 feet of track for track circuits 4000 to 5000 feet in length. Shorter track circuits may be operated with ballast resistance as low as 2 ohms per 1000 feet of track.

Track battery.

In the early track circuit installations the gravity type of battery was used, chiefly because it was about the only available type, although it appeared to be peculiarly adapted for this purpose due to its high internal resistance, which prevented an excessive flow of current from the battery while the track was occupied.

In line with progress and economical conditions, other types of battery were tried on track circuit work as the gravity battery had certain shortcomings, such as requiring considerable attention to keep it in proper condition as well as the expense of obtaining blue vitriol, etc. At the present time, caustic soda and storage batteries have largely replaced gravity batteries.

These batteries are of low internal resistance and will withstand very wide variations in current output (low to moderately high rates of discharge) with scarcely a perceptible change in their terminal voltage, which results in the voltage of the battery being practically the same under both wet and dry weather conditions.

While this low internal resistance makes these batteries ideally suitable to track circuit work, it also makes necessary the maintenance of a certain amount of fixed resistance (either in the battery lead wires or a resistance unit placed in series with one of the leads) between the battery and the rails.

This fixed resistance answers the same purpose as the internal resistance of the gravity cell and its function is to limit the prohibitively high rate of current which otherwise would flow to the rails during the time the track is short circuited, when all other resistance save the unit and battery leads to rails are shunted from the circuit.

It is desirable to have the resistance of this unit as high as possible in order to obtain longer life from the battery, as the lower the resistance for a given voltage the higher the discharge with track occupied.

The Signal Section, A.R.A., has published tables and curves showing the minimum limiting resistance which is considered safe from a relay shunting standpoint and they are reproduced for the information of the student.

Tables of Minimum Limiting Resistance Allowable in Series with Track Battery

Table I

For 2-ohm relay—maximum of 35 milli-amperes flow through relay coils with rails shunted.

Minimum allowable resistance at battery, including wires—ohms	Range of Battery Voltage				
	0.06 ohm train shunt	0.04 ohm train shunt	0.03 ohm train shunt	0.02 ohm train shunt	0.01 ohm train shunt
0	0-0.06	0-0.06	0-0.06	0-0.06	0-0.06
0.1	0.07-0.16	0.07-0.21	0.07-0.26	0.07-0.36	0.07-0.66
0.2	0.17-0.26	0.22-0.36	0.27-0.46	0.37-0.66	0.67-1.26
0.3	0.27-0.36	0.37-0.51	0.47-0.66	0.67-0.99	1.27-1.86
0.4	0.37-0.47	0.52-0.67	0.67-0.87	1.00-1.27	1.87-2.47
0.5	0.48-0.57	0.68-0.82	0.88-1.07	1.28-1.57	
0.6	0.58-0.67	0.83-0.97	1.08-1.27	1.58-1.87	
0.7	0.68-0.78	0.98-1.13	1.28-1.48	1.88-2.18	
0.8	0.79-0.88	1.14-1.28	1.49-1.68	2.19-2.48	
0.9	0.89-0.98	1.29-1.43	1.69-1.88		
1.0	0.99-1.09	1.44-1.59	1.89-2.09		
1.1	1.10-1.19	1.60-1.74	2.10-2.29		
1.2	1.20-1.29	1.75-1.89	2.30-2.49		
1.3	1.30-1.39	1.90-2.03			
1.4	1.40-1.50	2.05-2.20			
1.5	1.51-1.60	2.21-2.35			
1.6	1.61-1.70	2.36-2.51			
1.7	1.71-1.81				
1.8	1.82-1.91				
1.9	1.92-2.01				
2.0	2.02-2.12				
2.1	2.13-2.22				
2.2	2.23-2.32				
2.3	2.33-2.42				
2.4	2.43-2.53				

0.05 ohm train shunt not necessary as for practical purposes 0.06 ohm or 0.04 ohm may be used.

Assumptions.

Ballast resistance = Infinity.
Resistance of wiring between battery and track = Zero.
Rail resistance = Zero.
Resistance of wiring between relay and track = Zero.

Maximum permissible current flow through relay with rails shunted for 2-ohm relay, 30 milli-amperes and for 4-ohm relay, 20 milli-amperes.

Table II

For 4-ohm relay—maximum of 25 milli-amperes flow through relay coils with rails shunted.

Minimum allowable resistance at battery, including wires—ohms	Range of Battery Voltage				
	0.06 ohm train shunt	0.04 ohm train shunt	0.03 ohm train shunt	0.02 ohm train shunt	0.01 ohm train shunt
0	0-0.08	0-0.08	0-0.08	0-0.08	0-0.08
0.1	0.09-0.21	0.09-0.28	0.09-0.34	0.09-0.48	0.09-0.88
0.2	0.22-0.35	0.29-0.48	0.35-0.61	0.49-0.88	0.89-1.68
0.3	0.36-0.48	0.49-0.68	0.62-0.88	0.89-1.28	1.69-2.48
0.4	0.49-0.62	0.69-0.88	0.89-1.15	1.29-1.68	
0.5	0.63-0.75	0.89-1.09	1.16-1.42	1.69-2.09	
0.6	0.76-0.89	1.10-1.29	1.43-1.69	2.10-2.49	
0.7	0.90-1.02	1.30-1.49	1.70-1.96		
0.8	1.03-1.16	1.50-1.69	1.97-2.22		
0.9	1.17-1.29	1.70-1.89	2.23-2.49		
1.0	1.30-1.43	1.90-2.10			
1.1	1.44-1.56	2.11-2.30			
1.2	1.57-1.70	2.31-2.50			
1.3	1.71-1.83				
1.4	1.84-1.97				
1.5	1.98-2.10				
1.6	2.11-2.24				
1.7	2.25-2.38				
1.8	2.39-2.51				

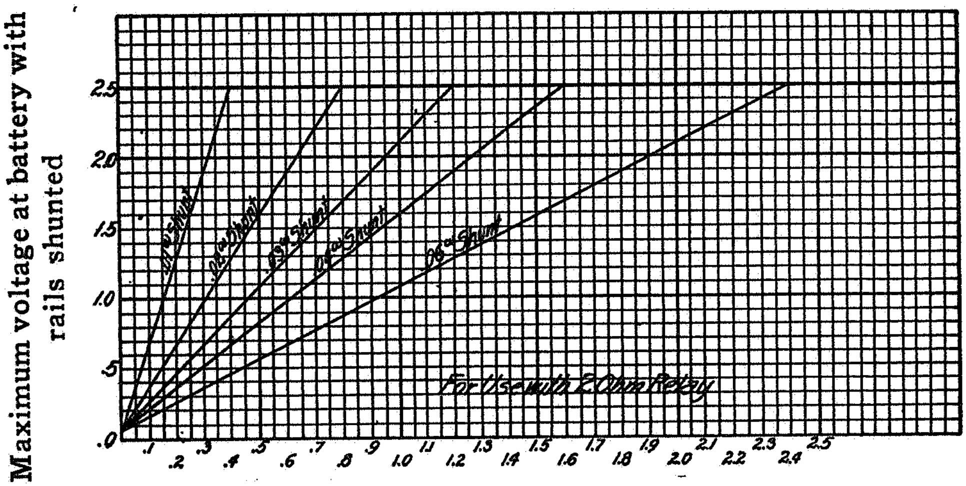
0.05 ohm train shunt not necessary as for practical purposes 0.06 ohm or 0.04 ohm may be used.

Assumptions.

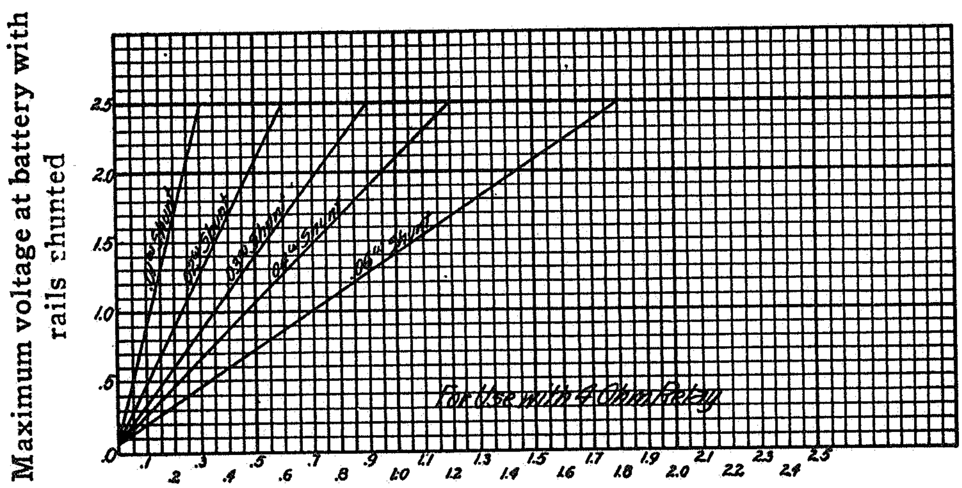
Ballast resistance = Infinity.
Resistance of wiring between battery and track = Zero.
Rail resistance = Zero.
Resistance of wiring between relay and track = Zero.

Maximum permissible current flow through relay with rails shunted for 2-ohm relay, 30 milli-amperes and for 4-ohm relay, 20 milli-amperes.

Curves for Determining Minimum Limiting Resistance Allowable in Series with Track Battery for Various Train Shunt Resistances and Various Battery Voltages



Minimum limiting resistance to be used between battery and rails, including wires.



Minimum limiting resistance to be used between battery and rails, including wires.

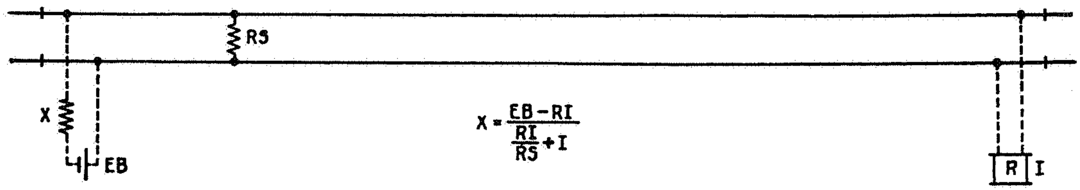
Assumptions.

Ballast resistance = Infinity.
Resistance of wiring between battery and track = Zero.
Rail resistance = Zero.
Resistance of wiring between relay and track = Zero.

Maximum permissible current flow through relay with rails shunted for 2-ohm relay, 30 milli-amperes and for 4-ohm relay, 20 milli-amperes.

Formula for Computing Limiting Resistances in Series with Track Battery

End Fed Circuits



Where:

R = Resistance of relay.
I = Maximum permissible current through relay with track shunted at battery.
RS = Resistance of track shunt.
EB = Maximum voltage across battery terminals with track shunted at battery end of track circuit.
X = Minimum resistance allowable between battery and track including wires.

Assumptions.

Ballast resistance = Infinity.
Resistance of wires between battery and track = Zero.
Rail resistance = Zero.
Resistance of wires between relay and track = Zero.

Maximum permissible current (I) through relay with track shunted:

30 milli-amperes for a 2-ohm relay.
20 milli-amperes for a 4-ohm relay.

Maximum battery voltage EB:

This voltage is determined for any make, number and arrangement of cells by measuring the terminal voltage when the battery is of maximum strength and when current discharge is as follows:

2.03 amp. when using a 2-ohm relay and 0.03 track shunt.
1.53 amp. when using a 2-ohm relay and 0.04 track shunt.
1.23 amp. when using a 2-ohm relay and 0.05 track shunt.
1.03 amp. when using a 2-ohm relay and 0.06 track shunt.
2.69 amp. when using a 4-ohm relay and 0.03 track shunt.
2.02 amp. when using a 4-ohm relay and 0.04 track shunt.
1.62 amp. when using a 4-ohm relay and 0.05 track shunt.
1.36 amp. when using a 4-ohm relay and 0.06 track shunt.

Where:

R $=4$ ohms.

I $=0.020$ amp.

RS $=0.06$ ohm.

EB $=0.24$ volt.

$$X = \frac{0.24 - (4 \times 0.020)}{\frac{4 \times 0.020}{0.06} + 0.020} = \frac{0.16}{1.354} = 0.118 \text{ ohm.}$$

The minimum resistance used should be not less than the value calculated.

Minimum allowable drop-away current.

The Signal Section, A.R.A., has specified that the minimum allowable drop-away current for track relays in service shall be:

(a) For 2-ohm relay—35 milli-amperes.

(b) For 4-ohm relay—25 milli-amperes.

The minimum drop-away current is given as shown to insure that the maximum train resistance shunt will permit of opening the relay with train at the battery end of circuit. It is desirable to have the drop-away value as high as possible and the train resistance shunt as low as possible, in order that the relay will open and remain open while the train is on any part of the track circuit. This also reduces the possibility of foreign current, that may be present in the rails, from picking up the relay with the train at the end of the track section farthest from the relay.

Arrangements of batteries.

As the voltages on the various track batteries vary, the limiting resistances will likewise vary, also different arrangements of connecting the batteries are used which cause variation in the resistances.

Ordinarily, where storage battery is used, a single cell suffices, due to the ampere capacity and voltage of the cell. Where caustic soda batteries are used they are generally connected in multiple or multiple-series. Where the track circuit is short, the usual arrangement is to connect two or more cells in multiple, which permits obtaining the full capacity of each cell. On track circuits of considerable length there may be various arrangements of cells, such as two cells connected in series with two or more similar sets connected in multiple, or one set of three cells in series with two or more similar sets in multiple. All these arrangements permit the disconnecting for inspection, renewal, etc., without interruption to the operation of the track circuit.

In arranging a track circuit, it is essential to maintain the proper voltage across the relay terminals for the entire life of the battery, which necessitates that consideration must be given to the peak as well as normal voltage of the battery, dry and wet ballast conditions, etc. Proper voltage across the relay terminals is such that will permit not less than the working current with minimum ballast resistance through the particular relay being used. An excessive amount of current through the relay may damage it or tend to produce residual magnetism, while if there is insufficient current the contacts will open, causing failures of one description or another. It is therefore essential for satisfactory operation that sufficient current flow through the relay to have it pick up and drop away properly under the most adverse conditions to which it may be subjected. If there is an excessive amount of current flowing through the relay, this would decrease the margin of safety for the drop-away of the relays, should the rails be coated with rust or sand.

The resistance unit connected in the battery feed lead is usually adjustable to permit regulating the voltage across the track relay terminals.

The relay and resistance units are quite frequently located a considerable distance apart and it is sometimes desirable to know what change in voltage takes place at the relay terminals when changes are made in the resistance unit. A simple method of determining this without making more than one trip over the section is given in the following: Determine accurately the present voltage across the relay terminals and then the voltage across the rails at the battery end of the circuit. Both readings should preferably be taken on the same scale of voltmeter, time between trains being selected to prevent a change in rail resistance. Also the readings must be taken under identically the same ballast conditions. After securing these readings, any change made in the voltage at rails of battery end, due to changes or adjustments in the total resistance between battery and rails, will give the same percentage increase or decrease in voltage at the relay terminals. In other words, if the voltage at the rails of the battery end is raised or lowered one per cent, the voltage across the relay terminals is also raised or lowered one per cent. For instance, suppose the voltage across the relay terminals was found to be 0.49 and the voltage across the rails at battery end was 0.55. By a slight lowering of the resistance between battery and rails the voltage across rails is raised to 0.57. This increase represents $\frac{0.57}{0.55}$ or a multiplying factor of 1.0363, and 1.0363 multiplied by 0.49, which is the original voltage across relay terminals, yields 0.508, which is the new voltage across the relay terminals. Again, suppose the voltage across the relay terminals was found to be 0.51 and the voltage across the rails at battery end was 0.57. Then by a slight increase in the resistance between battery and rails the voltage across the rails is lowered to 0.55. This decrease represents $\frac{0.55}{0.57}$ or a multiplying factor of 0.9649, and 0.9649 multiplied by 0.51, which is the original voltage across relay terminals, yields 0.49, which is the new voltage across the relay terminals.

During the early stages when gravity batteries were used generally for track circuits, track relays of various resistances ranging from 4 to 16 ohms were in use. Often on one maintenance section three or more different resistance relays could be found. Usually, the short track sections were equipped with the high resistance relays, while long sections used the lower resistance. Instead of merely adjusting a variable limiting resistance unit, such as those now in use, it was frequently necessary to change the entire relay or substitute other coils in order to adjust the individual circuit.

With the use of caustic soda and storage battery and the limiting resistance, practically all track relays in the ordinary track circuit have 2 or 4 ohms resistance, the thought being that there is greater economy of battery current, greater length of track circuit that can be properly operated and that more reliable shunting will be accomplished.

Taking into consideration the various elements entering into a track circuit, such as length, ballast resistance, etc., it follows that the combination of a low voltage at the battery and low limiting resistance unit result in a more nearly constant voltage at the relay terminals, as between the wet and dry ballast conditions, than does the higher voltage and higher limiting resistance units. The change in ballast resistance is about the most variable condition to contend with in track circuit work.

Formulae on resistances, etc.

The Signal Section, A.R.A., has also prepared certain formulae for making measurements on track circuits, the more important of which are: To obtain the resistance of complete track circuit (R) except battery, use $\frac{E_5}{I'} - R_1$, in which

E_5 represents voltage across the battery terminals with the ammeter in circuit

I' the total discharge from battery

R_1 the resistance of ammeter on scale used, including the leads.

To determine current (I) to track when E was taken, use $\frac{E}{R}$, in which

E is the voltage at battery

R is the resistance of complete track circuit.

Resistance of relay (R_2) can be found by using $\frac{E_6}{I''} - R_1$, in which

E_6 is the voltage at relay with ammeter in circuit
I'' the current at relay with ammeter in circuit
R_1 is resistance of ammeter on scale used, including leads.

To obtain current through relay (I_1), use $\frac{E_4}{R_2}$ in which

E_4 is the voltage at relay terminals
R_2 is resistance of relay.

To find the resistance of resistance unit (R_u), use $\frac{E - E_1}{I}$, in which

E is the voltage at battery
E_1 voltage at track side of resistance unit
I is discharge from battery.

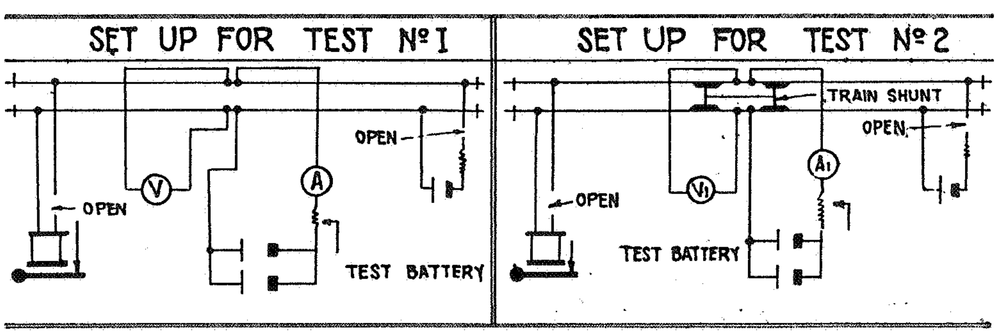
To find the resistance of rail connections (R_b) at battery end, use $\frac{E_1 - E_2}{I}$, in which

E_1 represents voltage at track side of resistance unit
E_2 voltage at rails and battery end
I discharge from battery.

To find resistance of rail connections (R_r) at relay end, use $\frac{E_3 - E_4}{I''}$, in which

E_3 represents voltage at rails and relay end
E_4 voltage at relay terminals
I'' current at relay with ammeter in circuit.

To determine train shunt resistance use the following set-ups and formulae:



$R = \frac{E}{I}$ Joint resistance of ballast and voltmeter.

$R_1 = \frac{E_1}{I_1}$ Joint resistance of ballast, voltmeter and train shunt.

$R_2 = \frac{1}{\frac{1}{R_1} - \frac{1}{R}}$ Computed resistance of train shunt.

Example: $R = 5$

$R_1 = 0.059$

$$R_2 = \frac{1}{\frac{1}{0.059} - \frac{1}{5}} = \frac{1}{16.95 - 0.2} = \frac{1}{16.75} = 0.0597$$

Rail and bonding resistance.

The resistance of the rail, angle bars and bond wires, to the flow of the track circuit current is usually called rail resistance. The resistance of the steel rails per 1000 feet is approximately 0.01 for 100 pound rail and 0.0077 for 130 pound rail.

The rail with angle bars held tightly in place carries practically all the current, but good bonding from rail to rail is necessary to keep the resistance at the joints at a minimum, unbonded joints being subject to wide variation in resistance due to changes in contact pressure. Therefore, it is essential that the bonding around the ends of the rails makes as good a connection as possible in order to keep the bonded rail resistance at a minimum.

The well-bonded rail resistance for a bonded track circuit is not greatly in excess of the solid rail resistance.

Low rail bond resistance is especially desirable where the ballast resistance is low.

To deliver the proper amount of current at the relay end so that the relay will pick up with sufficient margin for certain variations, the battery must have sufficient voltage to force this amount of current through the rails. The higher the bonded rail resistance the higher this voltage must be, hence the greater leakage from one rail to the other through the ballast. As the ballast resistance decreases the leakage increases and there may not be sufficient current available to operate the relay. It can then be readily seen that the lower the rail bond resistance is, the lower the voltage at the feed end of the circuit needs to be and that less variation occurs between low and high ballast resistance conditions.

With low rail resistance a train shunt of higher resistance will cause the front contacts of the relay to open. It also permits the use of higher resistance at the battery.

The formulae for obtaining the bonded rail resistances are:

To find total rail resistance (R_r), use $\frac{E_2 - E_3}{\frac{1}{2}(I + I'')}$, in which

E_2 represents voltage at rails and battery end
E_3 voltage at rails and relay end
I amperes flowing from battery
I'' amperes flowing through relay coils.

To determine resistance of rail (R_r) per 1000 feet of track (2000 feet of rail), use $\frac{R_r}{L}$, in which

R_r represents the total rail resistance
L length of track section in feet.

The resistance of rails and bonding per 1000 feet of track should not exceed 0.15 ohm.

Life of track battery.

In order to obtain a fairly definite idea of the life of a caustic soda battery on a given track circuit, the following calculations will need to be taken into consideration:

(a) The average current flow to track with ballast dry and the track circuit unoccupied.

(b) The average current flow to track with ballast wet and the track circuit unoccupied.

(c) The average current flow to track with the track circuit shunted, which is called actual average train shunt condition.

To obtain the latter condition, it is necessary to determine the maximum, minimum and average resistance of the shunted track circuit, by using the formula for obtaining the resistance of the complete track circuit except the battery, $\frac{E_5}{I'} - R_1$. To ascertain the maximum resistance of the shunted track circuit the readings must be taken with a train at the relay end of the track circuit. To ascertain the minimum resistance of the shunted track circuit, the readings must be taken with a train at the battery end of the track circuit; then the average resistance of the shunted track circuit is the sum of its maximum and minimum resistances divided by 2. Therefore, the average current flow to track with the track circuit shunted would be determined by dividing this resistance into the voltage of the battery, which according to Ohm's law is $I = \frac{E}{R}$.

It will be assumed that the particular track section on which the life is being figured has three cells of 500 ampere hours capacity connected in multiple, which amounts to a total of 1500 ampere hours. It must then be determined the number of hours daily that conditions (a), (b) and (c) cited above are in effect.

It will be assumed that the average normal current under condition (a) has been definitely found to be 0.210 ampere and that this current flows for an average of 19 hours daily, also that the average normal current under condition (b) has been found to be 0.400 ampere and that this current flows for an average of 2 hours daily; likewise, that the current flowing to track under condition (c) has been found to be 1.4 amperes and that this current flows for an average of 3 hours daily.

The ampere hours consumed daily under condition (a) may be found by multiplying the average current flowing from the battery 0.210 ampere, by the number of hours this current is flowing, 19 hours, which yields 3.99 ampere hours. Ampere hours consumed daily under condition (b) are determined on the same basis by multiplying 0.400 ampere by 2 hours which yields 0.8 ampere hour; likewise, the ampere hours consumed daily under condition (c) are determined by multiplying 1.4 amperes by 3 hours which yields 4.2 ampere hours.

Adding these values together, $3.99 + 0.8 + 4.2$ gives a daily ampere-hour consumption of 8.99. The number of days that the battery on this section will last would therefore be $\frac{1500 \text{ ampere hours}}{8.99 \text{ ampere hours}}$, which yields 166 days. Any conditions occurring that effect the values used in these calculations will vary the number of days of life of the battery accordingly.

Where storage battery is used it is necessary to arrange a program for charging, which is usually done by floating the battery on a rectifier or using two sets so that one will be on discharge while the other is charging, alternating them by operating a battery charging switch at stated intervals.

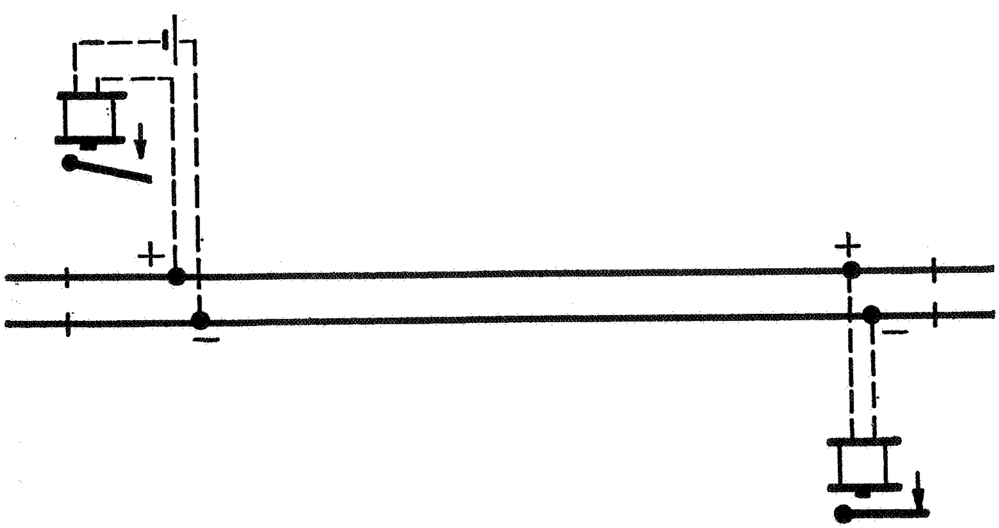


Fig. 8.
D.N.L. Track Circuit.

Miscellaneous neutral track circuits.

In the foregoing it has been assumed that the track circuits were arranged as shown in Figs. 1 to 7 inclusive, and that current is flowing through the relay always in the same direction.

Various other arrangements are used for certain purposes, such as providing a means of approach lighting signals, protection from foreign current, etc. An elaboration of a few of the other arrangements follows.

On a number of roads it was considered desirable to light electrically semaphore or light signals only when a train was approaching, or on account of using caustic soda or similar battery due to there being no commercial supply of power, in which case the cost would be excessive to have the lights burn constantly.

To change the location of the regular track relay may be undesirable due to disarranging other circuits, so that what is called a D.N.L. relay may be used to provide a means for accomplishing the approach lighting.

The D.N.L. relay is small and usually has a resistance of approximately 0.2 ohm. It has one front contact and sometimes a back contact. It is designed so that its direct pick-up and shunting values may be varied over a wide range by a simple adjustment. It is placed in one of the track battery leads between the battery and track, as shown in Fig. 8, where it either takes the place of the entire external limiting resistance unit or becomes a part of it, depending upon whether the total limiting resistance required in the track circuit is equal to, or greater than, the resistance of the D.N.L. relay coils. The relay depends for its successful operation upon the difference in the value of the maximum current which flows to track

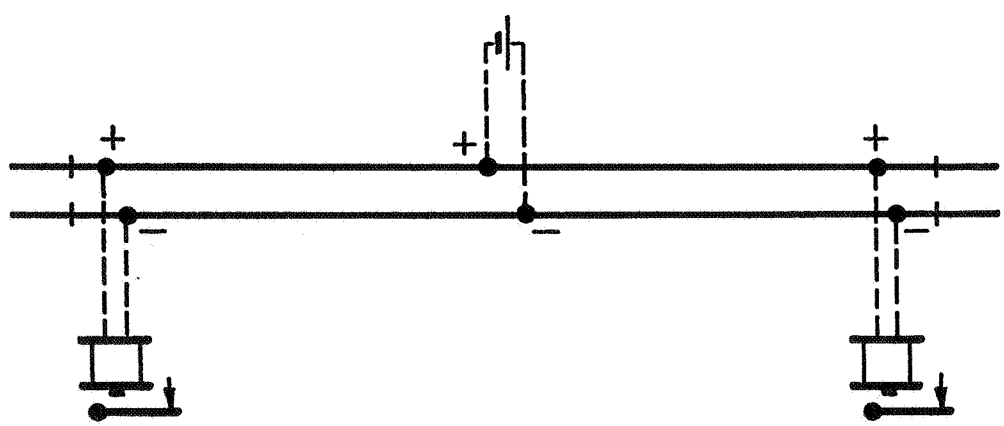


Fig. 9.
Center Fed Track Circuit.

during the wet ballast condition with the track circuit unoccupied and the minimum current which flows to track during the dry ballast condition with the track circuit shunted by a train when it first reaches that point on the circuit where it is desired to light the signal. The relay should be adjusted so that, regardless of condition of ballast, it should not pick up until a train has entered the particular section in which the relay is located.

In a number of localities stray direct currents are prevalent on account of electric railways and similar systems. The track rails form a good path for this stray current with the result that the regular track relay may pick up while a train is on the immediate track section due to high train shunt, broken bond wires, broken rail, etc., which may prevent the train from shunting the current from the relay, so that a Proceed signal may be displayed with the track occupied. The resistance of the track relay is such that it does not require a very high difference of potential between the rails at the relay end to cause it to pick up.

Circuit arrangements to overcome this difficulty are illustrated and explained.

Figure 9 shows an arrangement where instead of the track battery being located at one end of the track section, it is located in the center, and feeds both ways to relays at both ends. Suitable line circuits are carried through front contacts on these two relays to control signals governing this section of track. As a train enters this section both relays are de-energized and one or both are held open while the train is in the section. Any circuit carried through the front contacts of these relays will remain open until both relays have again picked up.

Figure 10 illustrates another arrangement in which the track battery is at one end of the track circuit, the regular track relay at the

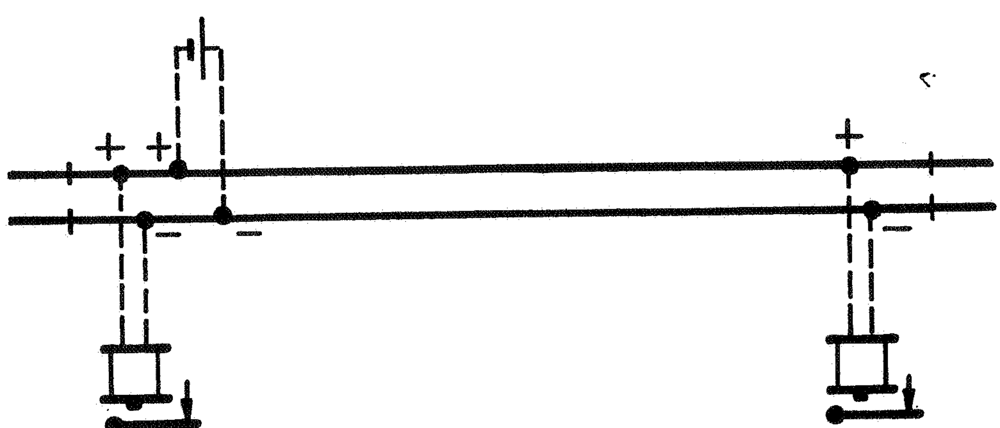


Fig. 10.
End Fed Track Circuit and Two Relays.

opposite end and another relay at the battery end, this relay being of a higher resistance than the regular track relay, usually being of 6 to 16 ohms resistance so that it will not shunt out the regular relay. The line circuits are arranged and the same reasoning applies as in Fig. 9.

Figure 11 illustrates another arrangement somewhat similar to Fig. 10, except that the relay at the battery end is controlled through a line relay "C" in addition to being shunted by the train. Relay "C" is controlled through a front contact on the regular track relay so that when a train enters this section it opens the control of relay "C" which opens the control of the relay at battery end. As the train proceeds, it will keep this relay shunted out even though the regular track relay should pick up. For this relay to pick up, it is necessary that the shunt be removed and the regular track relay be picked up.

To minimize the effect of foreign current on direct current track circuits, they should be installed and maintained as follows:

1. To minimize the effect of foreign current from sources external to the tracks:

   (a) One of the following arrangements of track circuits or equivalent shall be used:

      1. Short end fed circuits. (Similar to Fig. 1.)
      2. Center fed circuits. (Similar to Fig. 9.)
      3. Multiple relay circuits. (Similar to Figs. 10 and 11.)

   (b) The length of a track section shall be such that the difference of potential between rails with no battery connected will not be sufficient to operate the relay. The interference from an external source bears a direct relation to the length of the circuit. The voltage of the foreign current in the rails is due to the difference of the earth potential at different points.

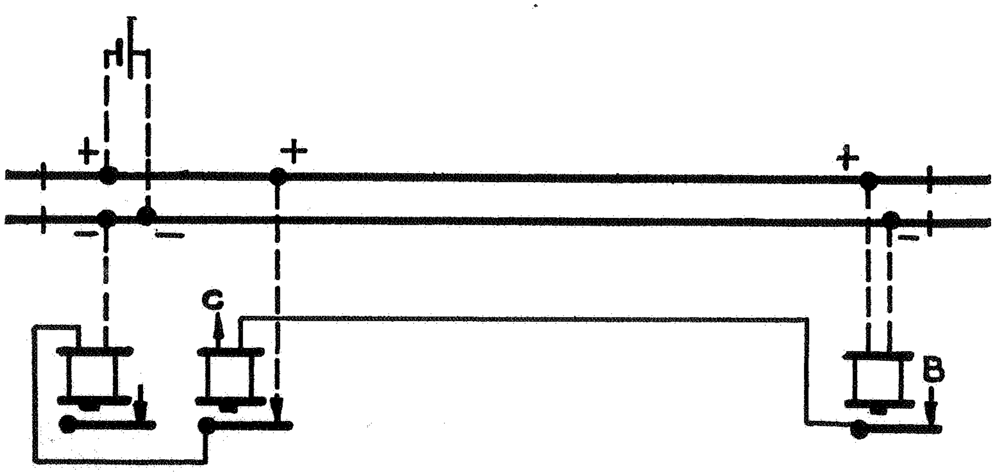


Fig. 11.
End Fed Track Circuit with Two Track and One Line Relay.

The length of the sections to make them free from foreign current interference depends upon so many factors that no rules can be given as to the lengths to be used. The lengths should be shortened generally from the standards used in territory free from foreign current. The length depends also on the rail resistance.

(c) Whenever the source of foreign current can be determined, such as at electric railway crossings, the track circuit battery shall be placed at the end nearest the foreign current source.

(d) A track circuit shall not be carried across an electric railway.

(e) Insulated joints at ends of track circuits, including those at end of fouling on turnouts, shall be opposite each other.

(f) Two sets of insulated joints shall be used at fouling points on tracks where foreign current is probable, such as where tracks are connected to or cross electric railways. The extra set of insulated joints shall be placed one rail length away from the joints in the standard position.

(g) Insulated joints shall be maintained in first-class condition.

(h) Pipe lines attached to rails shall be insulated.

(i) Ballast shall be kept clear from rails and rail fastenings.

(j) Bonding and return circuit on electric railways, in the vicinity, shall be maintained in first-class condition.

(k) Crossings of electric railways shall be bonded in accordance with Drawings 1428 and 1429.

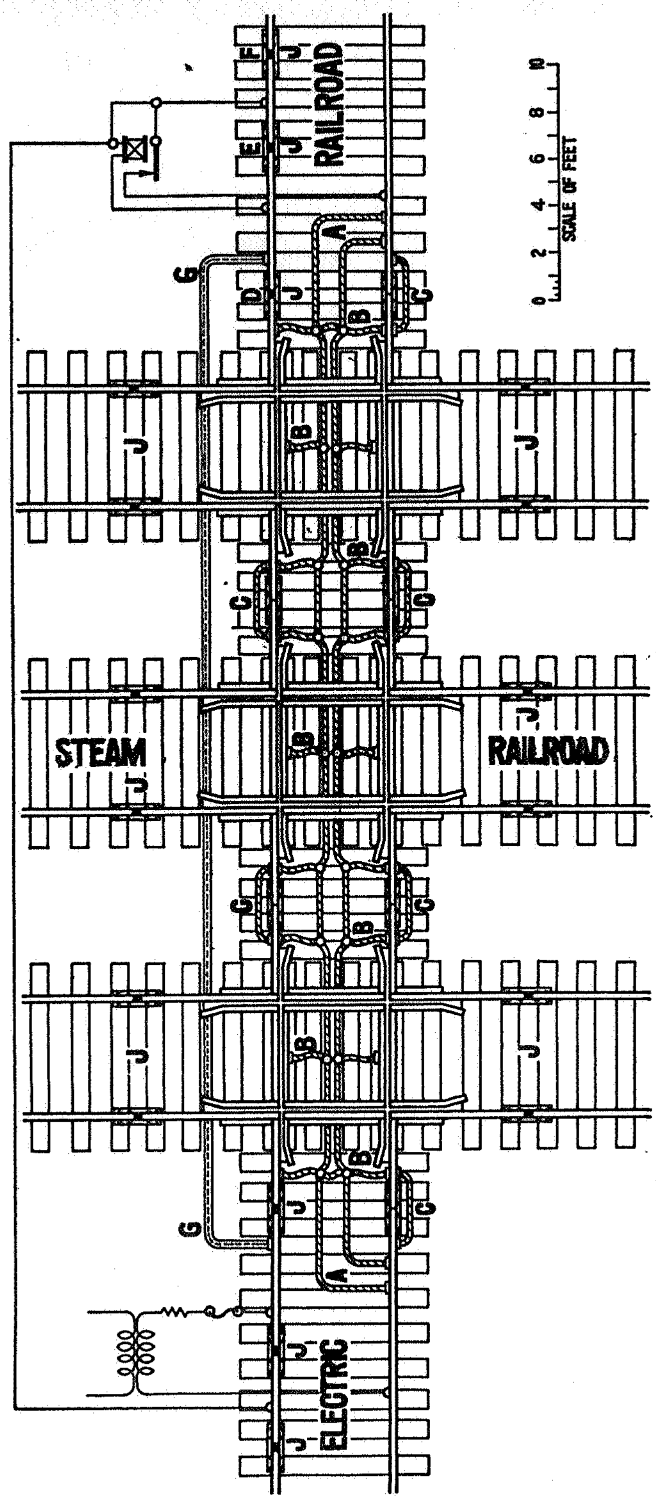
(l) Track circuit bonding shall be of low resistance and shall be maintained in first-class condition.

2. To minimize the effect of foreign current from adjoining track sections:

(a) Insulated joints shall be maintained in first-class condition.

(b) Ballast shall be kept clear from rails and rail fastenings.

(c) Track circuit bonding shall be maintained in first-class condition.



SPECIFICATION:

A-BONDS SHALL BE OF STRANDED COPPER, THE OHMIC RESISTANCE OF WHICH SHALL BE NOT MORE THAN ONE AND FOUR-TENTHS (1.4) TIMES THE RESISTANCE OF AN EQUAL LENGTH OF A RAIL OF THE ELECTRIC RAILROAD.

ALL BONDS SHALL BE WELDED OR OTHERWISE PROPERLY BONDED TO THE RAILS AND INSTALLED SUBSTANTIALLY AS SHOWN ON THE DRAWING.

INSULATION OF BONDS FROM GROUND SHALL BE NOT LESS THAN THE INSULATION OF RAILS FROM GROUND.

B-TAP BONDS SHALL BE NOT LESS THAN TWO (2) FEET LONG. } BONDS SHALL BE OF EQUAL CARRYING CAPACITY TO BONDS 'A'.
C-JOINT BONDS.

DE-SECTION LONG ENOUGH SO CAR CANNOT SPAN.

EF-SECTION SHORT ENOUGH SO SHORTEST CAR CANNOT STAND IN SECTION.

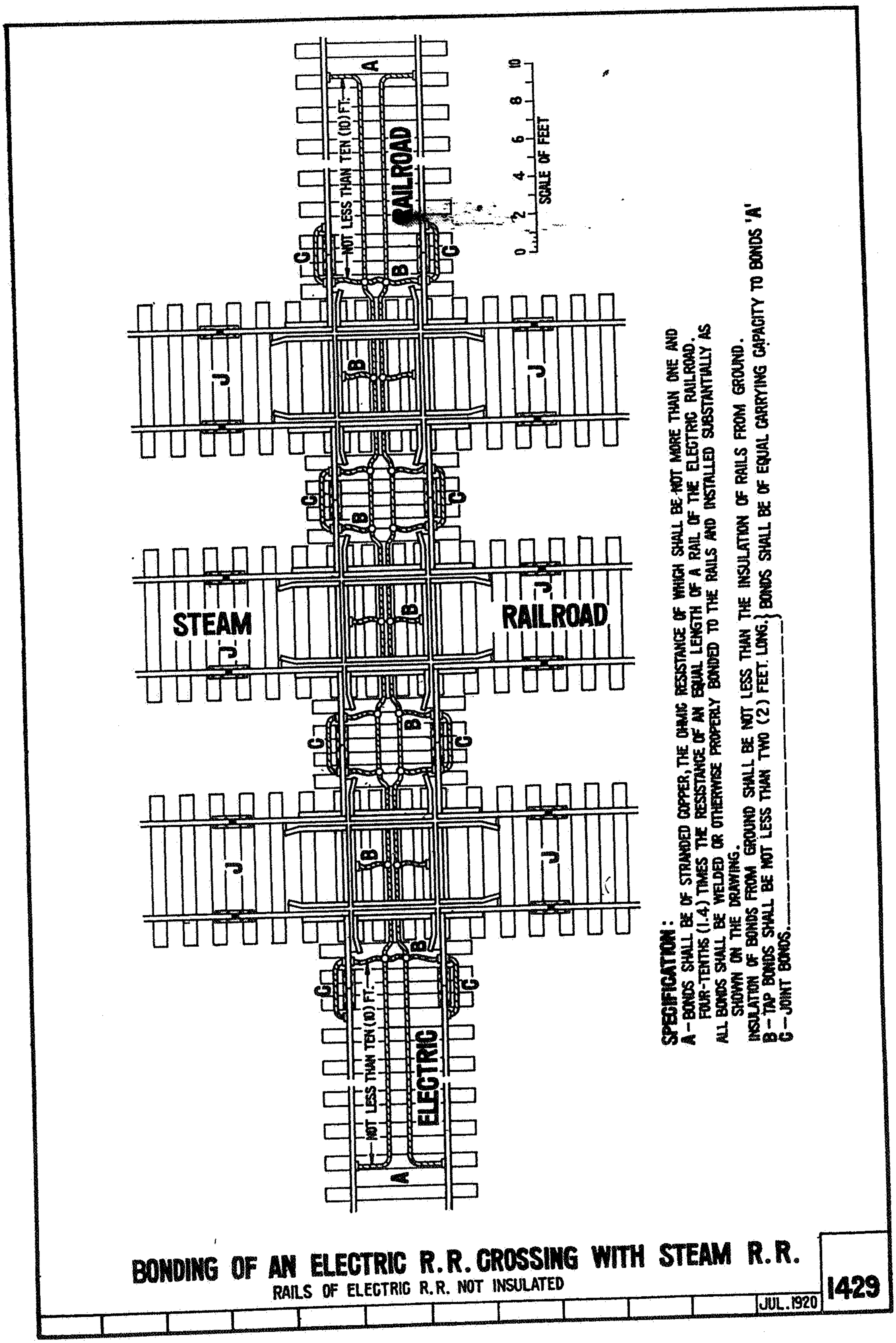
G-NO. 9 INSULATED WIRE IN CONDUIT.

J-INSULATING RAIL JOINTS.

BONDING OF AN ELECTRIC R.R. CROSSING WITH STEAM R.R.

ONE RAIL OF ELECTRIC R.R. INSULATED FROM CROSSING

JUL.1920 1428



BONDING OF AN ELECTRIC R.R. CROSSING WITH STEAM R.R.

RAILS OF ELECTRIC R.R. NOT INSULATED

Polarized track circuits.

In Chapter VI—Direct Current Relays, polarized relays are described. These relays can be used on track circuits in place of the neutral track relays previously illustrated. Polarized relays as used on track circuits are in lieu of line wires for controlling the Proceed position of signals in automatic block signal territory.

Figure 12 illustrates a typical polarized track circuit in which "A" represents the pole changing device, which may be operated by the signal, or a relay. The operation by the signal is described more fully in Chapter XX—Interlocking Circuits. With the pole changer in position shown it will cause the current to flow through the coils of track relay in the direction to close the polar contacts in one position and when the pole changer moves to the opposite position as shown in dotted lines, it will reverse the direction of flow of current in track relay which will cause the polar contacts to close on the opposite side. In each case it will be noted the neutral contacts are closed, so that the Approach position of the signal can be controlled through the neutral contact, and the Proceed position through the neutral contacts and the polar contacts which are closed only when the signal in advance has moved to the Approach or Proceed position.

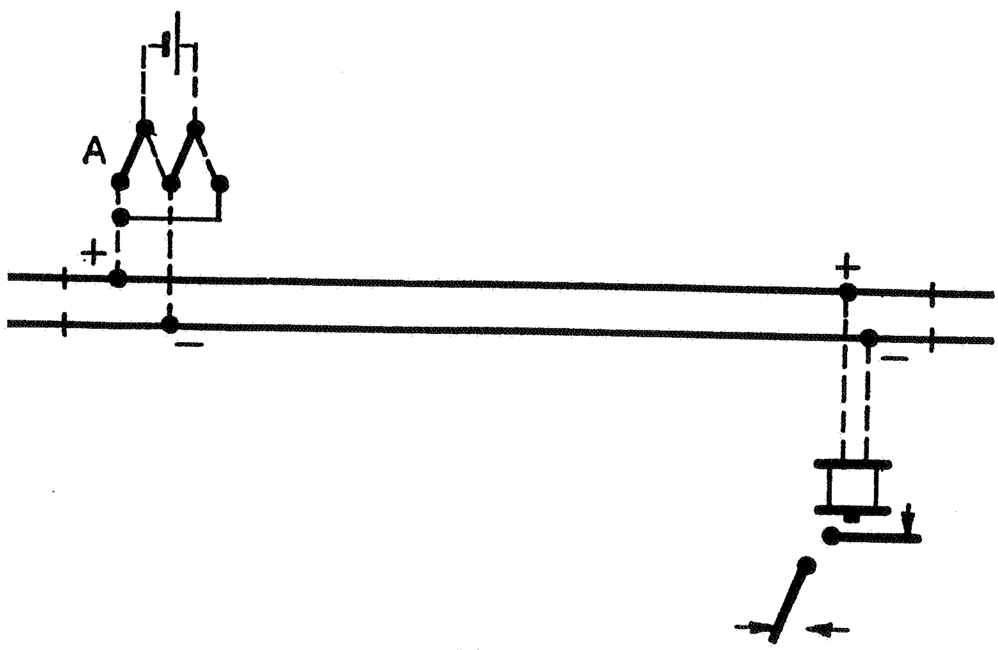


Fig. 12.
Polarized Track Circuit.

Frequently it is desirable or necessary to control a signal through two or more signals in advance in which case a pole changing relay may be used, as shown in Fig. 13.

By tracing this circuit it is seen that with the contacts of pole changing relay, P C, open, the top rail in the diagram is positive and the lower one negative. As soon as the pole changing relay picks up, the lower rail becomes positive and the top rail negative, reversing the flow of current through the track relay, changing the polar contacts as previously explained.

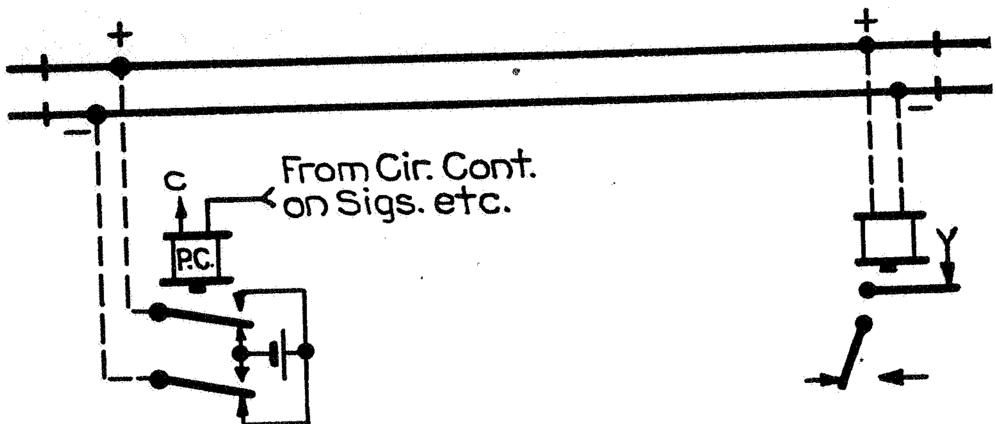


Fig. 13.
Polarized Track Circuit, Using Pole Changing Relay.

The detailed circuits for the control of signals, etc., will be dealt with more fully in subsequent chapters.

Under certain conditions it is not necessary to space the automatic signals as short a distance as on roads of denser traffic, and on account of the greater distance it is not practicable or feasible to use only one track circuit. It is therefore necessary to install what are known as cut-sections, two of which are illustrated in Figs. 14 and 15.

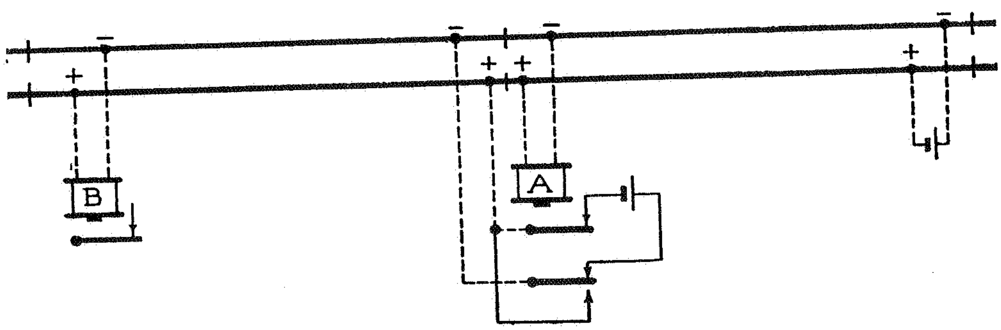


Fig. 14.
Neutral Cut-Sections.

These are neutral track circuits, one track section being controlled by the section ahead so that the first relay will not pick up until the last pair of wheels has passed off the last track section.

To further insure that the relay in the rear will not pick up until the relay in advance has, also as foreign current protection, the track section in the rear is shunted by the back contact of the relay in advance.

While only two track sections are shown, any additional sections necessary between two signals would be arranged as shown at relay A, Fig. 15, which represents polarized cut-sections, the various circuits for which can be readily traced.

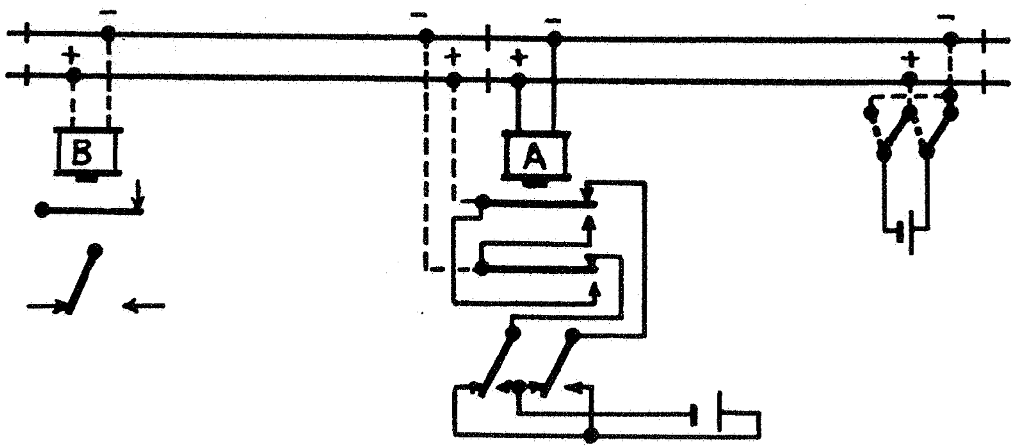


Fig. 15.
Polarized Cut-Sections.

This circuit also has the foreign current protection by providing a shunt on the track section in the rear through the back contact of relay on track section in advance.

Figures 14 and 15 represent two typical arrangements. Other types of cut-sections are used, but they are arranged along similar lines and should be readily traced and reasoned out.

American Railway Signaling Principles and Practices

QUESTIONS ON

CHAPTER VII

Direct Current Track Circuits

QUESTIONS ON CHAPTER VII

DIRECT CURRENT TRACK CIRCUITS

1. How is track circuit defined by the Signal Section, American Railway Association?

2. What is the most important link in the signal system, and why?

3. What national body, whose duties have reference to railroads, attested to the importance of the track circuit in railway transportation in their annual report dated November 22, 1910, and what were the general conclusions in this report with reference to track circuits?

4. List the essential parts of a direct current track circuit.

5. Are various types and arrangements of batteries used to operate direct current track circuits?

6. Why are bond wires applied to non-insulated joints in track circuit territory?

7. What type of bond wire is most generally used? List other types of bonding which are used and describe peculiarities of each type.

8. What resistance is recommended for direct current track relays?

9. At what points in track circuits are insulated joints used, why, and how are they applied?

10. What is the insulating medium used in insulated joints?

Historical.

11. Who started the development in about the year 1867, of means to indicate the presence of a train to a following train and why was his attention directed to the desirability of such equipment?

12. When was the first model exhibited to the American Institute Fair in New York City?

13. What type of system was first used? Describe its action.

14. Where was the first installation made following the exhibition, and did it operate satisfactorily?

15. What serious defects were discovered by the inventor and what was the chief objection to this type of circuit?

16. What change was made in the system to insure that every pair of wheels in the train must have controlling power over the signal throughout the entire section and what is the name of the principle involved?

17. In what years were patents applied for and exhibition made of the new system at the State Fair held in Erie, Pa., and was the new system successful?

18. Where was the new system first installed for actual service? Describe the difficulties experienced with reference to condition of the track.

19. When and by whom was the bond wire invented?

20. Draw a sketch of the typical direct current track circuit which now forms the basis of every efficient signal system.

21. In what year did Mr. Robinson obtain the patent on his track circuit in France, and in the United States?

Operation.

22. How is the track divided into sections?

23. Where is the battery and relay connected in the track circuit?

24. Describe the path of current flowing in the track section.

25. Describe the action which takes place when the train enters the track section.

26. Make a sketch of turnout with fouling circuit in multiple.

27. Make a sketch of turnout with fouling circuit in series.

28. Make a sketch of crossover between main tracks with fouling wires at each end.

29. Make a sketch of crossover between main tracks with insulated joints in center.

30. What are the two most desirable conditions in an ideal track circuit?

31. In what respect do the majority of track circuits fail to measure up to the ideal?

Ballast resistance.

32. Define ballast resistance.

33. List some of the paths for leakage in track circuits.

34. What is the variation in ballast resistance due to under different conditions and what effect does variable ballast resistance have on operation of the track circuit?

35. Describe the method usually employed for determining the ballast resistance of a track circuit, giving the formula and stating what precautions are necessary to insure fairly accurate results.

36. Work out an example illustrating how ballast resistance is determined for the entire circuit and per 1000 feet of track.

37. Under what conditions should the readings be taken in order to obtain the minimum ballast resistance of any particular track circuit?

38. What should be the minimum ballast resistance for a track circuit 4000 to 5000 feet in length and what may be the minimum for circuits shorter than this?

Track battery.

39. What type of battery was used in the early track circuit installations and why was it peculiarly adapted to the purpose?

40. What types of battery are now generally used, and why?

41. What is the advantage of low internal resistance in a battery used for track circuits?

42. What additional device must be used in series with low internal resistance batteries on track circuits?

43. What peculiarity of the gravity cell does this additional device replace and what is its function?

44. What are the requirements, with reference to the limiting resistance unit, in order to obtain longer life from the battery, and why?

45. Write the formula issued by the Signal Section, A.R.A, for computing the minimum allowable limiting resistance which is considered safe from a relay shunting standpoint.

46. In using the above formula what precaution must be observed with reference to the voltage of the battery, and how may the desired voltage be determined for any make, number or arrangement of cells?

47. In case it should be necessary to obtain minimum values of limiting resistance allowable in series with track batteries of different voltages operating in connection with 2-ohm or 4-ohm track relays, where would you obtain such information?

48. In case it should be necessary to consult curves for determining minimum limiting resistance allowable in series with track battery for various train shunt resistances and various battery voltages, where would you obtain this information?

Minimum allowable drop-away current.

49. What is the Signal Section, A.R.A., minimum allowable drop-away current for track relays in service? (a) For 2-ohm relay? (b) For 4-ohm relay?

50. Why is it important to maintain certain minimum drop-away current values with reference to maximum train resistance shunt values?

51. What is the most desirable condition with reference to the values of drop-away and train resistance shunt, and why?

52. How is the effect of foreign current in the rails governed by the relation between minimum drop-away current and maximum train resistance shunt?

Arrangement of batteries.

53. Is the value of limiting resistance dependent on voltage, or the arrangement of connections of the cells in the battery?

54. How many cells of storage battery are generally used?

55. How are caustic soda battery cells generally connected?

56. Where the track circuit is short, how are caustic soda cells generally connected, and why?

57. On track circuits of considerable length, how are caustic soda cells generally connected, and why?

58. Is it desirable to arrange connections so that cells may be disconnected for inspection, renewal, etc., without interrupting the circuit?

59. What is essential to insure proper voltage across the relay terminals for the entire life of the battery?

60. What is the proper voltage across the relay terminals?

61. What is the effect of (a) excessive amount of current in the relay coils, (b) insufficient amount of current in the relay coils, and why are these two conditions important in the satisfactory operation of the track circuit?

62. Is the resistance unit connected to the battery feed lead usually adjustable, and why?

63. If the relay and resistance units are located a considerable distance apart, and it is desirable to know what change in voltage takes place at the relay terminals when changes are made in the resistance unit, how would you proceed without making more than one trip over the section? Explain in detail and give examples.

64. What were the various resistances of track relays generally used with gravity battery?

65. On what track sections were the high resistance relays and the lower resistance relays, and what was done in order to obtain a similar effect to that now obtained by varying the value of limiting resistance?

66. What resistances are generally used in track relays under the modern arrangement of caustic soda or storage battery with a limiting resistance in series, and how does this arrangement effect operation of the circuit?

67. What combination of battery voltage and limiting resistance will provide a nearly constant voltage at the relay terminals under various ballast conditions?

68. What is the most variable condition to contend with in track circuit work?

Formulae on resistances of track circuits.

69. How would you obtain the resistance (R) of a complete track circuit, except battery?

70. Knowing the resistance (R) of the complete track circuit and the voltage (E) at battery, how would you determine the current (I) flowing to the track?

71. How would you obtain the resistance of a relay?

72. Knowing the voltage at the relay terminals and the resistance of the relay, how would you obtain the value of current through the relay?

73. How would you measure the resistance (R_u) of the resistance unit?

74. How would you determine the resistance (R_b) of rail connections at battery end of track circuit?

75. How would you determine the resistance (R_r) of rail connections at the relay end of the track circuit?

76. How would you determine the train shunt resistance? Make a sketch showing connections to be used in test and give example.

Rail and bonding resistance.

77. Define rail resistance.

78. What is the approximate resistance of rails per 1000 feet for 100 pound rail and 130 pound rail?

79. Will the rail with angle bars held tightly in place carry sufficient current, and is it necessary to bond the rails? Give reason.

80. What is the most important requirement with respect to maintenance of bonding?

81. Should the bonded rail resistance be much in excess of solid rail resistance?

82. In case the ballast resistance is low, what is the most desirable condition in connection with bonded rail resistance?

83. What is the requirement with respect to voltage in order to insure proper operation of the relay with sufficient margin?

84. How is the required voltage affected by high values of bonded rail resistance?

85. How is leakage affected by low ballast resistance and what effect does this have on current available to operate the relay?

86. What is the advantage of low rail bond resistance with respect to (a) the voltage required, (b) the variations of ballast resistance, (c) train shunt resistance, (d) value of limiting resistance?

87. How would you determine the total rail resistance (R_r) of a track circuit?

88. How would you determine the rail resistance (R_r) per 1000 feet of track?

Life of track battery.

89. In order to obtain a fairly definite idea of the life of a caustic soda battery on a given track circuit, under what three conditions would you have to consider the average current flow in the track and how would you carry out the test?

90. How would you obtain the maximum resistance of the shunted track circuit?

91. How would you obtain the minimum resistance of the shunted track circuit?

92. How would you obtain the average resistance of the shunted track circuit?

93. Knowing the average resistance, how would you obtain the average current flow?

94. Assuming that a track circuit is equipped with three cells of 500 ampere-hour capacity connected in multiple, and knowing the average current flow under different conditions, how would you obtain the daily ampere-hour consumption and the life of the battery?

95. Where storage battery is used, what arrangements are generally made for charging the battery?

Miscellaneous neutral track circuits.

96. Make a sketch of a track circuit arranged so as to provide approach lighting for an electrically-lighted signal by controlling the circuit energizing the lamp through back contacts on the track relay.

97. Make a sketch of track circuit using a D. N. L. relay in series with the battery to provide approach lighting.

98. Describe the characteristics of a D. N. L. relay with reference to size, usual resistance, contact equipment and adjustment of pick-up and shunting values.

99. How is the series D. N. L. relay generally connected in the circuit and does it replace the external limiting resistance?

100. Describe the principle of operation of a series D. N. L. relay used for approach lighting, and how it should be adjusted with relation to the rest of the track circuit.

101. What is the usual cause of stray direct currents flowing in the track circuit, and what effect are they liable to have upon the system?

102. How do you explain the fact that a very slight difference of potential may cause the track relay to pick up?

103. Make a sketch of a center fed track circuit and explain why this arrangement is sometimes used to minimize the effect of stray currents, and how the control of the signal circuit is made continuous with such an arrangement.

104. Make a sketch of an end fed track circuit with two relays, giving the resistance of the relays, and explaining the advantage of such an arrangement.

105. Make a sketch of an end fed track circuit with two track relays and one line relay. Explain the advantage of this arrangement.

106. List three alternate arrangements of track circuits which may be used to minimize the effect of foreign current from sources external to the tracks.

107. Describe in general terms the relation between the length of the track circuit and the interference from an external source, stating the manner in which you would determine the maximum length of track circuit under foreign current conditions.

108. Make a sketch of bonding of an electric railroad crossing with a steam railroad, in which one rail of the electric railroad is insulated from the crossing.

109. Make a sketch of bonding of an electric railroad crossing with a steam railroad, in which the rails of the electric railroad are not insulated.

110. In an electric railroad crossing with steam railroad, what are the Signal Section, A.R.A., requirements with reference to (a) kind, size, resistance and number of bonds, (b) type of bonds, (c) insulation of bonds from ground, (d) length of tap bonds, (e) length of joint bonds, (f) length of dead sections in crossing, (g) size of insulated wire in jumper around crossing?

111. Answer the following questions with reference to minimizing the effect of foreign current from sources external to the track:

(a) What is the best recommended practice with reference to the relative location of the two insulated joints at the ends of track circuits, including those at end of fouling on turnouts?

(b) Should more than one set of insulated joints be used at fouling points on tracks where foreign current is probable, and if so, where should the extra set of joints be placed?

(c) In what condition should insulated joints be maintained?

(d) Should pipe lines attached to rails be insulated?

(e) What is the requirement with reference to keeping ballast clear from rails and rail fastenings?

(f) How should bonding and return circuit on electric railways be maintained?

(g) How should track circuit bonding be maintained?

112. Answer the following questions with reference to minimizing the effect of foreign current from adjoining track sections:

(a) In what condition should insulated joints be maintained?

(b) What is the requirement with reference to keeping ballast clear from rails and rail fastenings?

(c) In what condition should track circuit bonding be maintained?

Polarized track circuits.

113. What is the advantage of using polarized relays on track circuits?

114. Make a sketch of a typical polarized track circuit and describe how it operates, and how the signal is controlled.

115. Make a sketch showing how a pole changing relay may be used to control a signal through two or more signals in advance, and describe its operation.