American Railway Signaling Principles and Practices

CHAPTER VII

Non-Coded Direct Current Track Circuits

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CHAPTER VII

NON-CODED DIRECT CURRENT TRACK CIRCUITS

The Signal Section, Association of American Railroads, 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."

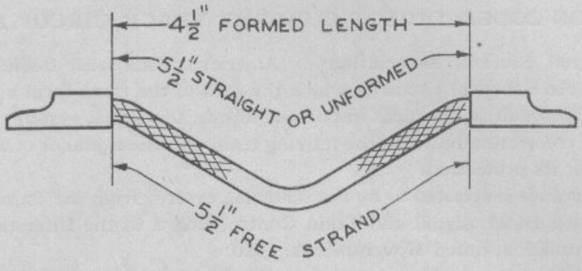
The essential parts of a non-coded direct current track circuit are the battery, rails, bonding, relay and insulated rail joints. Coded track circuits are described in Chapter XXV.

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, bonds are applied to insure a path of low and uniform resistance between adjoining rails.

These bonds are of different types. In earlier installations the most generally used were two or more No. 8 B.W.G. galvanized iron wires fastened into the web of each rail by channel pins. Frequently, No. 6 A.W.G. copper, or copper-clad wires were used instead of galvanized iron wires either to obtain increased conductivity or to improve conditions where the bonds were subject to salt brine, gases, etc. Another type of bond now generally used is known as the plug type bond, made up of single or duplex conductor of several strands of galvanized iron, copper, copper-clad or a combination of these welded to a tapered steel terminal or pin which is driven into a $\frac{3}{8}$ inch hole drilled in the web of the rail. Another is the rail head bond, a short bond welded or mechanically applied to the head of the rail. In fact, the method of bonding track circuits has and is receiving considerable attention and study, and experiments are being made with several other types of bonds. Drawings of rail head type bonds are covered on A.A.R. Sig. Sec. 1047 and 1048, and of plug type bonds on A.A.R. Sig. Sec. 1631 and 1632.

The relay used is fully described in Chapter VI—Direct Current Relays, and the resistances most generally recommended until recently for track



RAIL BOND AS SHOWN.

TRACK CIRCUIT CONNECTOR,
ONE TERMINAL ONLY, UNFORMED,
LENGTH AS SPECIFIED ON ORDER,
STUB END TINNED 2 INCHES.

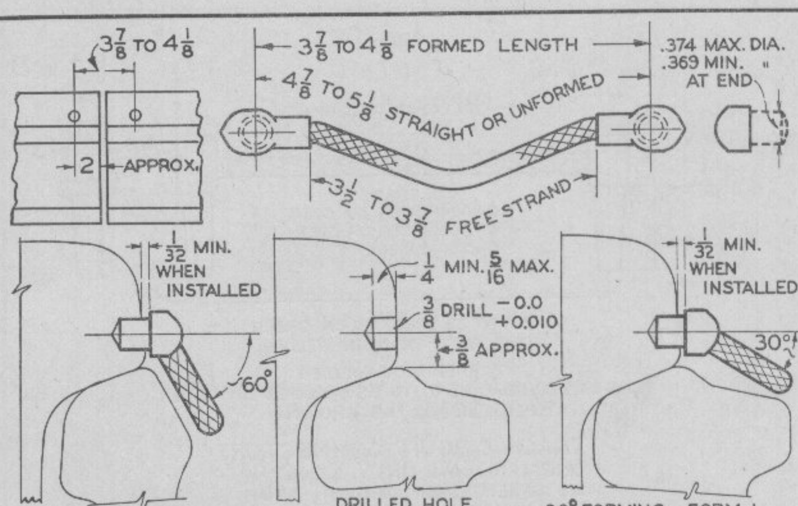
ORDER NUMBER		CONDUCTOR- NOMINAL DIAMETER 5/16", ROPE LAY CONSTRUCTION, CENTER STRAND OF 19 WIRES, SURROUNDED BY 6 STRANDS OF 19 WIRES EACH.
BOND	CONNECTOR	
10471	10472	EACH WIRE GALVANIZED STEEL, 0.02" DIAMETER.
10473	10474	EACH WIRE GALVANIZED STEEL, CENTER WIRE AND 6 SURROUNDING WIRES 0.022" DIAMETER, 12 OUTSIDE WIRES 0.020" DIAMETER, IN EACH STRAND.
10475	10476	EACH WIRE OF CENTER STRAND ANNEALED COPPER, 0.02" DIAMETER. EACH WIRE OF OUTSIDE STRANDS GALVANIZED STEEL, 0.02" DIAMETER.
10477	10478	EACH WIRE OF CENTER STRAND ANNEALED COPPER, CENTER WIRE AND 6 SURROUNDING WIRES 0.0242" DIAMETER, 12 OUTSIDE WIRES 0.0235" DIAMETER. EACH WIRE OF OUTSIDE STRANDS GALVANIZED STEEL, CENTER WIRE AND 6 SURROUNDING WIRES 0.021" DIAMETER, 12 OUTSIDE WIRES CONSIST OF 6 WIRES 0.016" DIAMETER AND 6 WIRES 0.023" DIAMETER.
10479	104710	EACH WIRE HARD DRAWN BRONZE, 0.02" DIAMETER.
104711	104712	EACH WIRE ANNEALED BRONZE 0.0224" DIAMETER.

NOTE: MANUFACTURING TOLERANCES ALLOWED ON WIRE SIZES.

WELDED TYPE RAIL HEAD BONDS
AND TRACK CIRCUIT CONNECTORS

AAR SIG. SEC. 1047A

M-1938 APR 1938



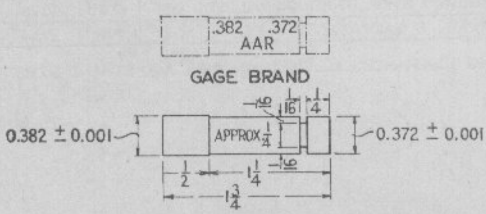
60° FORMING-FORM 2 DRILLED HOLE 30° FORMING- FORM 1

RAIL BOND AS SHOWN.

TRACK CIRCUIT CONNECTOR,

ONE TERMINAL ONLY, UNFORMED, LENGTH AS SPECIFIED ON ORDER, STUB END TINNED 2 INCHES.

ORDER NUMBER			CONDUCTOR
BOND		CONNECTOR	
FORM I	FORM 2		
10481	10482	10483	ROPE LAY CONSTRUCTION, CENTER STRAND OF 12 TO 19 WIRES, SURROUNDED BY 6 STRANDS OF 12 TO 19 WIRES EACH, MAXIMUM NOMINAL DIAMETER OF FINISHED CABLE 7/32, MINIMUM BREAKING LOAD 1400 LBS.



10484 PLUG GAGE FOR DRILLED HOLES.

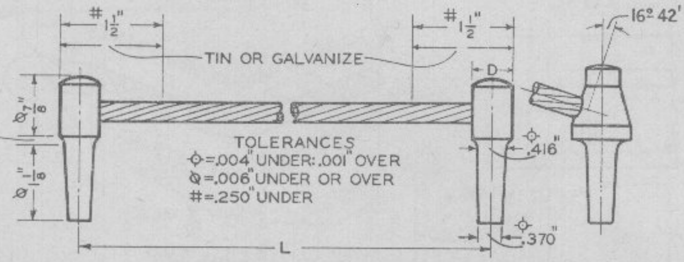
MATERIAL: CARBON STEEL DRILL ROD,
WATER HARDENED Rc 60/62.
CADMIUM PLATE 0.0005 OVER FINISHED GAGE.

NOTE: ALL DIMENSIONS GIVEN IN INCHES UNLESS OTHERWISE INDICATED.

MECHANICALLY APPLIED RAIL HEAD TYPE BONDS AND TRACK CIRCUIT CONNECTORS

AAR SIG. SEC. 1048C

M-1945 OCT. 1945 | M-1942 OCT. 1942 | M-1938 APR 1938



L= TO BE SPECIFIED ON ORDER
D= 11/16" WHEN THROUGH-WELDED,
9/16" WHEN BUTT-WELDED
TYPE OF TERMINAL HEAD TO BE SPECIFIED ON ORDER

RAIL BOND AS SHOWN.

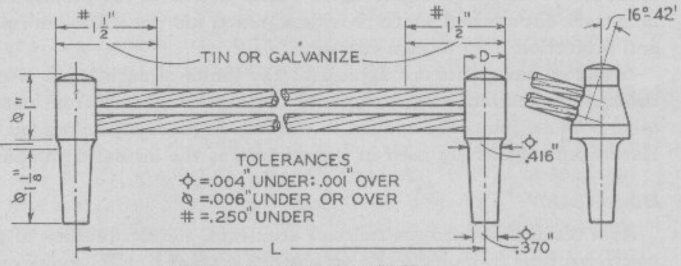
TRACK CIRCUIT CONNECTOR,
ONE TERMINAL ONLY, LENGTH
AS SPECIFIED ON ORDER, STUB
END TINNED 2 INCHES.

ORDER NUMBER		CONDUCTOR-WIRES IN STRAND	DIAMETER		LENGTH OF STRAND LAY
BOND	CONNECTOR		EACH WIRE	EACH STRAND	
16311	16312	I ANNEALED COPPER, 6 GALVANIZED STEEL	.109"	.327"	3.75"
16313	16314	7 GALVANIZED STEEL	.109"	.327"	3.75"
16315	16316	7 ANNEALED COPPER	.102"	.306"	3.75"
16317	16318	61 ANNEALED COPPER	.0333"	.233"	2.25"
16319	163110	3 ANNEALED COPPER, 16 GALVANIZED STEEL	.0661"	.330"	2.54"
163111	163112	3-40% COPPER COVERED STEEL, BUTT-WELDED	.128"	.276"	3.25"
163113	163114	3-40% COPPER COVERED STEEL, THROUGH-WELDED	.128"	.276"	3.25"
163115	163116	7-40% COPPER COVERED STEEL, BUTT-WELDED	.102"	.306"	3.00"
163117	163118	7-40% COPPER COVERED STEEL, THROUGH-WELDED	.102"	.306"	3.00"
163119	163120	7-40% COPPER COVERED STEEL, BUTT-WELDED	.081"	.243"	2.75"
163121	163122	7-40% COPPER COVERED STEEL, THROUGH-WELDED	.081"	.243"	2.75"
163123	163124	I-ANNEALED COPPER, 6 GALVANIZED STEEL	.077"	.213"	2.54"

NOTE: MANUFACTURING TOLERANCES ALLOWED ON WIRE AND STRAND SIZES.

SINGLE CONDUCTOR PLUG TYPE RAIL BONDS AND TRACK CIRCUIT CONNECTORS

M-1942	OCT. 1942	M-1938	APR. 1938	M-1933	MAY 1933	M-1931	MAY 1931	SEPT. 1930	AAR SIG. SEC. 1631 D



L=TO BE SPECIFIED ON ORDER
D= 5/8" WHEN THROUGH-WELDED,
1/2" WHEN BUTT-WELDED

TYPE OF TERMINAL HEAD TO BE SPECIFIED ON ORDER

RAIL BOND AS SHOWN.

TRACK CIRCUIT CONNECTOR, ONE TERMINAL ONLY, LENGTH AS SPECIFIED ON ORDER, STUB END TINNED 2 INCHES.

ORDER NUMBER		CONDUCTOR-WIRES IN EACH STRAND	DIAMETER		LENGTH OF STRAND LAY
BOND	CONNECTOR		EACH WIRE	EACH STRAND	
16321	16322	1 ANNEALED COPPER, 6 GALVANIZED STEEL	.077"	.231"	2.54"
16325	16326	7-40% COPPER COVERED STEEL, BUTT-WELDED	.081"	.243"	2.75"
16327	16328	7-40% COPPER COVERED STEEL, THROUGH-WELDED	.081"	.243"	2.75"
16329	163210	3-40% COPPER COVERED STEEL, BUTT-WELDED	.088"	.196"	2.25"
163211	163212	3-40% COPPER COVERED STEEL, THROUGH-WELDED	.088"	.196"	2.25"

NOTE: MANUFACTURING TOLERANCES ALLOWED ON WIRE AND STRAND SIZES.

DUPLEX CONDUCTOR PLUG TYPE RAIL BONDS AND TRACK CIRCUIT CONNECTORS

AAR SIG. SEC. 1632 D

M-1942	OCT. 1942	M-1938	APR. 1938	M-1933	MAY 1933	M-1931	MAY 1931	SEPT. 1930

relays were 2 and 4 ohms. The present tendency is to recommend lower resistance track relays which are a better match of the ballast resistance on long track circuits and which provide a greater margin of broken-rail protection and protection from foreign current.

Insulated rail joints are applied at the limits of each track circuit, also at turnouts, crossovers, etc., to restrict the flow of current from one rail to the other. These joints are applied to the rails in place of the regular splice bars. Hard fibre is generally used in these joints as the insulating medium.

Historical.

As a result of numerous railroad accidents, the desirability of providing a positive 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 such 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 picking up of this stick relay opened the signal control circuit, thereby placing the signal at Stop.

When the train or car proceeded to the proper point beyond, it actuated an instrument which shunted the stick circuit of the relay in the rear, releasing it and causing the signal to clear.

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

In the same year an installation of the system was made at Kinzua, Pa., on the Philadelphia & Erie Railroad, now a part of the Pennsylvania Railroad. This installation performed satisfactorily.

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 into a deeper study of the system from the standpoint of a railroad man with a view of finding its weak points.

He soon discovered there were serious defects which 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 block. 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 was 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 recognized these serious objections as inseparable from an open circuit system of signaling, and at once entered upon the problem of eliminating them 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 would be to insure that every pair of wheels in the train must have control over the signal throughout the block section.

He realized this could not be accomplished by any open circuit arrangement 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. In 1872 he made an exhibition of this system at the State Fair held at Erie, Pa. When a car entered the track circuit it diverted the current from the relay, thereby causing its armature to drop away. When the car moved out of the section the current returned to the relay, picking up its armature.

The operation was perfect, demonstrating the successful operation of the closed circuit system, and attracted 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 it took but a short time to convert the 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 iron fish plate on the inside. There were two holes through the 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 idea of the bond wire, or its equivalent, for electrically connecting the rails.

The Robinson closed rail circuit which now forms the basis of all efficient signal systems throughout the world, is illustrated in its typical form in Fig. 1.

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.

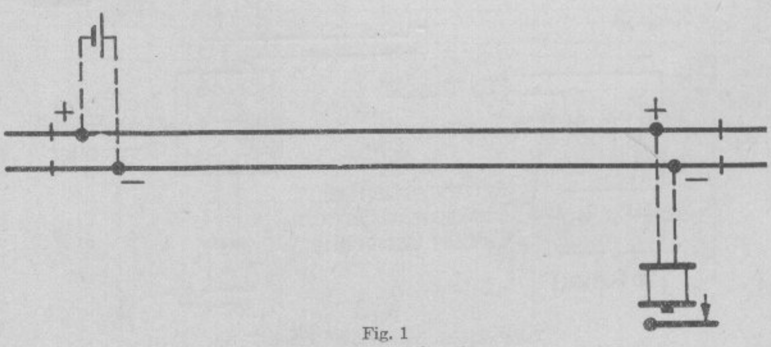


Fig. 1
Typical Track Circuit.

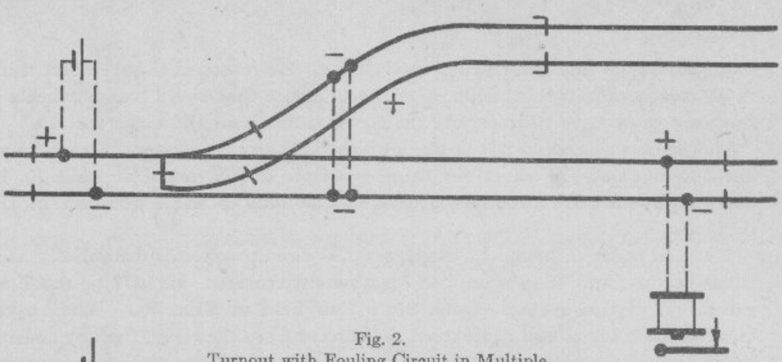


Fig. 2.
Turnout with Fouling Circuit in Multiple.

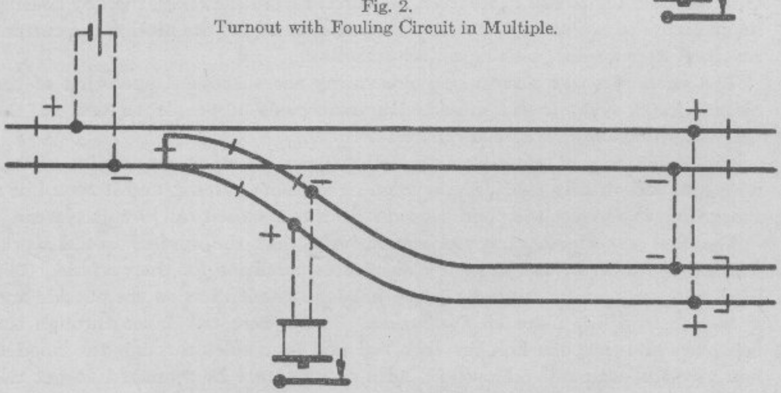


Fig. 3.
Turnout with Fouling Circuit in Series.

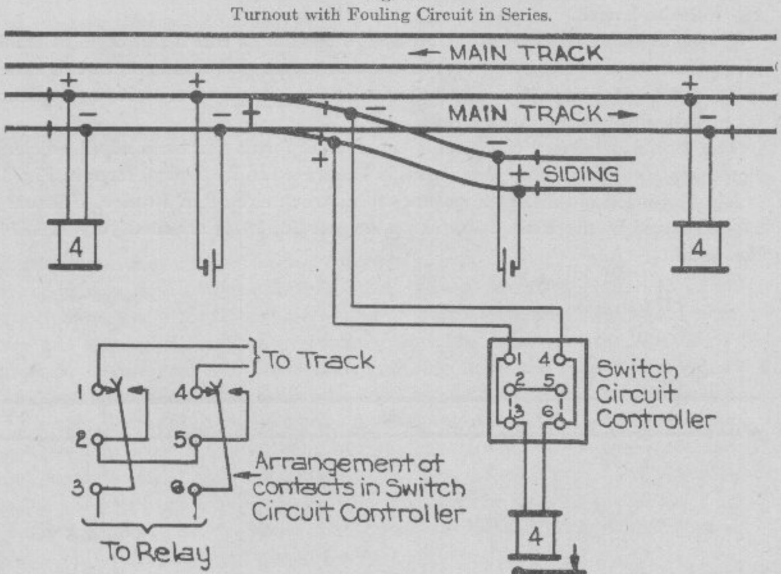


Fig. 4.
Turnout with Independent Track Circuit

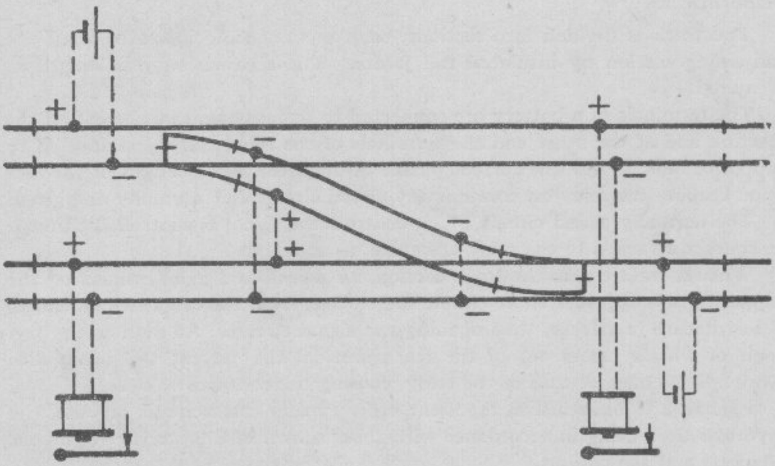


Fig. 5.
Crossover Between Main Tracks with Insulating Joints in Center.

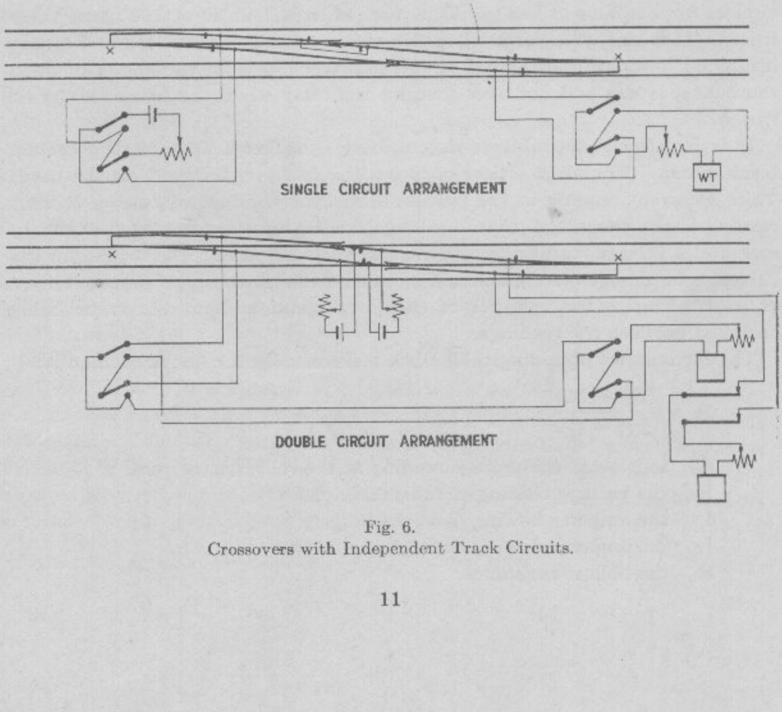


Fig. 6.
Crossovers with Independent Track Circuits.

Operation.

The track is divided into sections, each section being insulated from the adjoining section by insulated rail joints. The sections vary in length as required.

The terminals of a battery are connected to opposite rails at one end of the section and at the other end the terminals of the relay coil are connected to opposite rails. Thus, the current passes through the whole length of the section keeping the relay on continuously closed circuit and normally energized.

The normally closed circuit which controls the signal is controlled through a contact attached to the relay armature, as shown in Fig. 1.

When a train enters the track section the wheels and axles connecting the opposite rails together short circuit the current from the relay, which causes its armature to release, thus opening the signal 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 contacts to close.

Figures 2 to 6, inclusive, represent other typical track circuit layouts, the symbols used being in accordance with those shown in Chapter II—Symbols, Aspects and Indications.

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 or less per 1,000 feet when wet to 80 or 100 ohms when frozen. It is this wide variation which causes most 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 desirable to determine the ballast resistance of a certain track circuit. For all practical purposes the following method can be used: Take a current reading in the positive lead from the battery, also a current reading in the relay lead, then a voltage reading on the track at the battery end, and a voltage reading on the track at the relay end. The reading of the current and voltage 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:

$$R_b = \frac{(E_2 + E_3)}{2\,(I - I_1)}$$

E_2 represents the voltage reading at the rails, battery end

E_3 the voltage reading at rails, relay end

I the amperes flowing from the battery

I_1 the amperes flowing through the relay

R_b the ballast resistance.

As an example, assume that the meters indicated

0.8 volt at E_2
0.5 volt at E_3
*0.300 ampere at I
*0.115 ampere at I_1

Then

$$R_b = \frac{E_2 + E_3}{2\,(I - I_1)} = \frac{0.8 + 0.5}{2\,(0.300 - 0.115)} = 3.51$$

The ballast resistance for the entire circuit is therefore 3.51 ohms. To determine the resistance per 1,000 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 4,900 feet long, the ballast resistance per 1,000 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 when ballast is wet. Under the most adverse conditions the minimum ballast resistance should not be less than 2 ohms per 1,000 feet of track for track circuits 4,000 to 5,000 feet in length. Shorter track circuits may be operated with ballast resistance as low as 1 ohm per 1,000 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 developed for track circuits since the gravity battery required considerable attention to keep it in proper condition as well as being expensive. At the present time, caustic soda and storage batteries have 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 requires a 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 resistance answers the same purpose as the inherent internal resistance of the gravity cell and its function is to limit the high rate of current which otherwise would flow from the battery during the time the track is short circuited.

*After corrections for meter resistance.

It is desirable to have the resistance of this unit as high as possible, not only to obtain longer life from the battery, but to insure reliable shunting of the track relay. The resistance unit is usually adjustable so that its value ca ı be adjusted to suit the particular track circuit.

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

Tables of Minimum Allowable Resistance in Series with Track Battery for Standard or Conventional Non-Coded Direct Current Track Circuits

For Track Circuits Having 2-Ohm or 4-Ohm Relays

Explanations:

1. Tables I and II indicate the minimum resistance (Column 1) to be used with corresponding battery voltages to insure that the track relay will be de-energized when the specified train shunt resistance is applied at the battery end of circuit.

2. The minimum allowable resistance includes resistance of wiring, resistance unit, relay and pole changer contacts between track battery and track.

3. The drop-away value of relays in service must be not less than 35 milli-amperes for 2-ohm relay and 25 milli-amperes for 4-ohm relay.

4. The values shown are computed on the basis of a maximum current through relay of 30 milliamperes for 2-ohm relay and 20 milliamperes for 4-ohm relay when the specified train shunt resistance is applied at the battery end of circuit. This is to provide a factor of safety below the specified minimum service drop-away value of relays of 35 milliamperes and 25 milli-amperes, respectively.

5. To determine the minimum allowable resistance required:

(a) Select a train shunt resistance value applicable to rail surface conditions.

(b) Determine the maximum voltage of the track battery as required under Formula for Computing Minimum Allowable Resistance between Track Battery and Track, then from Table I or II in column under specified train shunt resistance select the voltage of same value, and opposite in Column 1 is shown the minimum allowable resistance.

6. The resistance value should be in all cases as much greater than the minimum allowable shown in Table I or II as will permit of reliable operation of the track circuit. This will result in much lower than 30 milliamperes flow through relay for 2-ohm relay or 20 milliamperes for 4-ohm relay when track is shunted with a given value shunt, or for the same value of 30 or 20 milliamperes, respectively, will insure shunting at a much higher value of train shunt resistance.

TABLE I

Maximum Voltage at Battery Terminals

For Use with 2-Ohm Relay

Minimum resistance Column 1 ohms	Train Shunt Resistance 0.10 volts	0.08 volts	0.06 volts	0.04 volts	0.02 volts
.0	0–0.06	0–0.06	0–0.06	0–0.06	0–0.06
0.1	0.06–0.12	0.07–0.13	0.07–0.16	0.07–0.21	0.07–0.36
0.2	0.13–0.18	0.14–0.21	0.17–0.26	0.22–0.36	0.37–0.66
0.3	0.19–0.24	0.22–0.29	0.27–0.36	0.37–0.51	0.67–0.99
0.4	0.25–0.31	0.30–0.37	0.37–0.47	0.52–0.67	1.00–1.27
0.5	0.32–0.37	0.38–0.45	0.48–0.57	0.68–0.82	1.28–1.57
0.6	0.38–0.43	0.46–0.52	0.58–0.67	0.83–0.97	1.58–1.87
0.7	0.44–0.50	0.53–0.60	0.68–0.78	0.98–1.13	1.88–2.18
0.8	0.51–0.56	0.61–0.68	0.79–0.88	1.14–1.28	2.19–2.48
0.9	0.57–0.62	0.69–0.76	0.89–0.98	1.29–1.43	
1.0	0.63–0.69	0.77–0.84	0.99–1.09	1.44–1.59	
1.1	0.70–0.75	0.85–0.91	1.10–1.19	1.60–1.74	
1.2	0.76–0.81	0.92–0.99	1.20–1.29	1.75–1.89	
1.3	0.82–0.88	1.00–1.07	1.30–1.39	1.90–2.03	
1.4	0.89–0.94	1.08–1.15	1.40–1.50	2.04–2.20	
1.5	0.95–1.00	1.16–1.23	1.51–1.60	2.21–2.35	
1.6	1.01–1.07	1.24–1.31	1.61–1.70	2.36–2.51	
1.7	1.08–1.13	1.32–1.39	1.71–1.81		
1.8	1.14–1.19	1.40–1.46	1.82–1.91		
1.9	1.20–1.25	1.47–1.54	1.92–2.01		
2.0	1.26–1.32	1.55–1.62	2.02–2.12		
2.1	1.33–1.38	1.63–1.70	2.13–2.22		
2.2	1.39–1.44	1.71–1.78	2.23–2.32		
2.3	1.45–1.51	1.79–1.85	2.33–2.42		
2.4	1.52–1.57	1.86–1.93	2.43–2.53		
2.5	1.58–1.63	1.94–2.01			
2.6	1.64–1.70	2.02–2.09			
2.7	1.71–1.76	2.10–2.16			
2.8	1.77–1.82	2.17–2.24			
2.9	1.83–1.88	2.25–2.32			
3.0	1.89–1.95	2.33–2.40			
3.1	1.96–2.01	2.41–2.47			
3.2	2.02–2.07	2.48–2.56			
3.3	2.08–2.14				
3.4	2.15–2.20				
3.5	2.21–2.26				
3.6	2.27–2.32				
3.7	2.33–2.39				
3.8	2.40–2.45				
3.9	2.46–2.51				

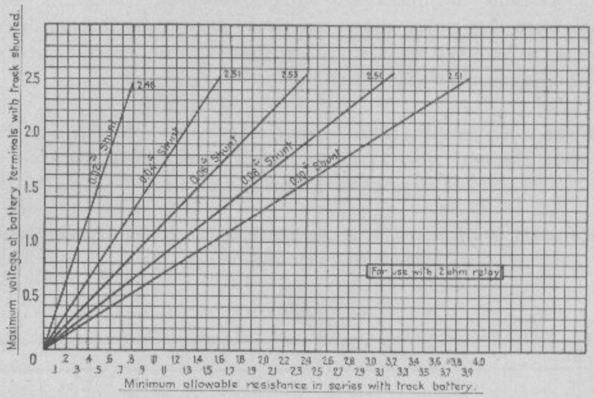
TABLE II

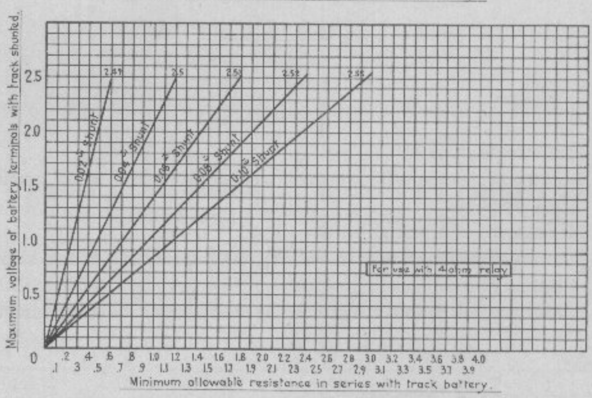
Maximum Voltage at Battery Terminals

For Use with 4-Ohm Relay

Minimum resistance Column 1 ohms	Train Shunt Resistance 0.10 volts	0.08 volts	0.06 volts	0.04 volts	0.02 volts
.0	0–0.08	0–0.08	0–0.08	0–0.08	0–0.08
0.1	0.09–0.16	0.09–0.18	0.09–0.21	0.09–0.28	0.09–0.48
0.2	0.17–0.24	0.19–0.28	0.22–0.35	0.29–0.48	0.49–0.88
0.3	0.25–0.32	0.29–0.38	0.36–0.48	0.49–0.68	0.89–1.28
0.4	0.33–0.40	0.39–0.48	0.49–0.62	0.69–0.88	1.29–1.68
0.5	0.41–0.49	0.49–0.59	0.63–0.75	0.89–1.09	1.69–2.09
0.6	0.50–0.57	0.60–0.69	0.76–0.89	1.10–1.29	2.10–2.49
0.7	0.58–0.65	0.70–0.79	0.90–1.02	1.30–1.49	
0.8	0.66–0.73	0.80–0.89	1.03–1.16	1.50–1.69	
0.9	0.74–0.81	0.90–0.99	1.17–1.29	1.70–1.89	
1.0	0.82–0.90	1.00–1.10	1.30–1.43	1.90–2.10	
1.1	0.91–0.98	1.11–1.20	1.44–1.56	2.11–2.30	
1.2	0.99–1.06	1.21–1.30	1.57–1.70	2.31–2.50	
1.3	1.07–1.14	1.31–1.40	1.71–1.83		
1.4	1.15–1.22	1.41–1.51	1.84–1.97		
1.5	1.23–1.31	1.52–1.61	1.98–2.10		
1.6	1.32–1.39	1.62–1.71	2.11–2.24		
1.7	1.40–1.47	1.72–1.81	2.25–2.38		
1.8	1.48–1.55	1.82–1.91	2.39–2.51		
1.9	1.56–1.64	1.92–2.02			
2.0	1.65–1.72	2.03–2.12			
2.1	1.73–1.80	2.13–2.22			
2.2	1.81–1.88	2.23–2.32			
2.3	1.89–1.96	2.33–2.42			
2.4	1.97–2.05	2.43–2.52			
2.5	2.06–2.13				
2.6	2.14–2.21				
2.7	2.22–2.29				
2.8	2.30–2.37				
2.9	2.38–2.46				
3.0	2.47–2.55				

Curves for Determining the Minimum Allowable Resistance in Series with Track Battery for Various Train Shunt Resistances and Various Maximum Battery Terminal Voltages, for Standard or Conventional Track Circuits





Explanations:

Assumptions, drop-away value of relay and maximum current flow through relay, with track shunted, are as shown in Formula for Computing Minimum Allowable Resistance between Track Battery and Track.

1. To develop a curve for train shunt resistances of various values:

(a) Select a train shunt resistance value applicable to rail surface conditions.

(b) Determine the maximum battery terminal voltage for any make, number and arrangement of cells by measuring the terminal voltage when the battery is at maximum strength and when current discharge is of value calculated from Formula for Computing the Current Discharge from Battery with the Selected Train Shunt Resistance RS, then determine the minimum allowable resistance in series with track battery from Formula for Computing Minimum Allowable Resistance between Track Battery and Track, and from this information any desired curve may be plotted.

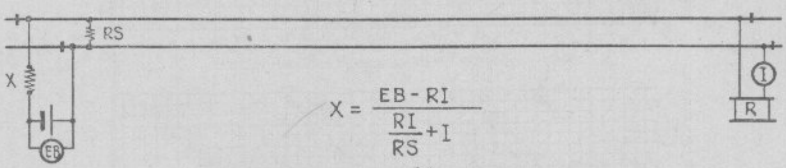
2. To determine from chart the minimum allowable resistance required:

(a) Determine the maximum battery terminal voltage as outlined in 1-b and from this value shown on chart draw a horizontal line until it intersects the selected train shunt resistance curve, then a line vertically to the minimum allowable resistance.

Formulae for Computing Minimum Allowable Resistance between Track Battery and Track and for Computing Related Current and Voltage Data

Formula for Computing Minimum Allowable Resistance between Track Battery and Track

End Fed Section



$$X = \frac{EB - RI}{\frac{RI}{RS} + I}$$

Where:

R = Resistance of relay.

I = Maximum permissible current through relay with track shunt RS applied.

RS = Resistance of track shunt.

EB = Maximum voltage across battery terminals with track shunted at battery.

X = Minimum allowable resistance between track battery and track.

Assumptions:

Ballast resistance = Infinity.

Rail resistance = Zero.

Resistance of wiring between relay and track = Zero.

Example:

R = 4 ohms.

I = 0.020 amp.

RS = 0.06 ohm.

EB = 0.89 volt.

$$X = \frac{0.89 - (4 \times 0.020)}{\frac{4 \times 0.020}{0.06} + 0.020} = \frac{0.810}{1.353} = 0.6 \text{ ohm.}$$

Maximum permissible current I through relay with track shunted:

30 milliamperes for 2-ohm relay.

20 milliamperes for 4-ohm relay.

Maximum battery terminal 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 shown in following table opposite selected train shunt:

Table of shunt current values:

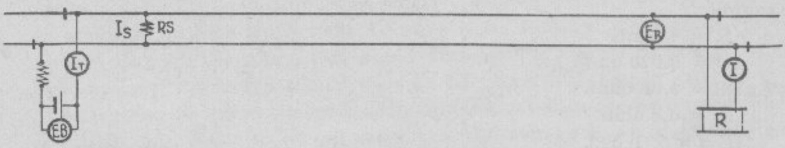
3.03	amps.	when	using	a	2-ohm	relay	and	0.02	ohm	track	shunt.
1.53	"	"	"	"	"	"	"	0.04	"	"	"
1.03	"	"	"	"	"	"	"	0.06	"	"	"
0.78	"	"	"	"	"	"	"	0.08	"	"	"
0.63	"	"	"	"	"	"	"	0.10	"	"	"

4.02	amps.	when	using	a	4-ohm	relay	and	0.02	ohm	track	shunt.
2.02	"	"	"	"	"	"	"	0.04	"	"	"
1.36	"	"	"	"	"	"	"	0.06	"	"	"
1.02	"	"	"	"	"	"	"	0.08	"	"	"
0.82	"	"	"	"	"	"	"	0.10	"	"	"

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

Formula for Computing the Current Discharge from Battery with the Selected Train Shunt Resistance RS

This formula is used to calculate the shunt current values shown in Formula for Computing Minimum Allowable Resistance between Track Battery and Track. The maximum battery voltage EB is taken during the time of this current discharge.



Where:

R = Resistance of relay.

I = Maximum permissible current through relay with track shunt RS applied.

RS = Resistance of track shunt.

E_R = Maximum allowable voltage on rails when track shunt RS is applied.

I_S = Current flow through track shunt resistance RS.

I_T = Current flow from battery when track shunt resistance RS is applied.

Assumptions:

Ballast resistance = Infinity.

Rail resistance = Zero.

Resistance of wiring between relay and track = Zero.

Example:

$R = 4$ ohms.

$I = 0.020$ amp.

RS = Resistance of track shunt.

$E_R = IR = (0.020 \times 4) = 0.080$ volt.

$$I_S = \frac{IR}{RS} = \frac{0.080}{0.06} = 1.333 \text{ amps.}$$

$I_T = I_S + I = 1.333 + 0.020 = 1.353$ amps.

Formula for Computing the Maximum Battery Voltage EB When the Train Shunt Resistance and the Minimum Allowable Resistance in Series with Battery has been Selected

This formula is used to calculate maximum voltage at battery terminals shown in Tables I and II.

Where:

R = Resistance of relay.

I = Maximum permissible current through relay with track shunt RS applied.

RS = Resistance of track shunt.

X = Minimum allowable resistance between track battery and track.

EB = Maximum voltage across battery terminals with track shunted at battery.

$$X\left(\frac{RI}{RS} + I\right) + RI = EB$$

Example:

$R = 4$ ohms.

$I = 0.020$ amp.

$RS = 0.06$ ohm.

$X = 0.6$ ohm.

$$0.6\left(\frac{4 \times 0.020}{0.06} + 0.020\right) + (4 \times 0.020) = 0.8120 + 0.080 = 0.89 \text{ volt.}$$

EB = 0.62 volt.

Minimum allowable drop-away current.

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

(a) For 2-ohm relay—35 milliamperes.

(b) For 4-ohm relay—25 milliamperes.

The minimum drop-away current is given as shown to insure that the maximum train resistance shunt will permit of the relay being shunted 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 be de-energized and remain so 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 of the various track batteries vary, the limiting resistances will likewise vary, also different arrangements of connecting the batteries are used.

Ordinarily, where storage battery is used, a single cell suffices, due to the ampere-hour 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 disconnecting cells for inspection, renewal, etc., without interrupting 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 to flow 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 interruption to the signal system. It is therefore essential for satisfactory operation that sufficient current shall flow through the relay to cause it to 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.

As previously stated 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 track 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 and battery voltage. 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.

With the use of caustic soda and storage batteries and the limiting resistance, practically all relays in ordinary track circuits are of 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. As previously mentioned, however, the present tendency is to recommend lower resistance track relays which are a better match of the ballast resistance on long track circuits and which provide a greater margin of broken-rail protection and protection from foreign current.

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 the most variable condition to contend with.

Formulae on resistances, etc.

The Signal Section, A.A.R., has prepared formulae for making measurements of resistances of the components of track circuits, the more important of which are:

To determine current, I, to track, use $I = I' \frac{E_2}{E_5}$, in which

- I is current to track, without ammeter in circuit
- I' is current to track, with ammeter in circuit
- E_2 is the voltage at rails at battery end, without ammeter in circuit
- E_5 is the voltage at rails at battery end, with ammeter in circuit

To obtain current through relay, I_1, use $I_1 = I'' \frac{E_4}{E_6}$, in which

I_1 is current to relay, without ammeter in circuit
I'' is current to relay, with ammeter in circuit
E_4 is the voltage at relay terminals, without ammeter in circuit
E_6 is the voltage at relay terminals, with ammeter in circuit

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

E is the voltage at battery
E_1 voltage at track side of resistance unit
I is current to track

To find the resistance of battery rail connections, R_B, use $R_B = \frac{E_1 - E_2}{I}$, in which

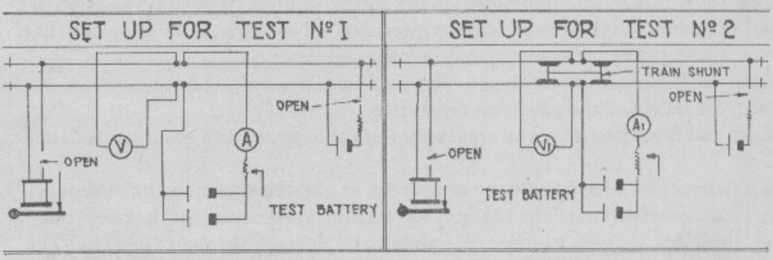
E_1 is the voltage at track side of resistance unit
E_2 voltage at rails, battery end
I is current to track

To find resistance of relay rail connections, R_R, use $R_R = \frac{E_3 - E_4}{I_1}$, in which

E_3 is the voltage at rails, relay end
E_4 voltage at relay terminals
I_1 current to relay

In the above formulae it will be noted that the current values are those obtained after correcting actual meter readings in accordance with Form 7021. (See Fig. 15.)

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



$R = \frac{V}{A}$ joint resistance of ballast and voltmeter

$R_1 = \frac{V_1}{A_1}$ 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:

$$R = 5$$
$$R_1 = 0.059$$

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

Following are Signal Section, A.A.R. Instructions for Train Shunt Resistance Test:

1. Meters must be in accordance with Specification 85.
2. Under rail and wheel surface conditions indicate as wet, bright, dull, light rust, heavy rust, sand, etc.
3. Current and voltage readings must be taken simultaneously.
4. Tests should not be made where foreign current affects the readings.
5. Test battery and resistance should be arranged to obtain approximately but not exceeding full scale deflection of ammeter with short circuit across rails at point of test.
6. Test must be made while equipment is standing at or moving past the point where test set is connected.
7. Rail joints on test section must be well bonded.

Rail and bond resistance.

The resistance of the rail, angle bars and bonds, to the flow of the track circuit current is usually called rail resistance. The resistance of the steel rails alone per 1,000 feet of single rail is approximately 0.01 for 100 pound rail and 0.0077 for 130 pound rail. To this must be added the resistance of bonded rail joints.

Good bonding from rail to rail is necessary to keep the resistance at the joints to a minimum, unbonded joints being subject to wide variation in resistance due to changes in contact pressure. Therefore, it is essential that the bonding at the rail ends should be of low resistance.

The rail and bond resistance for a track circuit with rail head bonds 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 and 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 and bond 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 $R_r = \frac{2 (E_2 - E_3)}{I + I_1}$, in which

E_2 represents voltage at rails, battery end
E_3 voltage at rails, relay end
I amperes to track
I_1 amperes to relay

To determine resistance of rail per 1,000 feet of track, r_r (2,000 feet of rail),

use $r_r = \frac{R_r}{L}$, in which

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

The resistance of bonded rails per 1,000 feet of track (2,000 feet of rail) should not exceed 0.15 ohm for two No. 8 B.W.G. galvanized iron bond wires per joint. The maximum values should be considerably less when plug type or rail head type bonds are used.

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, $\frac{E}{I'} - R_3$, where

E is the voltage at the battery
I′ is the current flowing to track as read by an ammeter
R_3 is the resistance of ammeter including ammeter leads.

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 $I = \frac{E}{R}$.

Another way of measuring the average current flow to track with the track circuit shunted would be to determine the corrected current I flowing to the track with a shunt at the relay end of the circuit and the corrected current I flowing to track with a shunt at the feed end of the circuit. The average current flowing to track with the track circuit shunted would then be the average of these two current values.

It will be assumed that the particular track section on which the battery life is being calculated has three cells of 500 ampere hours capacity connected in multiple, which amounts to a total of 1,500 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 from 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.

Miscellaneous neutral track circuits.

In the foregoing it has been assumed that the track circuits were arranged as shown in Figs. 1 to 6, 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.

It is sometimes desirable to light signals only when a train is approaching, 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 burn the lights continuously.

When the track relay is not conveniently located, a relay connected in series with the track battery is used to provide a means for accomplishing the approach lighting.

This 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 so designed 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. 7, 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 relay coils. The relay depends for its operation upon the difference in the value of the maximum current which normally flows to track with the track circuit unoccupied and the current which flows to track with the track circuit shunted by a train. 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.

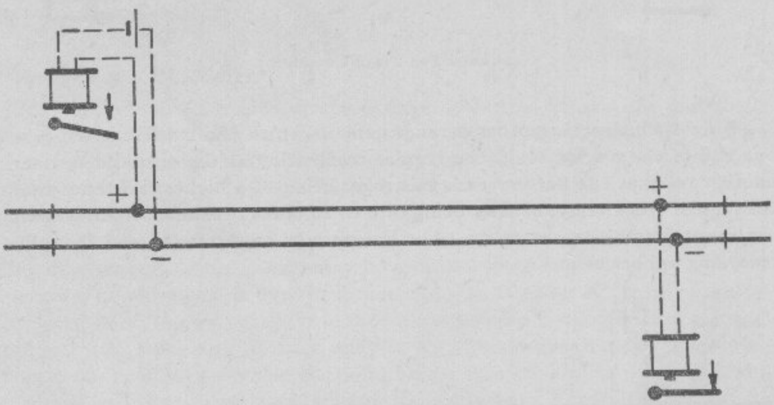


Fig. 7.

Track Circuit with Approach Lighting Relay.

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.

Arrangements of track circuits to overcome this difficulty follow:

Figure 8 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.

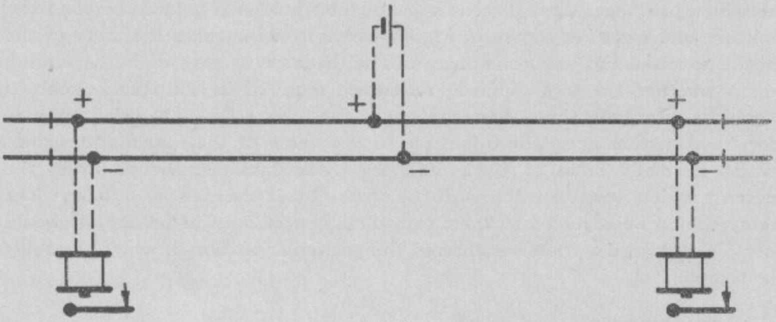


Fig. 8.
Center Fed Track Circuit.

Figure 9 illustrates another arrangement in which the track battery is at one end of the track circuit, the regular track relay at the 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. 8.

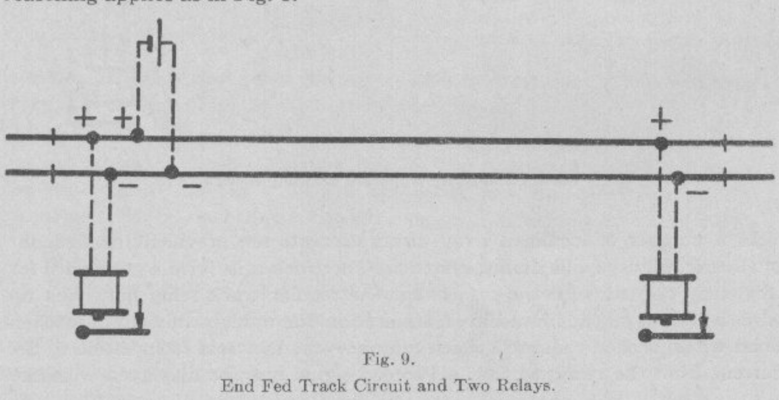


Fig. 9.
End Fed Track Circuit and Two Relays.

To minimize the effect of foreign current on non-coded direct current track circuits, they should be installed and maintained in accordance with A.A.R. Signal Section Requisites as follows:

1. 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.*

2. One of the following arrangements of track circuits should be used:

(a) Short end-fed circuits.
(b) Center-fed circuits.
(c) Multiple relay circuits.
(d) Coded track circuits.

3. Bonding of crossings of electric railroads shall conform to Drawing ....., dated .....

4. A separate track circuit shall be installed at either side of an electric railroad crossing.

5. Bonding and return circuit on electric railroads, in the vicinity, should be maintained in first-class condition.

6. Insulated joints should be maintained in first-class condition.

7. Ballast should be kept clear from rails and rail fastenings whenever practicable.

8. Bonding shall be maintained in good condition to insure low resistance.

9. Whenever the source of foreign current can be determined, consideration should be given to placing the track circuit battery at the end nearest the foreign current source.

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 10 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 the 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 the current in

* 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. 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 length to be used. The length should be shortened generally from the standards used in territory free from foreign current. The length depends also upon the rail resistance.

the 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 displays the Approach or Proceed indication.

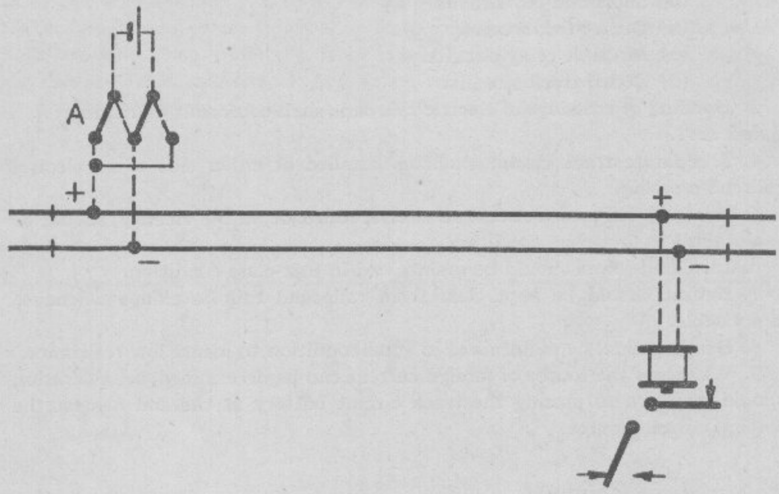


Fig. 10.
Polarized Track Circuit.

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. 11.

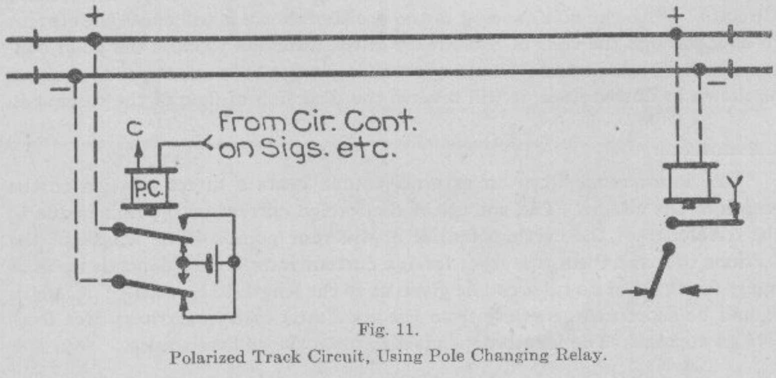


Fig. 11.
Polarized Track Circuit, Using Pole Changing Relay.

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.

The detailed circuits for the control of signals, etc., is 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. 12 and 13.

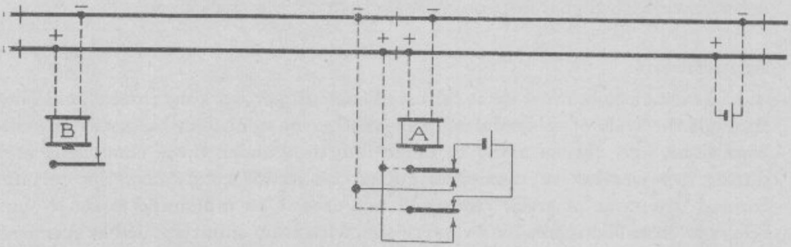


Fig. 12.
Neutral Cut-Sections.

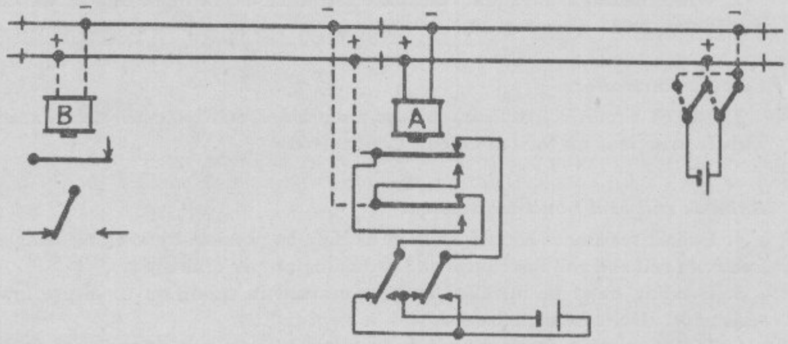


Fig. 13.
Polarized Cut-Sections.

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 in Figs. 12 and 13, any additional sections necessary between two signals would be arranged as shown at relay A in each of these figures.

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 12 and 13 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.

Instructions

Non-coded direct current track circuits should be maintained and tested in accordance with Signal Section, A.A.R. Instructions, as follows:

Adjustment.

1. Track circuits must be so adjusted that proper working current will flow through the coils of relay during wet weather or minimum ballast resistance conditions, and checks made to determine that under these conditions and during dry weather or maximum ballast resistance conditions, the current through the coils of track relay will not exceed 30 milliamperes for 2-ohm relays or 20 milliamperes for 4-ohm relays, with train shunt applied as specified in Tables I and II of Tables of Minimum Allowable Resistance in Series with Track Battery for Standard or Conventional Direct Current Track Circuits. (See pages 15 and 16.)

2. When making train shunt resistance test it should be made in accordance with Form 7003. (See Fig. 14.)

Circuit controllers.

3. Switch circuit controllers must be maintained and tested in accordance with Instructions for Switch Circuit Controllers.

Ballast, rail and bond resistance.

4. Ballast resistance should be kept as high as possible by keeping ballast free from rail and rail fastenings and providing proper drainage.

5. Bonding must be installed and maintained in condition to insure low resistance. Bolts in angle bars should be kept tight.

6. Direct current track circuit tests must be made in accordance with Forms 7021 and 7022. (See Figs. 15 and 16.)

7. Resistance of rails and bonding per 1,000 feet of track should not exceed 0.15 ohm.

8. Resistance of ballast per 1,000 feet of track should preferably be not less than 2 ohms when wet.

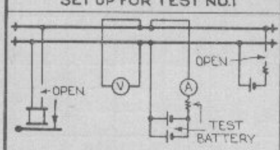
Batteries.

9. Batteries must be maintained and tested in accordance with Instructions for Batteries and Cells.

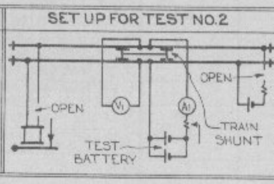
TRACK		EQUIPMENT					TEST NO.1			TEST NO.2 EQUIPMENT STANDING												TEST NO.2				
CIRCUIT NUMBER	RAIL SURFACE CONDITION	KIND	INITIAL	NUMBER	WEIGHT	WHEEL SURFACE CONDITION				1 AXLE				2 AXLES				ENTIRE EQUIPMENT				EQUIPMENT MOVING				
							V	A	R	V_1	A_1	R_1	R_2	V_1	A_1	R_1	R_2	V_1	A_1	R_1	R_2	M.P.H.	V_1	A_1	R_1	R_2

REMARKS

SET UP FOR TEST NO.1



SET UP FOR TEST NO.2



METER RECORD

METERS	MFG	TYPE	RANGE USED	RESISTANCE OF RANGE
AMMETER-A				
VOLTMETER-V				
AMMETER-A1				
VOLTMETER-V1				

$R = \frac{V}{A}$ JOINT RESISTANCE OF BALLAST AND VOLTMETER

$R_1 = \frac{V_1}{A_1}$ JOINT RESISTANCE OF BALLAST AND TRAIN SHUNT

$R_2 = \frac{1}{\frac{1}{R_1} - \frac{1}{R}}$ CUMPUTED RESISTANCE OF TRAIN SHUNT

EXAMPLE $R = 5$ $R_1 = .059$ $R_2 = \frac{1}{\frac{1}{.059} - \frac{1}{5}} = \frac{1}{16.95 - .2} = \frac{1}{16.75} = .0597$

INSTRUCTIONS

1. METERS MUST BE IN ACCORDANCE WITH SPECIFICATION 85.
2. UNDER RAIL AND WHEEL SURFACE CONDITIONS INDICATE AS WET, BRIGHT, DULL, LIGHT, RUST, HEAVY RUST, SAND, ETC.
3. CURRENT AND VOLTAGE READINGS MUST BE TAKEN SIMULTANEOUSLY
4. TESTS SHOULD NOT BE MADE WHERE FOREIGN CURRENT AFFECTS THE READINGS
5. TEST BATTERY AND RESISTANCE SHOULD BE ARRANGED TO OBTAIN APPROXIMATELY BUT NOT EXCEEDING FULL SCALE DEFLECTION OF AMMETER WITH SHORT CIRCUIT ACROSS RAILS AT POINT OF TEST.
6. TEST MUST BE MADE WHILE EQUIPMENT IS STANDING AT OR MOVING PAST THE POINT WHERE TEST SET IS CONNECTED.
7. RAIL JOINTS ON TEST SECTION MUST BE WELL BONDED

APPROX. TEMP. DEGREES F ______________ DATE OF TEST __________ TEST MADE BY __________

ARA SIG. SEC. 7003

TRAIN SHUNT RESISTANCE TEST

SEPT 1924 | MAR. 1925 | M-1926

Fig. 14.

______________R.R.

DIRECT CURRENT TRACK CIRCUIT TEST RECORD

RAIL, BALLAST RESISTANCE AND OTHER DATA

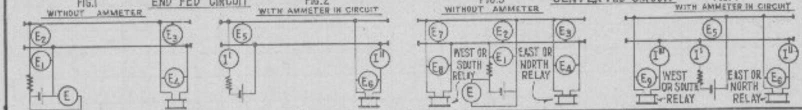
TOWN________ STATE________ DIVISION________ CIRCUIT NO.________

TYPE OF CIRCUIT: NEUTRAL ☐ RELAYED ☐ POLARIZED ☐ END FED ☐ CENTER FED ☐ LENGTH____ NO. OF RAILS ____ L = ____ M.FT.

RAIL	ANGLE BARS	INSUL. JOINTS	CROSS TIES	BALLAST	BATTERY	BONDS	TIE PLATES	RELAYS	EAST OR NORTH RELAY	WEST OR SOUTH RELAY		EAST OR NORTH RELAY	WEST OR SOUTH RELAY
WEIGHT	TYPE	TYPE	KIND	KIND	TYPE	TYPE	TYPE						
LENGTH	CONDITION	NUMBER	TREATMENT	% FREE OF RAILS	LENGTH OF LEADS	SIZE GAUGE	METHOD OF FASTENING	MAKE			RATED RESIST.		
ANCHORS PER RAIL		CONDITION	CONDITION	% DRAINAGE	GAUSE OF LEADS	LENGTH IN INCHES	TO TIE / TO RAIL	TYPE			NO. OF CONTACTS		
ROAD CROSSINGS NO.	R.R. CROSSINGS NO.		STATIONS NO.		HOUSING	NO. PER JOINT		LENGTH OF LEADS			RATED WORKING		
WATER SPOUTS NO.	COAL STATIONS NO.		SWITCHES NO.			CONDITION		GAUGE OF LEADS			RATED DROP-AWAY		

END FED CIRCUIT — FIG. 1 WITHOUT AMMETER; FIG. 2 WITH AMMETER IN CIRCUIT

CENTER FED CIRCUIT — FIG. 3 WITHOUT AMMETER; FIG. 4 WITH AMMETER IN CIRCUIT



TEST DATA

	FIG. NO.				
NO. AND ARRANGEMENT OF CELLS (M = MULTIPLE, S = SERIES)					
DATE SET UP					
INSERTED RESISTANCE AT BATTERY, RATED OHMS					
MOISTURE CONDITION OF BALLAST					
TEMPERATURE OF AIR (DEGREES F.)					
E VOLTS AT BATTERY	1 - 3				
E_1 VOLTS AT TRACK SIDE OF RESISTANCE UNIT	1 - 3				
E_2 VOLTS AT RAILS, AT BATTERY	1 - 3				
E_3 VOLTS AT RAILS, RELAY END	1 - 3				
E_4 VOLTS AT RELAY TERMINALS	1 - 3				
E_5 VOLTS AT RAILS, AT BATTERY	2 - 4				
E_6 VOLTS AT RELAY TERMINALS	2 - 4				
I^{I} CURRENT AT BATTERY	2 - 4				
I^{II} CURRENT AT RELAY	2 - 4				
MAXIMUM SHUNT RESISTANCE ACROSS RAILS TO DROP RELAY — RELAY END					
— AT BATTERY					
— *RELAY END					
RELAY WORKING, AMPERES ACTUAL					
RELAY DROP-AWAY, AMPERES ACTUAL					
*E_7 VOLTS AT RAILS, RELAY END	3				
*E_8 VOLTS AT RELAY TERMINALS	3				
*E_9 VOLTS AT RELAY TERMINALS	4				
*I^{III} CURRENT AT RELAY	4				
*RELAY WORKING, AMPERES ACTUAL					
*RELAY DROP-AWAY, AMPERES ACTUAL					

OBSERVED BY ________ DATE ________

* = ADDITIONAL TESTS FOR CENTER FED CIRCUITS.

COMPUTED DATA (COMPENSATED FOR AMMETER RESISTANCE)

I CURRENT TO TRACK	$I^{I}\frac{E_2}{E_5}$			
I_1 CURRENT TO RELAY	$I^{II}\frac{E_4}{E_6}$			
R_u RESISTANCE OF RESISTANCE UNIT	$\frac{E-E_1}{I}$			
R_B RESISTANCE OF BATTERY RAIL CONNECTIONS	$\frac{E_1-E_2}{I}$			
R_R RESISTANCE OF RELAY RAIL CONNECTIONS	$\frac{E_3-E_4}{I_1}$			
R_r RAIL RESISTANCE TOTAL	$\frac{2(E_2-E_3)}{I+I_1}$			
r_r RAIL RESISTANCE PER "M" FT. OF TRACK. (2000 FT. RAIL)	$\frac{R_r}{L}$			
R_b BALLAST RESISTANCE TOTAL	$\frac{E_2+E_3}{2(I-I_1)}$			
r_b BALLAST RESISTANCE PER M FT. OF TRACK.	R_bL			
*I_2 CURRENT IN RELAY	$I^{III}\frac{E_8}{E_9}$			
*R_{R_1} RESISTANCE OF RELAY RAIL CONNECTIONS	$\frac{E_7-E_8}{I_2}$			
*R_r RAIL RESISTANCE TOTAL	$\frac{4(2E_2-E_3-E_7)}{I+I_1+I_2}$			
*r_r RAIL RESISTANCE PER "M" FT. TRACK. (2000 FT. RAIL)	$\frac{R_r}{L}$			
*R_b BALLAST RESISTANCE TOTAL	$\frac{2E_2+E_3+E_7}{4(I-I_1-I_2)}$			
*r_b BALLAST RESISTANCE PER "M" FT. OF TRACK	R_bL			

COMPUTED BY ________ DATE ________

* = ADDITIONAL COMPUTATIONS FOR CENTER FED CIRCUITS.

INSTRUCTIONS FOR MAKING TESTS

1. METERS SHOULD BE ACCURATE.
2. BATTERY VOLTAGE SHOULD BE CONSTANT DURING PERIOD TESTS ARE BEING MADE.
3. THE TRACK CIRCUIT SHOULD NOT BE SHUNTED OR OPENED DURING PERIOD TESTS ARE BEING MADE. IF SHUNTED BY TRAIN OR OTHERWISE, OR OPENED, THE TESTS SHOULD BE REPEATED AND THESE VALUES RECORDED.
4. THE VOLTAGE READINGS SHOULD BE TAKEN ONE AT A TIME.
5. WHEN TAKING AMPERE READING I^{I} THE METER AT RELAY END SHOULD NOT BE IN CIRCUIT.
6. WHEN TAKING AMPERE READINGS I^{II} OR I^{III} THE METER AT BATTERY SHOULD NOT BE IN CIRCUIT.
7. A VARIABLE RESISTANCE SHOULD BE USED ACROSS RAILS TO OBTAIN SHUNT VALUE AT WHICH RELAY DROPS AWAY. THE TOTAL RESISTANCE OF SHUNT WIRE AND VARIABLE UNIT SHOULD BE RECORDED.
8. TO OBTAIN ACCURATE RESULTS, THE TRACK CIRCUIT SHOULD BE FREE FROM FOREIGN CURRENT, INCLUDING LEAKAGE OF CURRENT FROM ADJACENT CIRCUITS.

ARA SIG. SEC. 7021 | MAR. 1922 | JUNE 1922 | M-1922 | MAR. 1930 | M-1930

Fig. 15.

------------------------------------ R. R.

DIRECT CURRENT TRACK CIRCUIT TEST RECORD

EFFECT OF RAIL BREAKAGE OR REMOVAL AND OTHER DATA

Test to determine the current flow in relay with rail broken, or removed at center of track circuit, and to determine relative leakage current through ground and across ties.

TRANSFER THE FOLLOWING INFORMATION FROM FORM A.R.A. SIG. SEC. 7021

Town ________ State ________ Division ________ Circuit No. ________

Type of Circuit. Neutral ☐ Relayed ☐ Polarized ☐ End Fed ☐ Center Fed ☐ LENGTH {No. of Rails ________ No. of Feet ________

Cross ties, kind ________ Treatment ________ Condition ________ % Less than year old ________

Tie plates, kind ________ Method of fastening to ties ________ To rail ________

Battery, kind ________ Manuf. ________ Type ________ No. of cells ________ Connected ________

Relay, rated resist. ________ Actual resist. ________ Actual drop-away ________

Ballast, kind ________ Moisture conditions ________ Ballast resist. Total R_b ________

Rail, weight ________ Rail resist. R_r ________

TAKE COMPLETE SET OF TRACK CIRCUIT READINGS IN ACCORDANCE WITH A.R.A. SIG. SEC. 7021

Tests for condition of insulated joints, rail breakage, or removal.

I - Test condition of insulated joints by noting whether voltages E_2 and E_3 change when track is shunted on opposite sides of joints.

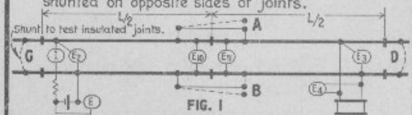


FIG. I

TESTS FOR CONDITION OF INSULATED JOINTS

E_2 Normal (Rails not shunted) ________ Volts.

E_3 " (" " ") ________ "

E_2 With rails shunted at C ________ "

E_3 " " " " D ________ "

TEST FOR RAIL BREAKAGE OR REMOVAL

Battery Polarity	Normal				Reverse				Average				Remarks
Switches Open	A	B	A + B	None	A	B	A + B	None	A	B	A + B	None	
E													
I													
E_2													
E_{10}													
E_{11}													
E_3													
E_4													
I Relay Computed													

TESTS FOR LEAKAGE ACROSS GROUND AND ACROSS TIES

Track battery and relay should be disconnected, switches A and B opened, jumpers J added, and voltage applied from auxilliary battery C across insulated joints at center of track circuit.

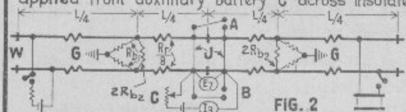


FIG. 2

TESTS FOR FIG. 2

Read voltage E_7 and current I_3 for both polarities of battery C.

With W end of circuit	Positive	Negative	Average	Remarks
E_7				
I_3				

LIST OF SYMBOLS { R_b = Total ballast resistance. R_r = " rail " .

R_{b1} = Part of ballast resistance due to leakage through ground.
R_{b2} = " " " " " " " across ties.

Calculations: $R_{b1} = \frac{E_7}{I_3} - \frac{R_r}{8} =$ ________ Ohms. $R_{b2} = \frac{R_b \quad R_{b1}}{R_{b1} - R_b} =$ ________ Ohms.

The above tests should be obtained on typical track circuits having good ballast, and having poor ballast, and under both wet and dry ballast conditions, and with primary and lead plate storage batteries.

Tests made by ________ Observed by ________ Date ________ 19____

Calculations made by ________ Date ________ 19____

Remarks: ________

ARA SIG. SEC. 7022 | SEP. 1930 | MAY. 1931 | M-1931 |

Fig. 16.

Bonding.

10. Bonding must be inspected as instructed and renewed when necessary.

11. Frogs must be so bonded that when removed, track circuit will be opened.

12. Shunt wires must be kept in place and in good condition.

13. Fouling circuits must be so maintained as to avoid breaks or undue resistance.

Insulated rail joints.

14. Insulated rail joints must be maintained and tested in accordance with Instructions for Insulated Rail Joints.

Rectifiers.

15. Rectifiers must be maintained and tested in accordance with Instructions for Rectifiers and Motor-Generators.

Relays.

16. Relays must be maintained and tested in accordance with Instructions for Direct Current Relays.

Shunting sensitivity.

17. When making shunting sensitivity test of a track circuit it should be made by determining the maximum resistance that can be placed across the rails opposite the relay and opposite the battery to cause the relay contacts to open. The maximum train shunt equivalent is usually considered to be 0.06 ohm. (15 feet of No. 16 A.W.G. copper wire has a resistance of 0.06 ohm.)

18. Shunting tests must be made at the clearance point of turnout, with fouling circuit in multiple and immediately adjoining the frog at each end of crossover or either side of insulated joints at center of crossover, as instructed.

19. Shunting tests must be made during dry weather conditions when the maximum current is flowing through the relay coils.

20. Top of rails should be kept free from sand, rust, and other foreign matter that affects proper shunting of track circuit.

21. Resistance between battery and rails must be not less than that shown in Tables of Minimum Allowable Resistance in Series with Track Battery for Standard or Conventional Non-Coded Direct Current Track Circuits. (See page 14.)

22. Minimum limiting resistance allowable in series with track battery must be determined in accordance with Curves for Determining the Minimum Allowable Resistance in Series with Track Battery for Various Train Shunt Resistances and Various Maximum Battery Terminal Voltages, for Standard or Conventional Track Circuits. (See page 17.)

General.

23. When track or other conditions are such that they may cause signal interruption or unsatisfactory operation of signal apparatus, the section foreman or whoever is immediately responsible for such conditions must be

requested to remedy the condition. If such request is not acted upon within a reasonable time the matter must be reported to proper authority in writing.

24. Track circuit connectors and connections must be maintained in good condition.

25. Wire and cable must be maintained and handled in accordance with Instructions for Wire and Cable.

26. Lightning arresters must be properly connected and maintained.

27. Ground resistance test must be made in accordance with Instructions for Resistance of Made Ground.

28. Pipe lines under rail must clear base of rail at least ½ inch.

29. If a track circuit fails to operate properly, check against the following possible causes:

(a) Broken rail.

(b) Loose connections.

(c) Defects in bonding.

(d) Defects in insulated rail joints.

(e) Defects in switch rod, gage-plate or pipe-line insulation.

(f) Low resistance ballast.

30. Experiments or changes must not be made in track circuits except by permission of proper authority.

31. Any unusual occurrences or developments in track circuits must be promptly reported to proper authority.