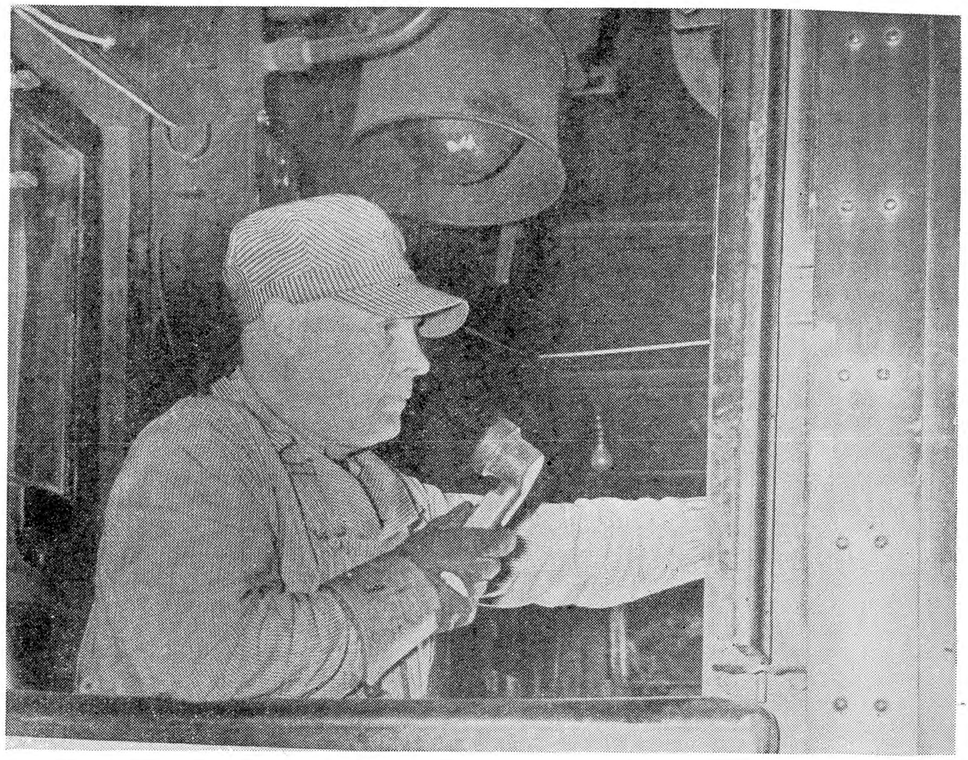

Locomotive engineman using two-way telephone train communication system to talk with train conductor

Inductive Train Communication*

A discussion of the principles of design and operation of the system being installed on the Pennsylvania Railroad

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RECENT study of the uses and requirements for train communication has developed that it will be essential to make available two frequencies on vehicles in main line operation. This is necessary in order to provide an additional channel for high priority conversations that cannot wait for other conversations to be completed and at the same time to provide a system by which it is possible for any operator to break in on all conversations in the affected territory in an emergency.

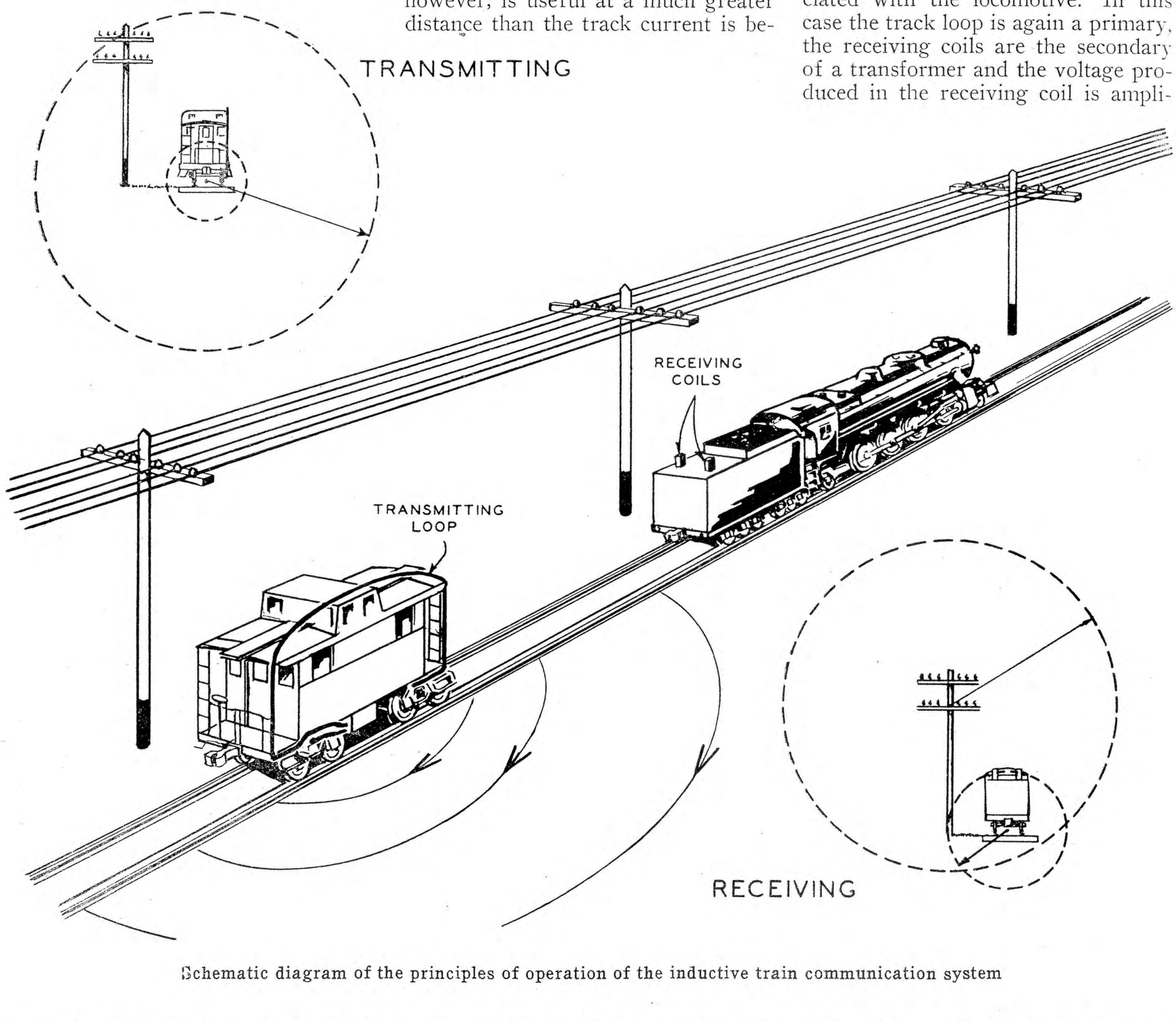
The Inductive Method of Transmission

We shall now take a look at the way in which the communications energy flows from one station to another in our inductive system. An alternating electrical current in a conductor produces fields of two kinds, one known as the radiated field and the other known as the inductive field. The radiated field is the one that is used in the transmission of radio and it is propagated continuously away from the conductor. The inductive field is the one that is used in our train communication system. In the neighborhood of the conductor the inductive field is very much stronger than the radiated field. The inductive field is sometimes called "the field that stays at home." It expands out from the conductors when the current in the conductor is increasing and collapses into the conductors when the current is decreasing. This expansion and contraction of the field has the effect of producing voltages and currents in other conductors enclosed by it, thereby transferring electrical energy from one conductor to another without metallic connection. Perhaps one of the most familiar illustrations of the inductive principle is the alternating current transformer in which the flow of current in the primary winding produces an inductive field by which energy is transferred to the secondary winding, which is electrically separated from the primary. Any field produced by an alternating current in one circuit and linked with another circuit produces this transformer effect and sets up a voltage in the second circuit.

Consider now a caboose and a locomotive on a track with an adjacent lead of wayside wires. We shall assume that transmission is from the

*This is an abstract of a paper presented before a meeting of the New York Railroad Club on October 19, 1944. The first half of the paper discussed the history of the development of train communication, giving in detail the features of train communication developed by the Union Switch & Signal Company and installed on the Bessemer & Lake Erie and the Pennsylvania, see page 665, December, 1943, page 387, July, 1940, and page 152, March, 1944. Dr. Grondahl's paper then explained the reason for further progress in development which has led up to the adoption of the design which is now being manufactured for installation on the Pennsylvania, on 245 miles of four-track main line between Harrisburg and Pittsburgh, Pa., including 275 locomotives, 90 cabooses, and 6 wayside stations.

caboose and that a loop connected to the output circuit produces a magnetic field that threads the body of the caboose. A large part of this field envelops the track under the caboose and induces in the track a voltage in exactly the same way that the current in the primary of a transformer induces a voltage in the secondary of the transformer. This voltage is the result of the fact that the current that we are discussing is an alternating current and the field intensity is at all times changing, being reversed for every reversal of the alternating current. A small variable part of the field also links the line wires and produces a voltage in them.



Schematic diagram of the principles of operation of the inductive train communication system

In the Rails and on the Line Wires

The voltage induced in the track results in a current in the track which travels in the same direction in both rails and returns through the ground and the rails on the other side of the caboose. The rails, together with the ballast leakage to ground, and the ground return circuit, constitute a complete loop, and the current in this loop also produces a magnetic field. Some lines in this magnetic field surround the line wires on the adjacent pole line. This fact makes the wires on the pole line the secondary of a transformer, of which the track loop and the transmitting loop are cooperating primaries, so that here we have another inductive transfer of communications power. The line wires have a high resistance so that the voltage produced in them results in a very small current. This current, however, is useful at a much greater distance than the track current is because the attenuation is very much less. The attenuation in the track is great because the leakage from track to ground is high. The attenuation in the line wires is small because the leakage through capacity to ground is very low. The drop in a lead of line wires in the Middle Division of the Pennsylvania has been found to be about 0.4 db per mile. The result of this low attenuation is that the current travels with a very small diminution for long distances to provide long range transmission from the caboose over the line wires.

Near the locomotive we may imagine a magnetic field produced by the current in the line wires and partly surrounding the track rails. This magnetic field produces a voltage in the rails which again results in a current in a track loop similar to the one that we described in connection with the caboose.

The current in the track loop is accompanied by its own magnetic field, a part of which links the receiving coils shown on the tender deck associated with the locomotive. In this case the track loop is again a primary, the receiving coils are the secondary of a transformer and the voltage produced in the receiving coil is amplified and demodulated in the receiver. The resulting audio frequency currents are used to energize a loud speaker or the receiver of a hand set.

Transfer by Inductive Field

It will be seen that in this transmission, from the transmitting loop on the caboose to the receiving coils on the locomotive, several transfers of energy from one circuit to another are made and that these transfers are all by means of an inductive field. No radiated field is involved in the whole transmission. In all cases the circuits are so near to one another that the inductive field of one circuit effectively links the conductors of another circuit. This character of transmission is the reason for the name, The Union Inductive Train Communication System.

It is apparent from this discussion that line wires are essential for long distance transmission by the inductive method. In fact line wires are essential for transmission from vehicle to vehicle for distances beyond 2,000 ft. Any conductors that parallel the track and are not too far away from the track will help in this transmission. A lead of wires within a distance of 100 or 150 ft. of the track is usually considered entirely satisfactory, although somewhat greater distances may be tolerated. The nearer the leads of wires the less power is required for a given range of transmission. The ranges that have been referred to above are on the assumption that the wires are not more than 150 ft. away.

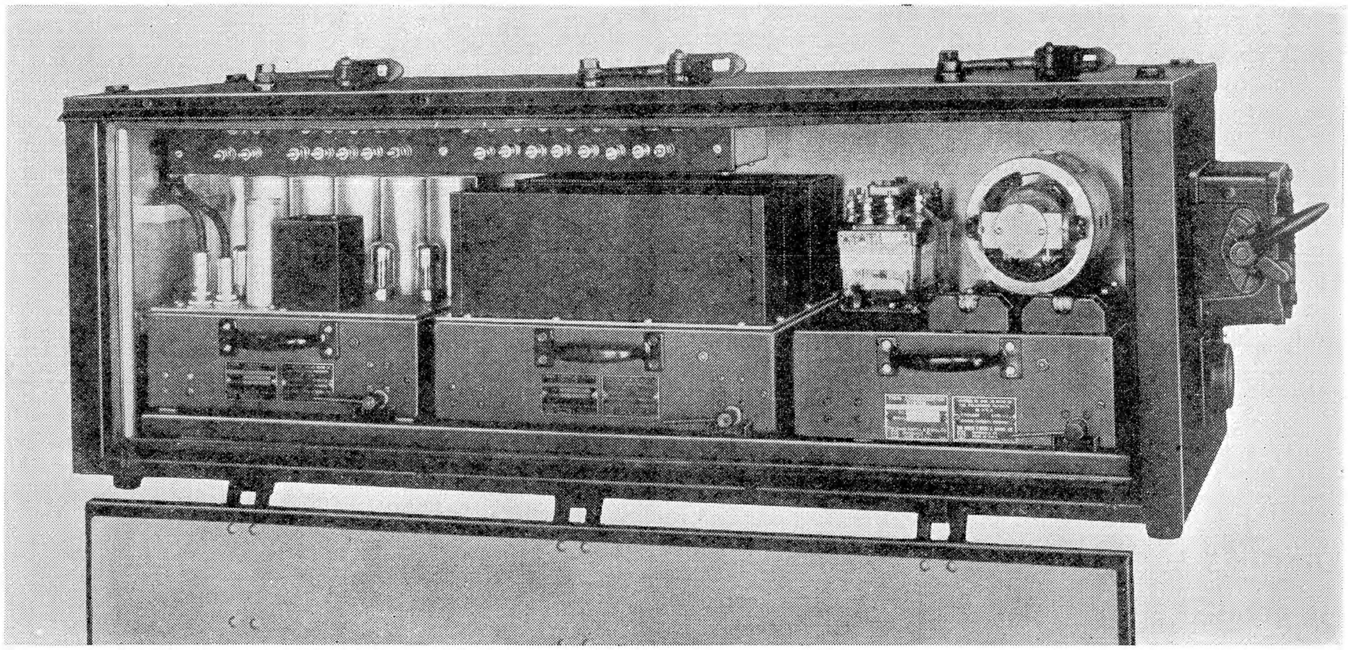
Track Bonding Not Essential

It is apparent also that in our transmission from one vehicle to another we make important use of the track loop, and in such a track loop it is of some advantage to have the rails bonded. This is especially true in the lower carrier frequencies. At the frequency we are using in the Pennsylvania installation the bonding is not so important and we expect that in many applications bonding will not be at all necessary.

In the transmission from an office the coupling to the line wire may be more direct, since the office is stationary. In that case the output of the transmitter is usually connected with one terminal to a line wire or a pair of line wires, and with the other terminal to the track. Instead of connecting directly into the line wire it is possible and sometimes practiced to connect the terminals of the output transformer to two pieces of wire extending for two or three pole lengths in opposite directions along the pole line and connected at their distant ends to the track. The inductive coupling between such a loop and the line wires is quite adequate for transmission and makes it unnecessary to make metallic coupling.

In receiving at a station we are similarly free to use many different methods. The coupling for reception may be to a line wire or a pair of line wires, directly or through a transformer connected between the line wires and the track, or even across a resistor in such a connection, or across the impedance of a short length of rail near the station. At the station it will be seen that the coupling may be either inductive or direct, but in any event there are between the station and the vehicle still at least 2 steps in the transmission which are purely inductive.

It will be seen from all this that the transmission is confined very closely to the right-of-way and is dependent on available conductors so that interference at considerable distances from these conductors is not possible.



Equipment for use on locomotive or caboose in the inductive train communication system

The Union Company is at present building equipment for the installation on the Pennsylvania Railroad. I should like to use the apparatus that is designed for this installation as an illustration of the construction and the operation of the Union Inductive System. The equipment provides two frequency channels on all vehicles and at all wayside stations. The carrier frequencies for the two channels are 88,000 and 120,000 cycles respectively.

We shall first discuss briefly the transmitter and the receiver. The voice currents delivered from the microphone circuit modulate the carrier frequency delivered by an oscillator. The modulation is a frequency modulation and is accomplished by means of a reactance tube which varies the frequency of the oscillator over a predetermined range at a rate which depends on the frequencies of the voice currents. The output of the modulator is amplified in the driver and again in the power amplifier consisting of four 6L6 tubes. The modulated carrier current goes to the output transformer which supplies the energy to the transmitting loop.

At the receiving station, the energy is picked up by receiving coils and is amplified in its received form in two stages of a carrier current amplifier. It is then heterodyned with the output of an oscillator to produce an intermediate frequency which we prefer to choose higher than the carrier frequency. The intermediate frequency which carries the initial modulation is then amplified through three stages, the last of which serves as a limiter. After this amplification it goes through a discriminator which is the frequency modulation term for a demodulator. Here the voice frequency is separated out from the intermediate frequency. The voice frequency is then further amplified and delivered to the loud speaker or telephone receiver. The band of frequencies used in this system is about 6,000 cycles wide, that is 3,000 cycles on either side of the nominal carrier frequency. This makes available a voice band from approximately 200 to 2750 cycles which is capable of giving a very satisfactory reproduction of voice.

Methods of Power Supply

The power supply consists of a dynamotor which is energized from a battery in the case of a caboose or a diesel electric locomotive, and from a headlight generator on a steam locomotive. Wherever possible a 32-volt supply is used. On diesel electrics it is sometimes necessary to provide for operation with a 64-volt, 78-volt, or even a higher voltage supply. This can be done either by a voltage changer consisting of rotating machines or a voltage reduction consisting of the necessary resistors in various forms. It is possible to build the dynamotors with the appropriate primary voltage so that no additional apparatus is required. This seems likely to be the most practical method of handling the various voltages that are likely to be encountered.

The power requirements of the equipment that has been described are approximately 300 watts during standby or reception, and from 500 to 600 watts during transmission. These are extreme requirements and will probably be reduced.

Two-Way, Two-Frequency System

A two-way two-frequency vehicle installation such as is being installed on the Pennsylvania Railroad has one transmitter which is capable of transmitting on two frequencies. The changeover from one frequency to the other is made at the transmitter by means of relays which are controlled from the control panel. Such an equipment has two independent receivers, one for each frequency; one loud speaker, one hand set and two receiver coils, one of which is tuned to each of the two frequencies. The transmitting loop is common to the two frequencies and is tuned to the desired frequency by additional contacts in the same apparatus that selects the frequency for the transmitter.

All the controls are assembled on the control panel and are indirect in that the circuits themselves are controlled over relays which are energized over circuits that center in the control panel.

The operation is as follows: When it is desired to talk on the 88 KC carrier, which we shall call frequency F1, the hand set is removed from its support and a frequency selecting lever on the control box is moved to the F1 position. The lever is latched and stays in this position as long as the hand set is off its rest. The frequency selecting lever in this position energizes the F1 transmitter and the F1 receiver. To send a calling signal, another lever is moved to the position corresponding to frequency F1. The call signal lever is spring return and as soon as it is released by the operator it returns to its neutral position. After the calling signal has been sent, the conversation goes on as with a regular simplex telephone equipment with the use of a push-to-talk button on the handle of the hand set.

Similarly, if it is desired to talk on frequency F2, which in this case we have assumed to be a 120 KC, the frequency selecting lever is moved to its opposite position and the calling signal on this frequency is produced by moving the signal lever to the corresponding position. When the hand set is replaced after the conversation is completed it releases a latch and the frequency selecting lever returns to its neutral position under action of a spring.

To Send an Emergency Call

If it is desired to send an emergency call the signal lever is moved back and forth between its two extreme positions sending a signal on both F1 and F2. This has the effect that any equipment within range will reproduce the calling signal on one frequency or the other, or both. If at any station within range frequency F1 is being used for transmission, that station will hear an intermittent signal on frequency F2, and vice versa. If the station is not being used at all it will hear the calling signal on both frequencies.

When the frequency selecting lever is set on F1, the hand set is connected to frequency F1 and the loud speaker is connected to frequency F2. Conversely, if the lever is set at frequency F2 and the conversation is on F2, the loud speaker is connected to receiver F1. This is done in order to accomplish the result that was just described, namely, to make it possible always to receive an emergency call. When an emergency calling signal is heard, all operators discontinue their conversations and listen for the emergency message.

On the control panel there is a manual volume control which may be used to control the volume of the incoming signal. There is in addition a miniature light connected to the power supply, which when lighted shows that the power is turned on. The energization of the other light, also on the control panel, shows that carrier current is going out over the transmitting loop. A side tone on the hand set shows that modulation is going out over the transmitting loop. By means of the side tone the speaker can hear himself by way of the transmitting loop and the corresponding receiver operating under those conditions at a very much reduced gain. Adequate modulation is indicated by a lamp energized through a discriminator connected to the output of the transmitter. In order to keep the operator informed that his receiving amplifier is in sensitive operating condition, the squelch circuit is so adjusted as to produce a very small amount of hissing noise in the receiver.

Plug-In Mounting of Frames

It remains to point out the nature of the construction of this equipment. The frames, of which there are four, namely, power supply, transmitter, and two receivers, are all arranged to make all necessary connections by simply pushing them into their proper positions on the shelf. A set of plugs at the back of the frame meshes with corresponding sockets built on the shelf. The frames are clamped in position by means of levers that are visible on the front of each frame. By means of this clamping arrangement bars on the frame engage corresponding bars on the shelf, holding the frame rigidly and preventing any motion of one relative to the other.

The method of applying the frames to the shelf has been developed not only for the reasons of rugged construction that have already been pointed out, but also to make the equipment convenient from the standpoint of service and replacement of parts. To remove any one of the frames it is only necessary to throw the lever and pull the frame out. To put in another frame it is only necessary to push it into its position and turn the clamping lever. All frames are interchangeable with corresponding frames in other sets, so that replacement of a damaged part is quickly and easily made.

The interchangeability extends even to the office equipments in that the receiver frames and the transmitter frames that are used on vehicle equipments will also be standard for the office equipments.