Technical Meeting of the Institution

held at

The Institution of Electrical Engineers

Wednesday, November 15th, 1967

The President (Mr. H. W. HADAWAY) in the Chair.

The Minutes of the Technical Meeting held on 28th September, 1967, were read and approved.

The President introduced and welcomed to the meeting Monsieur G. Alt (Associate) who was present for the first time since his election to membership.

The President then requested Mr. H. Duckitt to read his paper entitled " Coded Track Circuits."

Coded Track Circuits

*by H. DUCKITT (Member)**

1. INTRODUCTION

The use of the track rails to act as electrical conductors for signal purposes was first suggested in mid-19th century British patents, but it was the year 1872 which marked the appearance in America of the steady-energy track circuit which in many improved forms has, to the present day, maintained its superiority as a means for train detection. As time progressed, signal system requirements became increasingly severe and to meet some of the problems the coded track circuit was developed. Incentive for coded track circuit development in America appears to have been the need for a continuous train control system to permit speed limit enforcement in accordance with the conditions imposed by multi-aspect signal layouts. At first, two forms of track circuit energy were used, alternating current coded track circuit energy for cab signal control being superimposed upon the steady-energy track circuits used for controlling the wayside apparatus. As development work progressed, it was recognised that coded track circuit energy could operate wayside track relays via suitable code detection equipment; and, in addition, that the coded rail current in each track circuit would also operate the train equipment if the train pick up coil system was mounted ahead of the leading axle and the train was moving towards the feed end of each track circuit. Accordingly the first installation of coded track circuits at Philadelphia in 1933, by the Pennsylvania Railroad of America, was made for the joint control of both wayside and cab signals.

**Westinghouse Brake & Signal Co. Ltd.*

In Great Britain the use of coded track circuits on main line railways has been confined to those sections where the form of code detection used to operate a track relay is advantageous in that it provides a better train shunt than can be obtained with a conventional steady-energy track circuit.

Recently the London Transport Board has stipulated automatic train operation for its new Victoria Line and this has led to the production of coded track circuit equipment using solid state elements in the code generation and code detection units.

It is in the context of train speed control within an automated railway system that there is a future for coded track circuits. Before we consider abandoning the track rails to use cables laid in the trackway for transmitting coded information to a train, we should remember that the coded track circuit can achieve *with safety* the two functions of providing for train detection and for the transmission of coded information to a train. Currently and in the foreseeable future a track circuit would seem to be the most economic way of providing for safe train detection, particularly at major interlockings which are the basis of the signal engineer's art. We should also note that San Francisco has opted to use a system employing coded rail currents for the safety of its extensive rapid transit system, despite having investigated both radar and " wiggly-wire " forms of control. Let us examine, therefore, some of the features of earlier coded track circuit equipment and then look at what can be achieved with modern technology.

2. DEFINITION

A simple description of a coded track circuit is that it is a track circuit in which the steady rail current is interrupted a predetermined number of times per minute so as to form a code consisting of uniform recurring impulses of rail current. By using codes of different numbers of impulses per minute, the current in the rails can be employed to perform functions additional to the basic one of detecting the presence of a train.

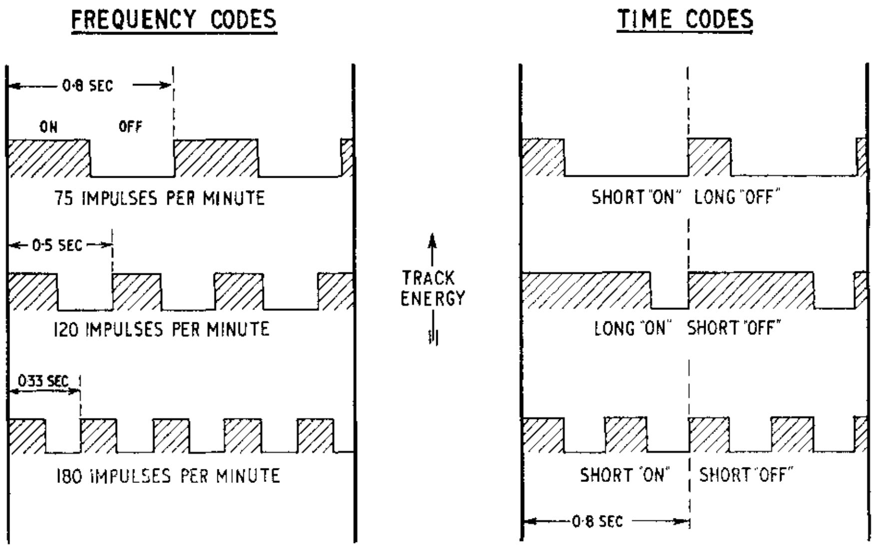

Fig. 1. Frequency and time codes.

3. EARLY CODING SYSTEMS AND THEIR PROBLEMS

The signalling supply current used can be d.c. or a.c. according to circumstances, d.c. being employed where there is no electric traction and battery-operated track circuits operate wayside signalling, whilst coded a.c. track circuits are used where cab signalling is required and where electric traction is involved.

The adoption of low code rates permits the use of electro-mechanical coding and decoding relays whilst facilitating adequate separation of code frequencies from those of commercial and signalling supplies. Either frequency or time codes can be employed.

In a frequency code system the duration of the ON periods when energy is supplied to the track is usually equal to the duration of the OFF periods when energy is removed from the track, and the length of each complete cycle comprising an ON and an OFF period is varied to provide the different codes. Where economy in power consumption is vital, the energy can be applied to the track in the form of recurring short-duration impulses, and this is really a variant of the frequency code principle. The Jeumont impulse track circuit using a differential track relay to detect the impulse repetition rate is a modern example of this latter form of coded track circuit and there is an adequate description of the arrangement in the paper on Train Detection which was presented to this Institution by Mr. B. H. Grose in January, 1964.

With a time code system the cycle length is constant but the time of the ON period is now varied in relation to the time of the OFF period. Frequency and time codes are illustrated in fig. 1.

With long track circuits, or when inductive pick up to train-carried code receiving equipment is involved, there is usually a fair amount of code distortion due to rail inductance and to the time constants of receiving equipment. In consequence, the design of receiving equipment for selective code reception with safety in a time code system becomes complex and frequency codes are preferred.

A simple d.c. coded track circuit suitable for battery operation and using a single code rate appears in fig. 2a. At the feed end of section AT is located the code transmitter CT whose contact 1 makes and breaks continuously to produce one of the frequency codes shown in fig. 1. There is a code-following relay ACFR at the relay end of the track circuit and contacts 1 and 2 of this relay will operate continuously at the code rate with contact 1 supplying local current first to P1 and then to P2 of the decoding transformer. This latter action, continuously repeated, produces a low-frequency a.c. output from the secondary winding of the decoding transformer. Then by the use of the centre-tapped secondary winding shown, in combination with the synchronous mechanical rectification effected by contact 2 of relay ACFR, unidirectional current is available for the energisation of final relay HR.

There are two important factors which arise out of the simple circuit of fig. 2a. Firstly, the repeated application of current of the same polarity to the track rails and ballast can sometimes cause a gradual build-up of residual rail-to-rail voltage if

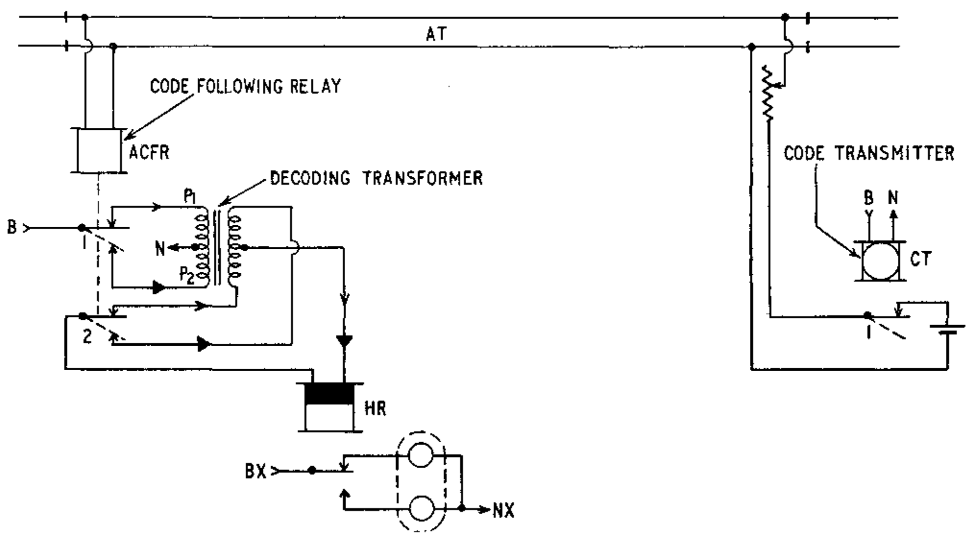

Fig. 2a. Coded track circuit with transformer decoding.

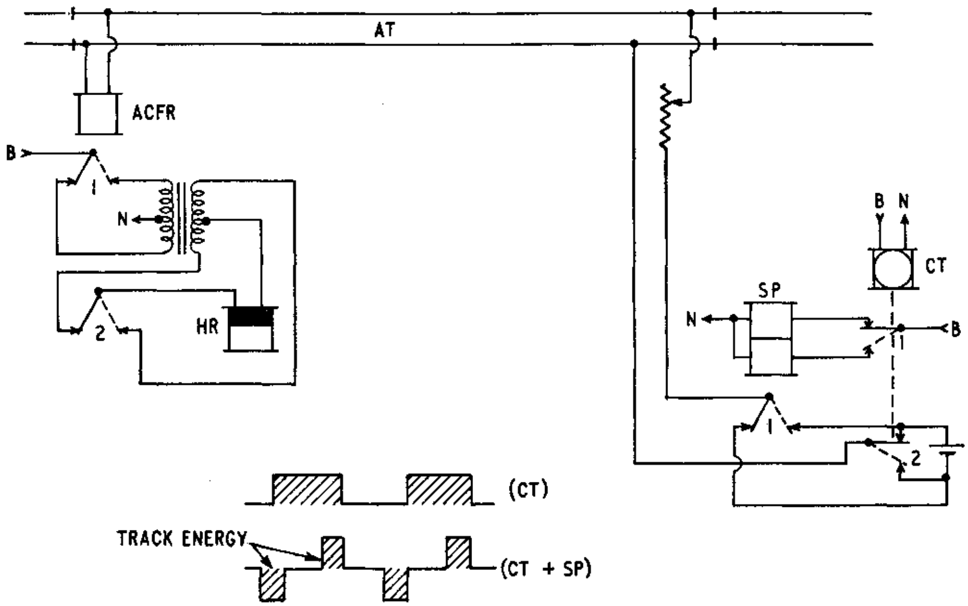

Fig. 2b. Polar impulse track circuit.

the chemical composition of the ballast is such as to give a storage battery effect. This means that the track voltage does not fall to zero in the OFF period of each code cycle and in bad cases the code-following relay may be prevented from following the code rate. Remedial action can take the form of arranging for a de-energised contact of the code transmitter to short-circuit the track during OFF periods of the code, but the best method is to provide code transmitter contacts to apply positive and negative voltages alternately to the track at the code rate.

Fig. 2b illustrates the use of a polar impulse code using a stick polar relay for ACFR and this arrangement provides the advantage of low power consumption in addition to using alternate positive and negative impulses which prevent any storage effect due to track ballast composition.

The second important factor which arises if we wish to develop from the simple circuit of fig. 2a is the safety of any decoding transformer circuit if the local B-N supply, which feeds the primary of the transformer is obtained by semi-conductor rectification of an a.c. supply source. In the latter case there will be an alternating ripple component superimposed on the d.c. local supply and with the code following relay stopped, that is with track occupied, the ripple component will be transformed by the decoding transformer to appear as a.c. in the transformer secondary winding. With the mechanical rectification contact 2 of relay ACFR in circuit there can be no false operation of final relay HR since the latter will not operate to alternating current of ripple supply frequency. However, if we wish to up-date our equipment by eliminating the code-following relay with its continuously operating contacts, and to use some solid-state code-following device to feed the decoding transformer primary, then inevitably we have to contend with a ripple component in the transformer and we do not have the security afforded by synchronous mechanical rectification of the transformer output. In consequence, an alternative safe method of working the HR relay is needed.

Three ways of achieving safety have been found possible, one being to design the special HR relay of fig. 3, which can be connected directly to the decoding transformer output and which will respond only to code frequency but not to a.c. of commercial frequency or higher. A second method, shown in fig. 4, is to use a special decoding transformer incorporating

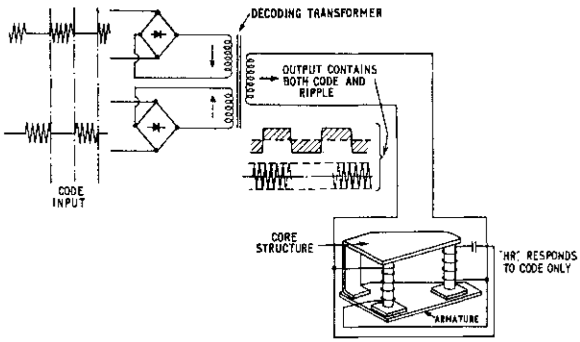

Fig. 3. Decoding with 3-limbed relay.

a magnetic shunt and copper slugs to provide a by-pass for flux due to ripple frequency current, ensuring that only code frequency a.c. appears at the output and allowing semiconductor rectification to be used for normal code energisation of a neutral type direct current HR relay. Thirdly, it is possible to use a decoding transformer followed by a transductor and to arrange for the latter to respond only to a low-frequency code rate from the transformer with the neutral direct current HR relay operating from the transductor output. This latter arrangement has the advantage that additional transductors can be provided to give amplification sufficient to operate a B.R. standard relay requiring 1.6 watts. Use has been made of a decoding transformer—transductor—relay configuration for the wayside code detection equipment on the Hainault-Woodford section of London Transport and this application will be dealt with later when describing the circuit of fig. 10.

Returning now to basic principles and assuming that we require individual selection of one of a number of code frequencies, then the circuit shown in fig. 5 is applicable. In the arrangement shown, the decoding transformer has additional windings to provide a suitably matched output voltage to meet the requirements of the 120 and 180 per minute code rate filter units. Each of the filter units employs a series resonant circuit

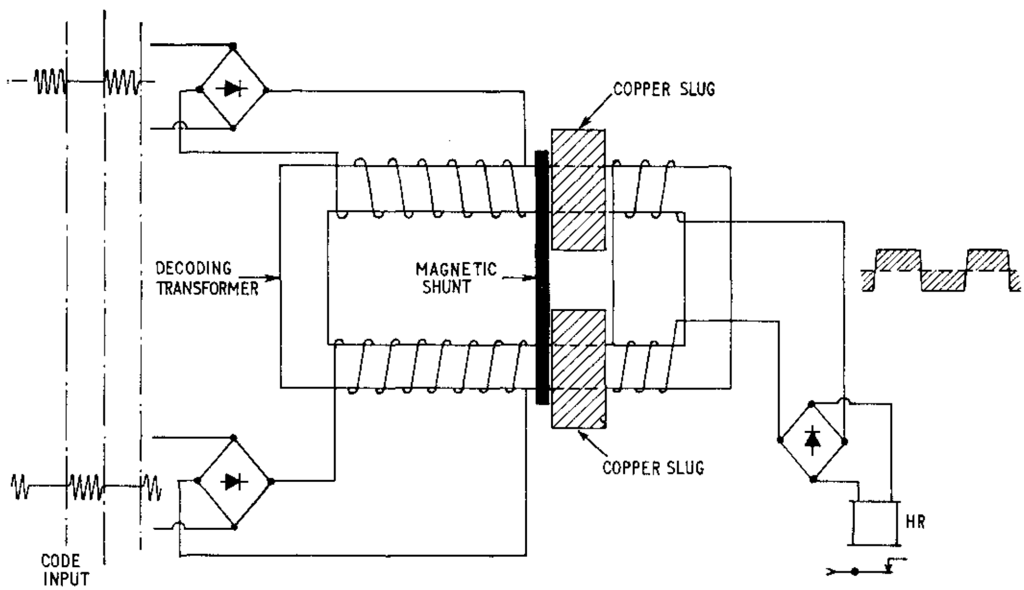

Fig. 4. Decoding transformer to pass code frequency only.

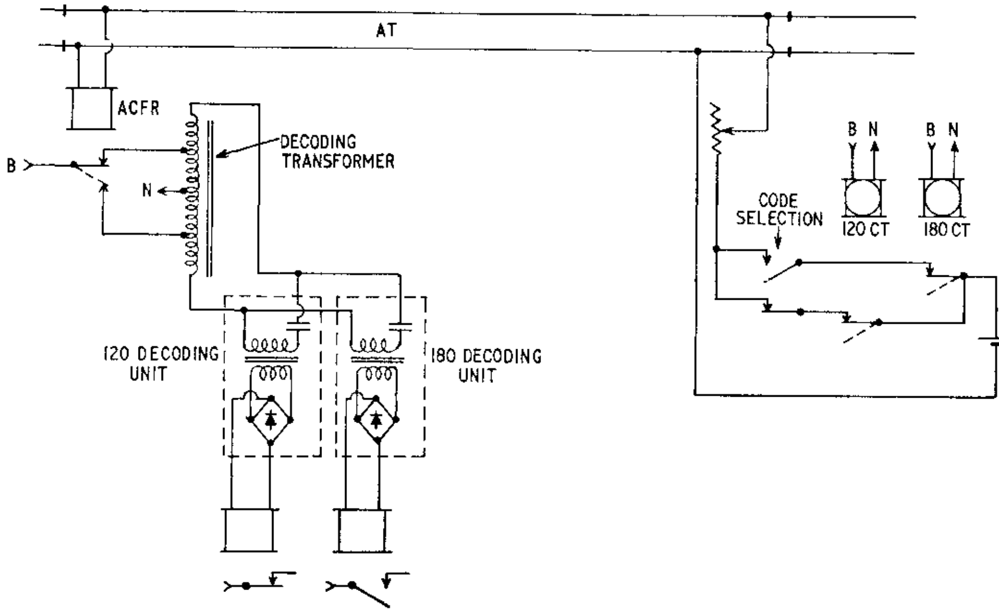

Fig. 5. Multi-code track circuit.

comprising a condenser and a double-wound inductance. The important design feature here is that the specific form of series filter shown is used for code detection in conjunction with pendulum type code transmitters 120CT and 180CT. The code transmitters can be assumed not to drift in code frequency under fault conditions, since each frequency is determined by virtue of the mass and length of a pendulum. Further, the code detection circuits at the relay end of the track circuit can only drift under fault conditions towards a higher resonant frequency. If, therefore, the highest code rate is allocated to the least restrictive signal aspect and the lower code rates to progressively more restrictive aspects, then we have achieved a situation in which any failure in the code detection equipment will result in the display of a more restrictive signal aspect than intended. Selective code filters of the type shown in fig. 5 have been used in train equipment for cab signalling purposes as well as for wayside equipment.

Safety can be seen to depend on what type of code detection circuit is used in relation to the way in which code frequencies are allocated to the various signalling aspects. For example, an alternative form of code detection can select the code frequency by checking the number of code cycles received in a given time interval, and in this case there is the possibility that a fault may lengthen the time period to permit an excessive number of code cycles to be indicated. Safety in this latter system is ensured by allocating the lowest code rate to the least restrictive signal aspect and higher code rates to progressively more restrictive aspects.

An essential feature of the decoding circuits of figs. 2 and 5 is the provision of code-following relay ACFR. The use of such a relay enables a higher train shunt to be obtained than with a steadily energised track relay because the shunt resistance is that required to prevent the code-following relay picking up (prevent shunt) after it has been de-energised by interruption of the track feed due to coding action. This is higher than the drop shunt given by the steadily-energised track circuit. By the use of a prevent shunt, a coded track circuit can solve the problem of a very low ballast track section of moderate length, or can be used for a long section where the ballast is normal. If a coded track circuit is used to give an advantageous train shunt and no specific code frequency selection is called for, then other decoding circuits are possible.

Fig. 6 illustrates a method of detecting

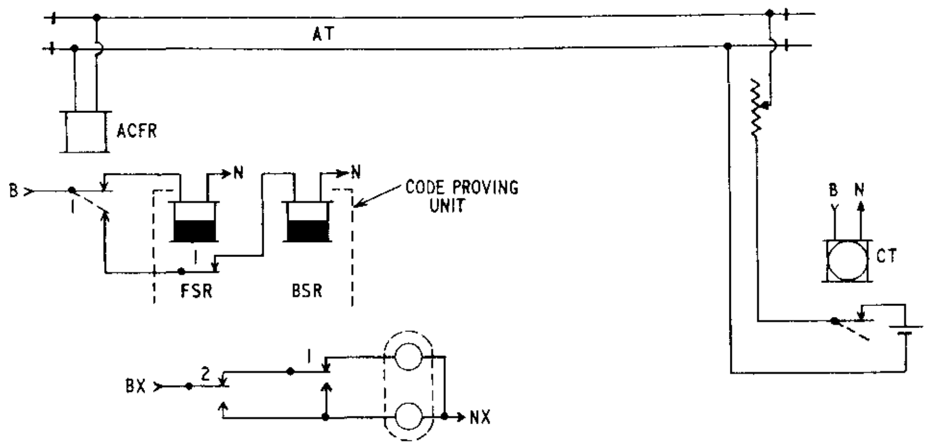

Fig. 6. 2-relay decoding.

code by using relays FSR and BSR in conjunction with the code-following relay ACFR. Relay FSR is slow-release so that it will not drop away during the OFF periods of the code and similarly BSR will not drop away during the ON periods of the code. In order to provide the quickest possible response to the shunting of the track, contact 2 of relay FSR is used to notify occupation, but subsequent indication of track clearance requires the sequential energisation of both FSR and BSR.

This method of decoding can be used to provide an additional function since the track can be energised with steady energy, when relay FSR only will pick up, whilst the application of coded energy provides for the energisation of both FSR and BSR.

A simple form of pulsed track circuit in which the track feed is interrupted approximately 45 times per minute is shown in fig. 7. The code-following relay ACFR follows the code rate and its contacts charge condensers C1 and C2 from the local supply, and discharge the condensers via the winding of final relay HR. For safety, the moveable arm of ACFR is made so that bridging of the back and front contacts is physically impossible.

4. CODE GENERATION

A simple low frequency code can be obtained by interconnecting two relays and arranging that the time constants of

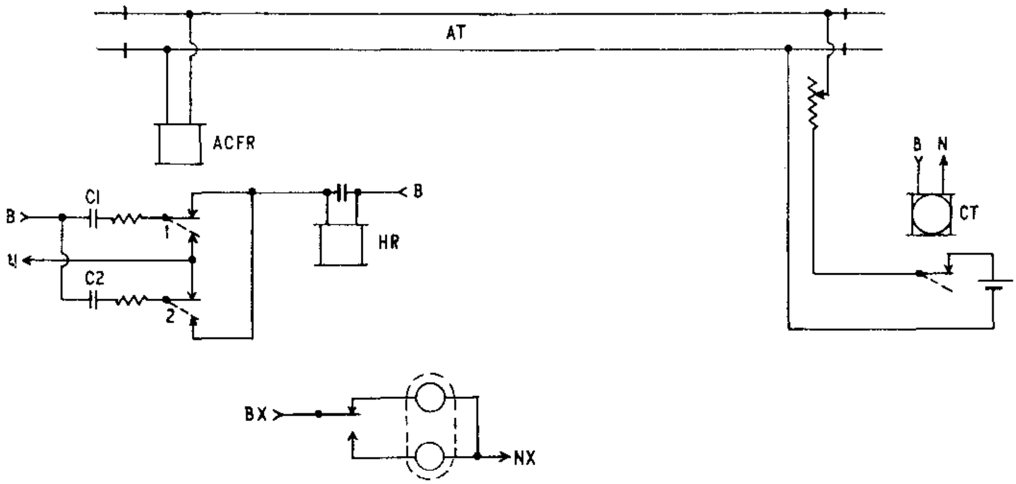

Fig. 7. Pulse decoding.

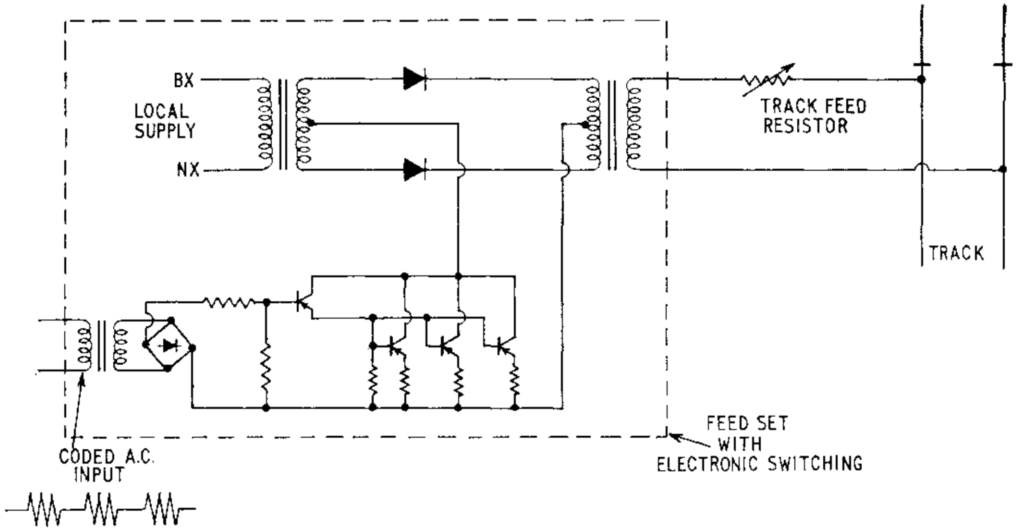

Fig. 8. Track feed set with electronic switch.

the coil-operating circuits are such that the relays alternately pick up and release, at the desired rate. The transmitter for the pulsed track circuit of fig. 7 consists of two separate armatures and contact assemblies mounted in one relay case with a 3-core magnetic structure in which the centre core is common to the magnetic circuits of both armatures.

Where there is a requirement to select signal aspects by using different low-frequency codes, then the integrity of each code frequency relating to a restrictive signal aspect is vital and the code genera-

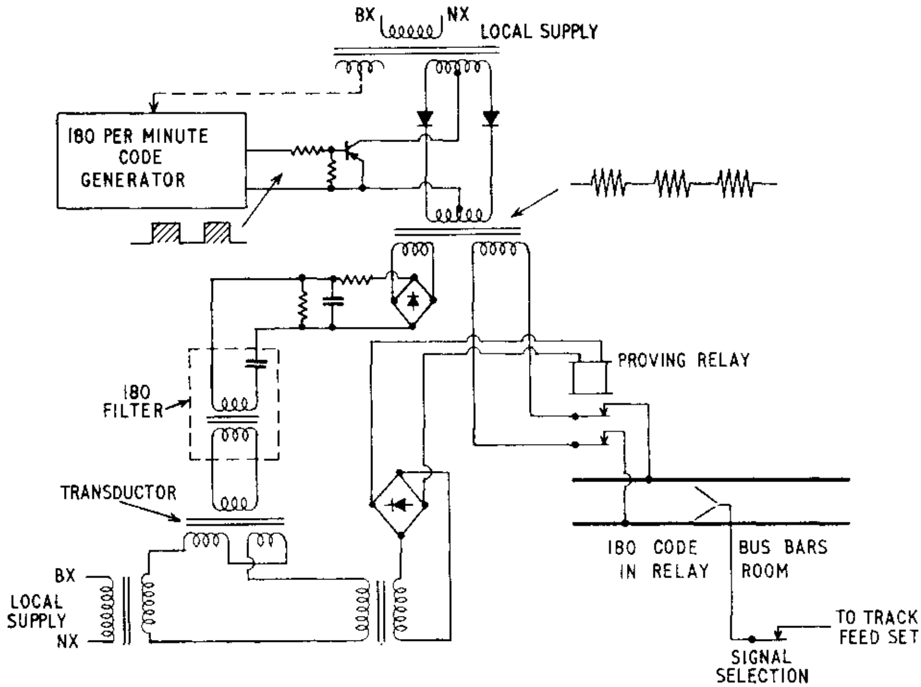

Fig. 9. Solid-state code generator with checking circuit.

tors must be designed with this in mind. In the early days use was made of oscillating code transmitters in which the oscillatory motion of a flywheel was controlled by a coil spring, and the speed was dependent upon the weight of the flywheel and the strength of the coil spring. An improvement in the direction of safety was the introduction of code generators using the mass and length of a pendulum as the basic code-speed determining elements.

Until recent times, code generators have been equipped with contacts both for the maintenance of oscillatory motion and for the switching of track-feed current. Electronics, and particularly the introduction of transistorised electronics, has changed this situation.

Today there are contactless coding circuits which have eliminated the continuously-operating contacts of former years, with a consequent reduction in servicing. A simple all-electronic code generator can be used where the coding frequency is not concerned with a vital restrictive signal aspect, whilst contactless pendulum generators employing electronic circuits for maintenance of pendulum movement and for output purposes, can provide the vital code frequencies.

When using codes for selecting one of a number of signalling aspects, some economy in the use of code-generating equipment is desirable and modern practice is to generate codes centrally to cover a given territory and then allow the wayside signalling circuits to select the code suited to each track circuit feed. In this respect a typical code generator for the London Transport Board's new Victoria Line will be a self-contained unit comprising a power pack, a code generation element and an output amplifier, the whole being capable of operating up to twenty-four track circuit feed units.

The adoption of solid-state coding with central code generation entails the use of a corresponding electronic switch in each track circuit feed set. One method of switching the a.c. feed to a track circuit uses a combination of a diode bridge circuit and transistors and is shown in simplified form in fig. 8. It might be thought that controlled silicon diodes would allow a simpler switching circuit, but intensive tests have revealed that the use of such diodes can cause false coding under marginal code input conditions, whereas the transistor circuit illustrated is free from the possibility of wrong-side failure.

The simple coded a.c. feed circuit of fig. 8 has been used where the resistance of the cable connections to the track rails only amounts to a few ohms. In future, to allow for long feed connections, the output transformer will provide a higher voltage and an additional step-down transformer is being provided adjacent to the point of connection to the track rails. In this latter case the adjustable feed resistance is located with the additional transformer at the rail connection location.

Future coding requirements may well involve the generation of a greater number of code frequencies, each related to the signal instruction for a given maximum train speed. Code generators based on oscillatory motion have a limited range and there are serious design problems for frequencies below 75 per minute and above 270 per minute. Some thought, therefore, needs giving to the design of safe all-electronic generators. One possible solution is to use a simple transistor oscillator which in itself is not safe, and then check the code frequency by using a series filter incorporating a condenser and double-wound inductance for the energisation of a signalling safety type relay. By this means, shown in fig. 9, a code would only be transmitted to switch track feed currents *via* signal circuit selection contacts after the code had been checked as correct, and the solution would appear to be economic where central code generation is acceptable.

5. CODE DETECTION WITH A.C. CODED TRACK CIRCUITS

Steady-energy a.c. track circuits use two-element phase-sensitive track relays and operate with adjacent track circuits in phase opposition, so that in the event of breakdown of an insulated block joint the relay of one track circuit cannot operate from the wrongly-phased track voltage of the adjacent track circuit. Several attempts to achieve a safe phase-sensitive coded a.c. track circuit were made before the satisfactory wayside code detection circuit, shown in simplified form

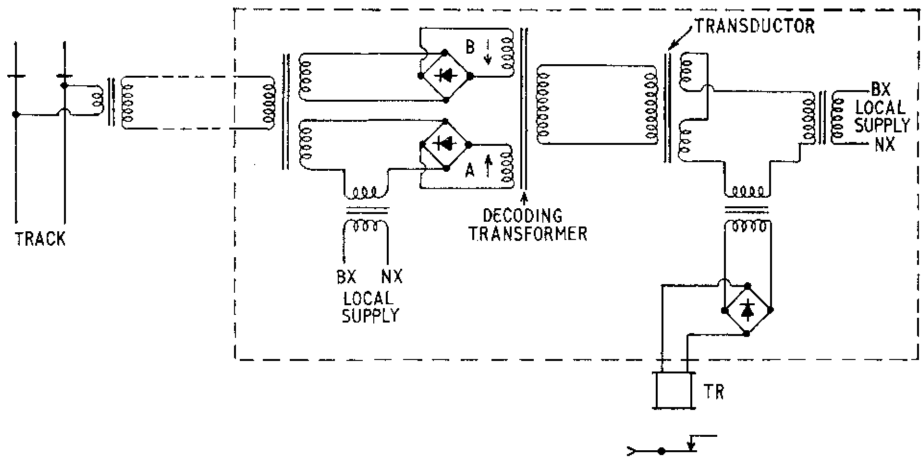

Fig. 10. Phase-sensitive code detection circuit.

in fig. 10, was evolved to deal with the problem of insulated block joint failure. Phase sensitivity is in respect of the signalling supply frequency component of the composite-coded a.c. track circuit feed. The circuit of fig. 10 is used on the Hainault-Woodford section of London Transport and for track circuits up to 2 000 ft. in length there is sufficient power from the track to switch the decoding transformer without the interposition of a code-following device.

In operation, and during the OFF period of a track code, the local supply provides ampère-turns to switch the decoding transformer to one polarity of magnetic flux with the net ampère-turns prominent in winding A. During the ON period of a track code and with correct phase relationship between the local and track a.c. inputs, the current to winding A will reduce due to phase opposition of the local and track voltages. At the same time the current to winding B will rise and the net ampère-turns will be prominent in winding B, thus switching the decoding transformer to the opposite flux condition.

The decoding transformer employs core material having a rectangular magnetic hysterisis loop and a low-frequency output is obtained from the secondary winding only if the core is switched by having net ampère-turns prominent first in winding A and then in winding B. If the track voltage is in phase with the local supply so as to add to the input to winding A during the ON period of a track code, then the decoding transformer is never switched because the net ampère-turns remain prominent in winding A.

A second feature to be noted in fig. 10 is the use of a transductor interposed between the decoding transformer and relay TR. The transductor is of fail-safe design and responds only to low code frequency output from the decoding transformer, but not to the higher frequency output which results from the ripple content in the rectifier source d.c. fed to windings A and B. With one transductor stage as shown, the power available for relay operation is 100 milliwatts but additional transductor stages are possible if more power is required.

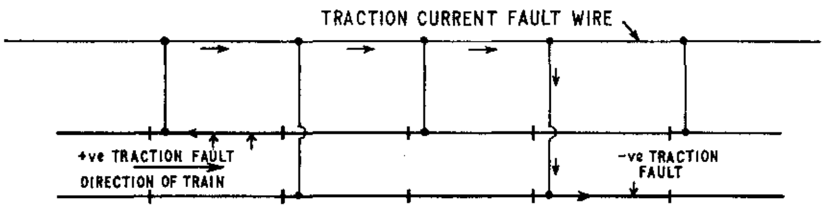

Fig. 11. Traction fault conductor for Victoria Line (L.T.B.).

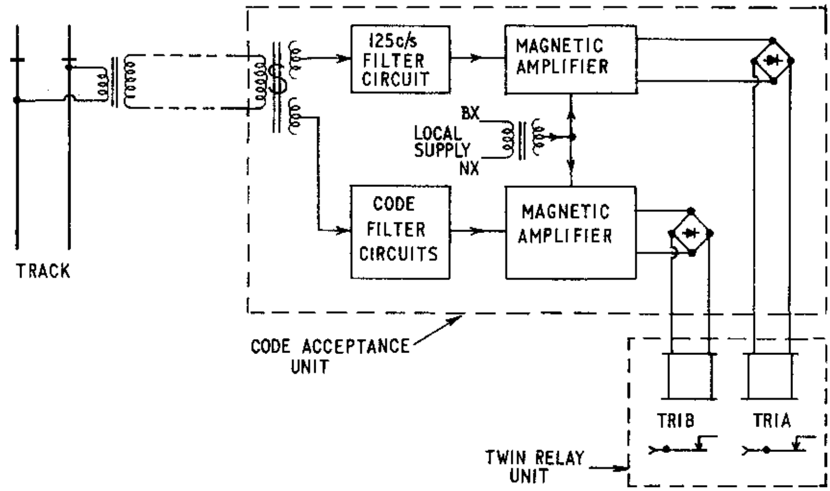

Fig 12. Code acceptance unit for Victoria Line track circuits (L.T.B.).

Code frequency response is determined by the time constants of the decoding transformer-transductor configuration and extends upwards to about 15 c/s compared to the 7 c/s maximum code frequency used for normal track circuit operation.

Mr. H. W. Hadaway in his paper " Fail Safe " presented to this Institution on February 9, 1967, stated that London Transport intends to use coded track circuits having insulated block joints in both rails and employing a connection from one track rail at the entering end of each section to a traction current fault wire. Such an arrangement, shown in fig. 11, deals with problems arising from traction faults and insulated block joint failures when considered in relation to both wayside track circuit equipment and train-carried code detection equipment. Reference should be made to Section 6 of Mr. Hadaway's paper for details of the functioning of the traction fault wire system. Where such a fault wire is used, there is no necessity for a wayside a.c. code detection system to be phase-sensitive. Mr. Hadaway also described the new miniature twin relay unit which London Transport is adopting for future safety circuits.

The abandonment of phase sensitivity and the use of the twin relay configuration have resulted in a new form of wayside track circuit code acceptance unit for the London Transport Victoria Line. Basically there are two important requirements: (1) to detect the presence of current at signalling supply frequency; and (2) to detect the presence of one of the code frequencies. Fig. 12 shows the arrangement in block schematic form. A track transformer is used to step up the track voltage at the relay end of the section and there is little loss due to cable resistance in transmitting back to a code acceptance unit located in a relay room. The input transformer is saturable to limit the possible excursion of voltage input to a code acceptance unit due to track ballast variations. From the output of the saturable transformer the circuit branches: one branch has a filter selective to the signalling supply frequency and this is used to operate one half of the twin relay unit, TR1A. The other branch has code selective filters to operate the second half of the twin relay unit, TR1B Because the power requirements are of the order of two watts per relay, magnetic amplifier circuits wound to meet signalling safety requirements are interposed between filters and relays.

6. REVERSIBLE CODED TRACKS INCORPORATING RETURN CODES

The signal engineer can make use of coding equipment to carry out signalling functions without the use of line wires. For example, during the OFF periods of the code cycle a return code may be transmitted from the relay end to the feed end of a track circuit. This enables

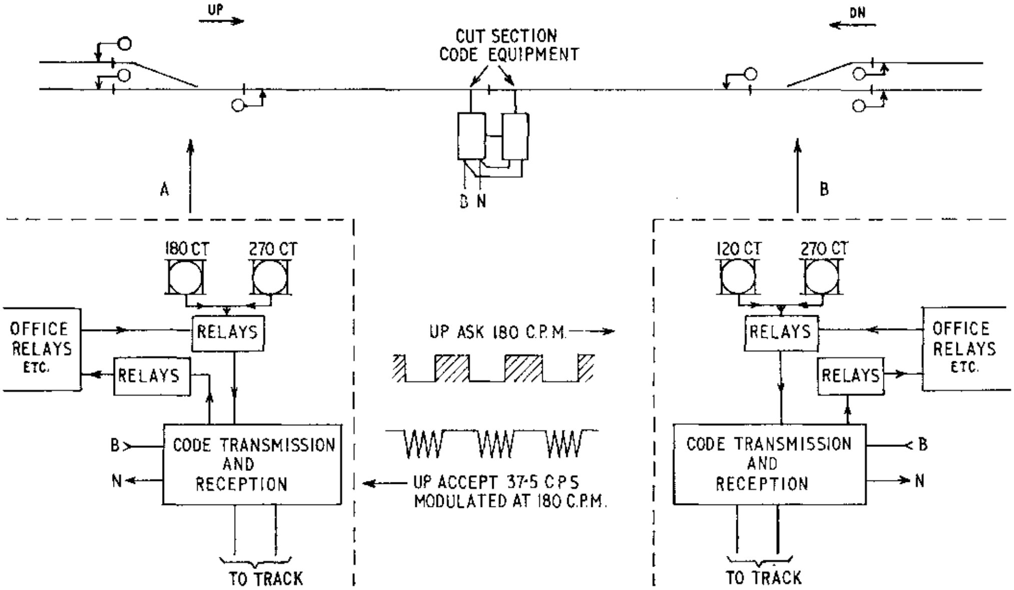

Fig. 13. Single-line block, stations A and B manned.

approach locking relays to be operated or signals to be approach-lit without the use of line wires.

By using reversible coded track circuits with facilities for return code transmission, it is possible to provide for single line block working. The block schematic diagram, fig. 13, shows a single line between stations A and B with the block divided into track sections of some 10 000 ft per section. The overall system design permits the inclusion of additional cut sections and of intermediate signals.

Typically, codes are used in accordance with the following tabulation to allow staff at stations A and B to co-operate in

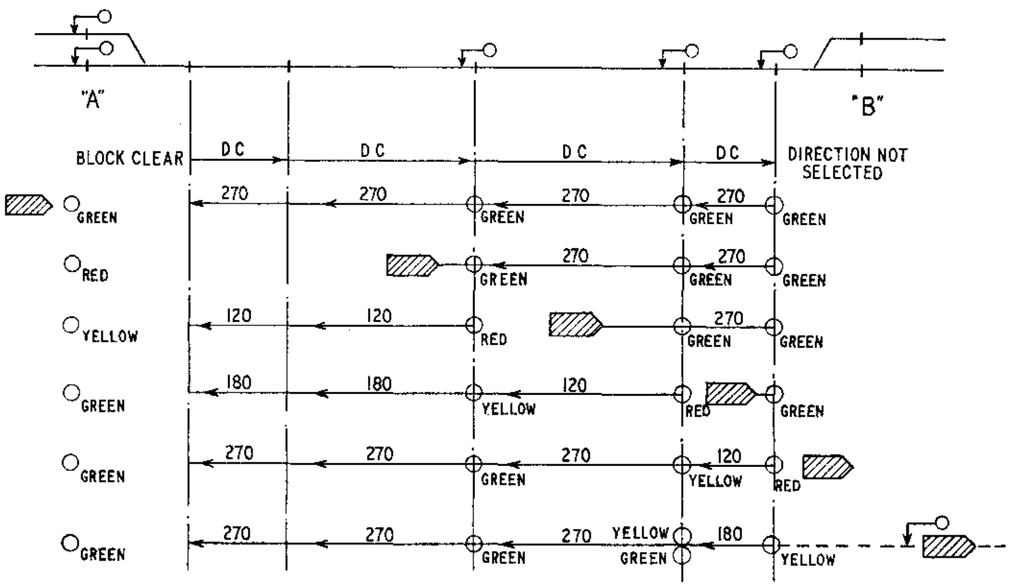

Fig. 14. Single-line block, stations A and B remotely controlled.

passing a train through the section.

Train proceeding from A to B:

(1) Station A transmits 180 per minute code to B to request permission to enter a train at A.
(2) If station B accepts, a 37·5 per second code is transmitted from B to A during the OFF periods of the 180 per minute code existing from A to B.
(3) Coincidence of 180 per minute transmission and 37·5 per second reception permits the starter signal to be pulled off at A.
(4) Train enters section and shunts the entry track leading to a "Train on line" indication at both A and B. Station B can now pull off the home signal.
(5) Train arrives at B and the code condition as per (3) is restored.
(6) Station equipment at A and B is normalised.

Prior to the train entering the section, a cancellation can be effected from A by transmitting a 270 per minute code in lieu of the 180 code. Alternatively, if station B wishes to cancel acceptance before the train has left A, then the transmission of the 37·5 per second code from B is discontinued.

Train proceeding from B to A:

The operation is similar but a 120 per minute code from B signifies a request and a 25 per second return code from A signifies acceptance. Cancellation from the originating station B prior to train departure is by transmitting to A a 270 per minute code in lieu of the 120 code.

The 120, 180 and 270 per minute codes are obtained from contactless pendulum code generators, whilst the higher return code rates of 25 and 37·5 per second are generated by simple electronic circuits. The required code is then used to operate a transistor switch in the d.c. feed circuit to the track rails. One polarity of d.c. is employed for codes in direction A-B and the opposite polarity for codes in direction B-A. Although solid state equipment is used for code generation and transmission, it is economic to use a sensitive polarised code-following relay to receive a code and a contact of this relay controls the feed to a group of selective code filters. Each code filter unit is composed of a series resonant filter and a matching transductor designed to operate a signalling relay.

A further use of coding to facilitate single line working is where stations A and B are remotely controlled from a central office. Fig. 14 illustrates the way in which 120, 180 and 270 per minute codes are used to give correct aspect display for the starter, intermediate, outer and inner home signals. To simplify the diagram, the signals for movement from A to B only are shown but a similar sequence is available for movement from B to A by reversing the direction of the track circuit transmissions on command from the central office. The block clear condition permits steady d.c. when the control switch at the central office is in mid-position whilst movement of the central office switch to select a direction of train movement removes the steady d.c. from the tracks and replaces it with coded track circuit energy in the appropriate direction.

7. JOINTLESS TRACK CIRCUITS WITH CODED RAIL CURRENTS FOR AUTOMATIC TRAIN CONTROL

To meet the requirement for train detection in territory employing continuous welded rail, the signal engineer has adopted the jointless audio-frequency track circuit. For train detection only there is no need for coding, but a future call for more and more automation must be borne in mind and the requirement to add coded rail currents for automatic train control needs consideration.

Probably the best-known jointless track circuit, and one used in Great Britain, is that originated by the Aster Company of France. There are two forms of Aster track which should be examined: fig. 15 shows the early "Z" bond configuration already in use for the demarcation of the track circuit sections; whilst fig. 16 illustrates how the new higher-powered version is used.

We have to consider whether the arrangements of figs. 15 and 16 can be used by simply coding the existing audio-frequency rail currents or whether we must superimpose coded rail currents at different audio frequencies for train control purposes. If neither solution is possible with the known Aster systems, then what type of jointless track circuit will meet the requirements both for train detection and for the transmission of safety information to a train?

If we add coding to each of the audio-frequency currents used for train detection in a jointless track circuit system, then we shall complicate the wayside electronic receivers used for track relay operation and the train-carried equipment would have either a relatively wide band receiver or would be complex in order to select carefully each of the track circuit carrier frequencies. Further, the number of safety codes which could be transmitted to a train would be equal to the number of code frequencies used and wayside code generation would be complex and expensive if the number of codes, each representing a maximum speed limit, increased to between five and nine in future systems of automatic train control.

The correct solution would seem to be to retain the existing steady-energy audio-frequency range of currents for train detection and to superimpose one or two coded audio-frequency currents for transmission of information to a train. Two audio frequencies can provide six distinctive commands to a train if two code frequencies are used, and nine distinctive commands if three are employed.

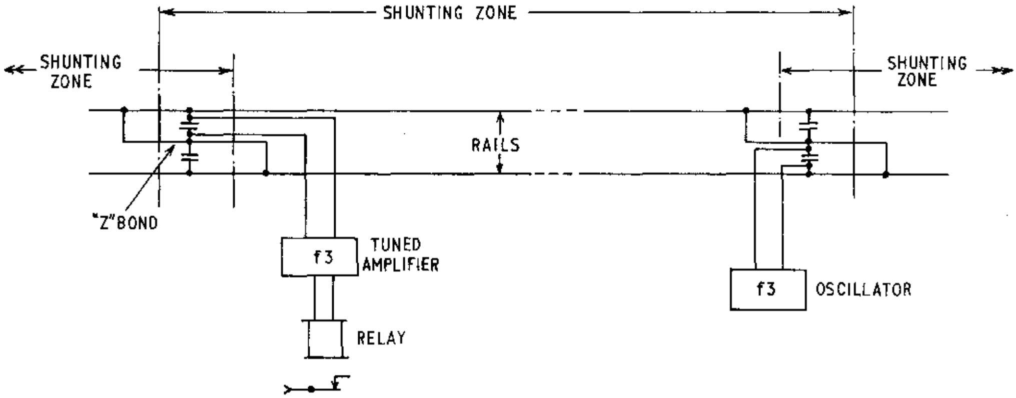

Fig. 15. " Aster " track circuit with " Z " bonds.

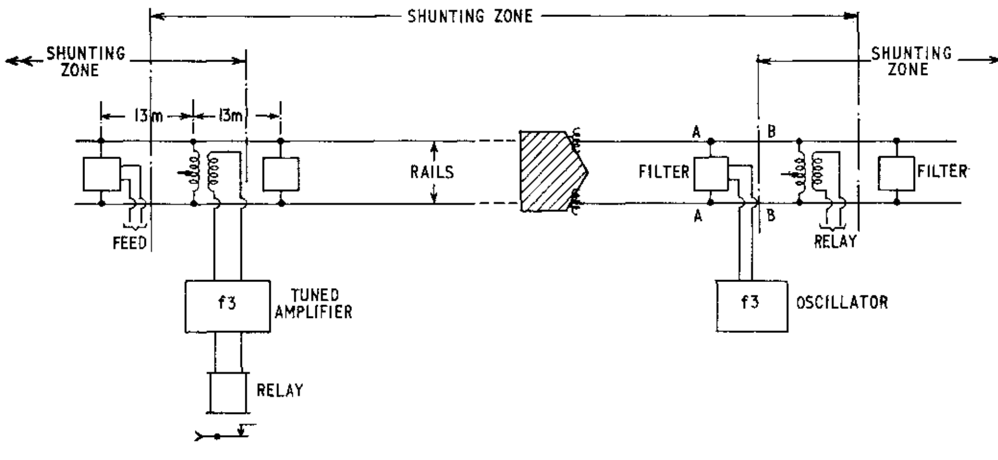

Fig. 16. " Aster " track circuit, style " U ".

The track circuits of figs. 15 and 16 have two disadvantages when considering the addition of one or more audio frequencies for information transmission to a train.

In the first instance the electrical filter circuits, which are composed partly of rail inductance and used as a demarcation between two adjacent track sections, will select only the two audio frequencies associated with train detection in those sections. Additional train information frequencies are therefore become an embarrassment.

Secondly, we must consider that a train moving from one section to the next needs to retain code information for the first section up to a given leaving point and there must then be a smooth and instantaneous change to the code appropriate to the second section. Jointless audio-frequency track circuits have a small overlap zone in which it is necessary to avoid mixed code reception. This can be done by transmitting code to a train only when the track relay for a section is released on occupation of the section, and arranging that this action also cuts off the code transmission to the previous section.

If this latter principle is applied, then the circuit of fig. 16 allows a gap in information transmission to a train from the position when the front axle reaches A-A to the point B-B, when the track relay for the next section releases. Taking this factor into account, it is unfortunate that of the two arrangements shown in figs. 15 and 16, only the one in fig. 16 is liable to be accepted for train detection purposes in electrified territory in Great Britain due to the need to ensure that a train remains detectable under broken rail conditions where electrical inter-road cross-bonding exists.

If we analyse the foregoing conditions relative to the requirements for combining train detection and coded train information in a system of jointless track circuiting, we find that a solution requires the various audio frequencies associated with the demarcation of two adjacent sections to be transmitted and received at one and the same physical position. Further, the electrical filter circuits need to cope with both train detection frequencies and coded information carrier frequencies so that the use of the track rail inductance as part of the electrical filter network is inconvenient.

The system illustrated in figs. 17 to 22 inclusive provides a satisfactory solution to the problems outlined and has been used with success for the Montreal Expo 67 transit expressway.

Fig. 17 shows the simple audio-frequency track circuit as used for train detection. It comprises a transmitter, the running rails of a section of track, a receiver and track relay, a small impedance bond known as a " Mini-Bond "

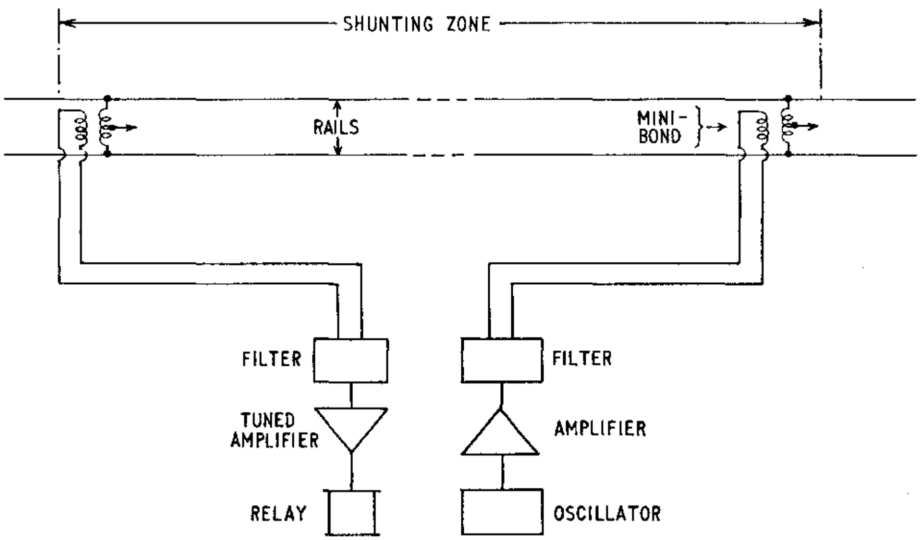

Fig. 17. Mini-Bond track circuit simplified.

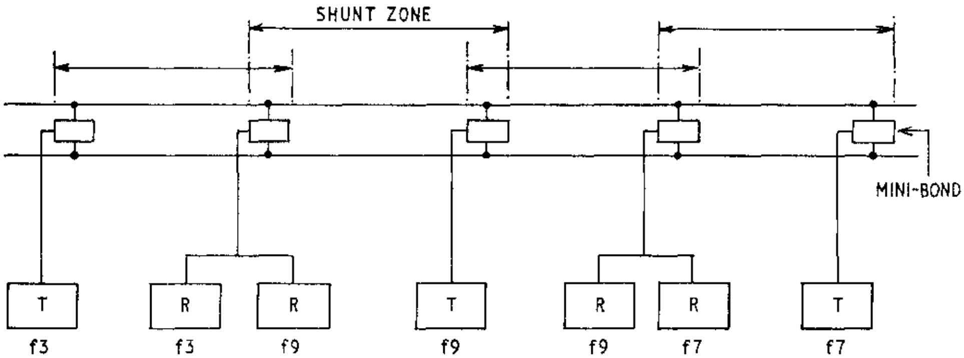

Fig. 18. Mini-Bond track circuit audio-frequency assignments.

and cable. The Mini-Bond with a centre-tapped track winding permits the use of both running rails for traction return current whilst allowing connection for traction current to pass to an adjacent track road or to a substation. A high-voltage secondary winding on each Mini-Bond is used to couple audio-frequency transmitters and receivers to the running rails through cable; this allows for centralised housing of the transmitters and receivers. A single audio-frequency transmitter may feed two track circuits, one in each direction along the track, and a typical frequency assignment is shown in fig. 18. To allow for both short and long track circuits, and to permit the use of different frequencies for adjacent track roads, some ten frequencies in the 2 to 5 kc/s range may be required.

Fig. 19 shows the additional equipment required for code transmission to a train whilst fig. 20 illustrates a composite arrangement of wayside equipment.

The train command code equipment for Montreal Expo 67 uses audio frequencies of 990 and 1 170 c/s with code rates of of 7·5 and 10·0 per second to provide the speed commands listed below—

Speed, m.p.h.	
0	Absence of any signal
10	990 modulated at 7·5 per second
20	990 modulated at 10·0 per second
25	1170 modulated at 7·5 per second
30	1170 modulated at 10·0 per second
45	990 and 1170 alternately at modulation rate of 10·0 per second
Special	990 and 1170 alternately at modulation rate of 7·5 per second

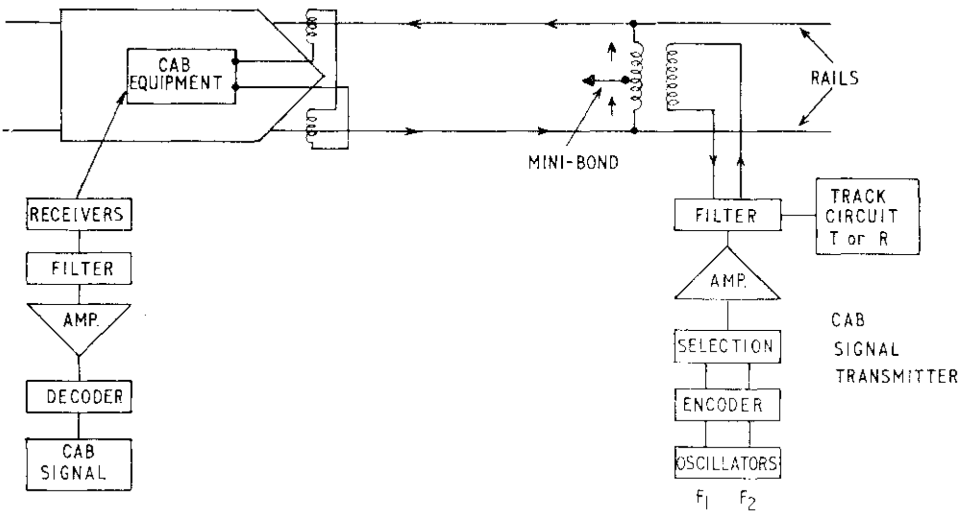

Fig. 19. Superimposed coding equipment for train control.

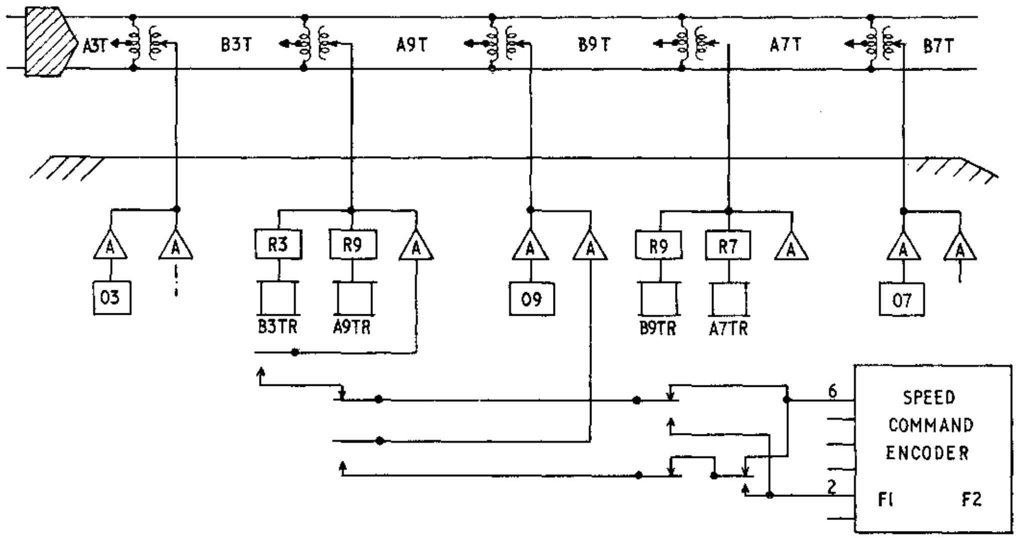

Fig. 20. Composite wayside equipment for train detection and train command.

A block schematic of the code modulator is given in fig. 21, whilst fig. 22 illustrates the train receiver and decoding logic. It will be apparent that the use of one additional code rate would allow for three additional speed commands. To achieve good demarcation between adjacent track circuit sections, the impedance of the wayside electrical circuits is low when reflected at the track rails by a mini-bond. In consequence the train shunt obtainable at the mini-bond positions is liable to be of the order of 0.1 ohm, although a higher value will be obtainable at intermediate positions. This complies with Association of American Railroads' practice, which requires that shunting tests for a track circuit must be made during dry weather

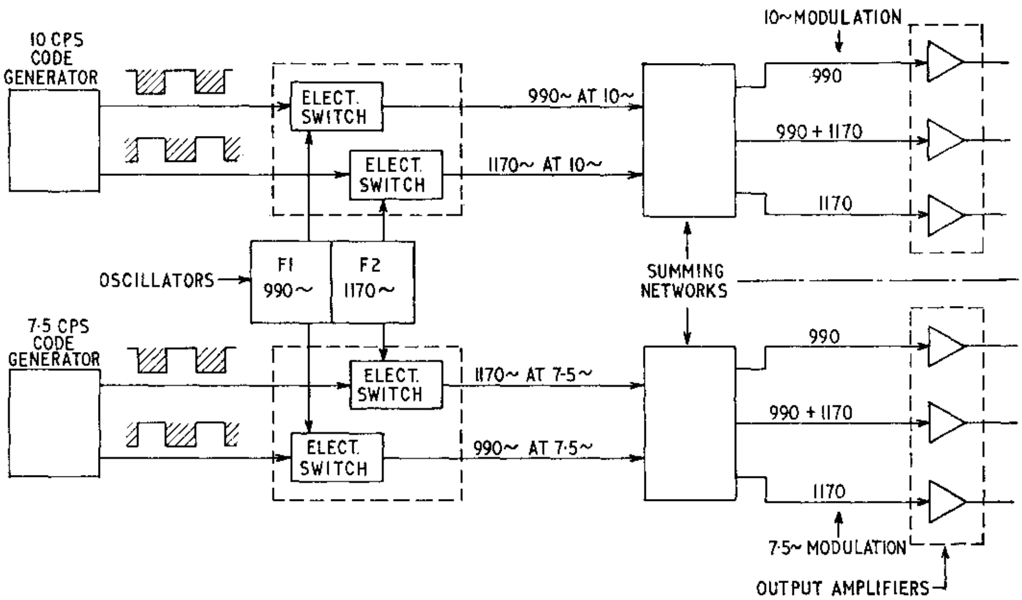

Fig. 21. Principle of encoding.

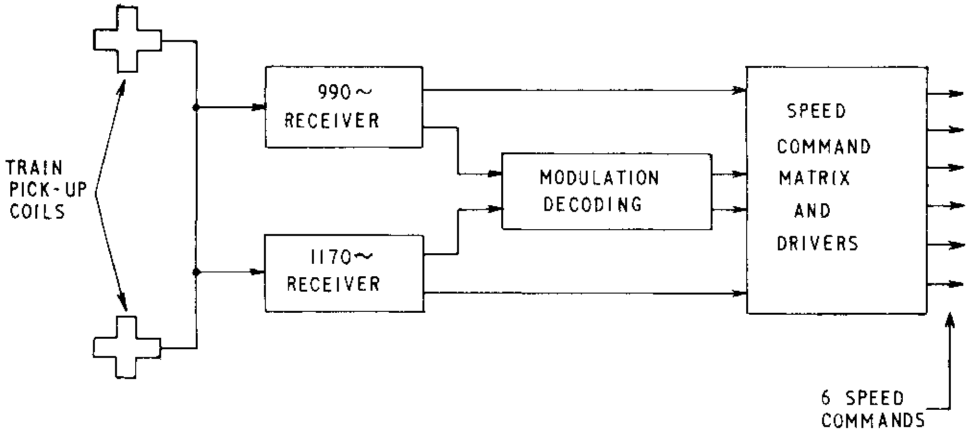

Fig. 22. Principle of decoding.

conditions when the relay energisation is a maximum and only if the shunt resistance is less than 0.06 ohm must corrective measures be taken.

The relevant practice for British Railways is given in the instructions to staff engaged on maintenance of signalling apparatus and reads as follows:—

"The drop shunt resistance should always be noted when testing track circuits. The drop shunt resistance of all track circuits except those with impedance bonds should not be less than 0.5 ohm at any time. On impedance bond track circuits the drop shunt resistance should not be less than 0.3 ohm. Where these values are difficult to attain the Technician should report the matter to his Technician in Charge or Inspector".

The rules for track circuit testing and the choice of train shunt value would appear to be very arbitrary. If we are to take full advantage of jointless track circuits and provide coded command information to a train in addition to train detection, then a review of current practice in relation to train shunt values would appear to be timely.

8. CONCLUSION

Relatively only a few of the possible applications for coded track circuits have been dealt with in this paper. Applications using frequency codes have been described and these meet the safety requirements called for in railway signalling. The possibility of using time division multiplex coding systems with a form of security checking must not be overlooked. However, before a time division multiplex system can be used for safety purposes, there must be consideration as to the way in which an adequate security check can be made. This will not be easy, since fault analysis is difficult due to the complexity of components and circuitry in a time division code system.

8.1 *Acknowledgments*

Finally, I wish to thank my colleagues for their help in the preparation of this paper and to the management of the Westinghouse Brake and Signal Co. Ltd. for permission to present it.

DISCUSSION

Mr. R. Dell, in opening the discussion, congratulated Mr. Duckitt on his comprehensive and detailed paper. Submission of a paper on this subject was most timely as he believed that coded track circuits were of growing importance. Mr. Duckitt was undoubtedly an authority on the subject, and he was glad to take this opportunity of expressing his thanks to him for the help he had given London Transport in developing coded track circuit equipment for use in automatic train operation. He also agreed entirely with Mr. Duckitt's statement that the rails were still the best form and means of supplying circuits to detect the presence of trains, and that they offered many facilities for conveying signals to the train.

In all signalling equipment, reliability, in addition to safety, was a very important feature and coded track circuits of the contactless type could give very reliable operation. Some features of the results obtained by London Transport in the use of coded track circuits on the Hainault Loop might be of interest. There were 81 track circuits on the Hainault Loop and after the first year, when they did have some trouble with the failure of transistors (eventually traced to the use of a resonant circuit, which, as mentioned by Mr. Duckitt in his description, had now been removed), the reliability had much improved. During the last year-and-a-half of experience with these 81 coded track circuits they had had four failures. One was caused by a broken rail connection, one by a faulty code generator, one by a faulty track feed set, and the cause of one was unknown. " Cause unknown " meant it was working when the lineman attended and it had not failed again.

Mr. Duckitt had mentioned some of the equipment which was being provided for the Victoria Line and one or two things deserved comment. Fig. 8 in the paper showed the track feed set with the electronic switch which they proposed to use on the Victoria Line. The important difference between this circuit and the one experimented with on the Hainault Loop was the use of a.c. coded input, and the particular advantage of this arrangement was that by the use of the transformer (shown on the left-hand side of the diagram) the coded supply was isolated and avoided commoning up the positive side of the transistor system, which was necessary if d.c. pulses were used. He thought this was an important feature of the circuit—commoning up a lot of d.c. currents with separate feeds could result in unreliability.

The code acceptance circuit which had finally been selected for the Victoria Line was shown in Fig. 12. In deciding to use this circuit, he gave up the phase sensitivity feature of the previous circuit with some reluctance, but he believed that the circuit now decided upon was a good one, using, as it did, completely separate circuits for operating the two relays of the twin relay set. He asked Mr. Duckitt if he would comment on the relative safety features of the circuits shown in Fig. 12 and Fig. 10.

As to jointless track circuits, the arrangements shown for providing codes suitable for conveying signals to trains and combining this with jointless track circuits offered very interesting possibilities and he had no doubt that they must be seriously considered in future. When doing so however, he thought that Signal Engineers would have to be very careful to be certain that the full safety factors were maintained and in this regard there was one point which caused him some concern. The point was that with the audio frequencies used, and assuming fairly long track circuits, the current employed in the rails must be relatively small. He would expect this to result in a very small signal pick-up, and this in turn would result in a very high degree of amplification in the receiving equipment. Could Mr. Duckitt give some figures for the currents which would be used for the coded circuits and what values these currents would produce in the receiving coils before amplification ? If his assumption was correct that the pick-up signal was small, did not this cause a risk of interference from adjacent circuits or from other sources ? On London Transport they had had some experience with the possibility of interference between adjacent circuits, and Mr. Duckitt had referred in the paper to the use on the L.T. system of block-joints in both rails where coded track circuits were employed. This arrangement was adopted after the early experiments on the Hainault Loop, when they had blockjoints in one rail only, which showed that there was quite serious interference between codes arising from adjacent circuits. It was mainly to clear this trouble that blockjoints had been put in both rails. Could they be sure, if they had track circuits without blockjoints, that there would be no risk of interference between codes on adjacent circuits (he was thinking that there could be more than one track in the vicinity).

With regard to train shunt values. Mr. Duckitt had trailed his coat in the paper and had made quite certain that the point was not missed. He proposed that a review should be made of train shunt values. Mr. Dell had intended to ask if he meant that we would lift up the American to British values or *vice versa*, but Mr. Duckitt now seemed to have made that point clear. He thought, however, that any study of train shunt values must be done in conjunction with a very full knowledge of what the wheel/rail contact resistance actually was. On London Transport they had for many years maintained a one-ohm figure for train shunt and had continued this in their coded track circuits. This was higher than the 0.5 ohm that Mr. Duckitt mentioned. Now they had also carried out some tests of rail/wheel contact resistance and the figures obtained, measured with the train moving, varied from 0.03 ohm per axle to 0.6 ohm for an individual axle. These figures were comparatively high resistance and showed that even with a clean rail the wheel contact resistance was not always as low in value as could be hoped and could involve a lack of safety unless it was ensured that the train shunt was maintained at a high value.

Mr. Dell said in conclusion that he thought Mr. Duckitt's paper would be referred to many times in the future, because he believed that coded track circuits were coming into increased prominence.

Mr. H. Duckitt, replying to Mr. Dell, said that regarding the relative merits of the circuits of Figs. 10 and 12, the arrangement shown in Fig. 12 provided for much improved frequency discrimination in respect both of the alternating signalling current and of the code frequency content of that current. This improved discrimination was the technical reason for using the circuit for the London Transport Victoria Line.

Considering for a moment what was done to detect appropriate track circuit coded commands to a train, it would be found that the usual procedure for the train-carried equipment was first to detect receipt of a.c. of correct frequency, i.e. 125 c/s in the case of London Transport. After selection of this signalling current, the code content was detected and the appropriate output circuit operated. With track circuit code detection the circuit of Fig. 10 operated in a similar manner (i.e. signalling frequency first and then code detection) whilst in Fig. 12 the signalling frequency and code detection were carried out in parallel, but both must be present for relay operation. For safety, either method would suffice.

Because London Transport had separate positive and negative conductor rails, and because they had adopted the use of a traction fault wire in the configuration of Fig. 11, it had been possible to use the code acceptance circuit of Fig. 12, which did not detect the phase of the alternating current component of the coded track circuit current. However, if a.c. coded track circuits were to be used with an electrified railway using the running rails for return current, it would seem very desirable to retain a phase-sensitive detection circuit such as that of Fig. 10 in order to guard against false track relay operation under the fault condition of a shorted insulated blockjoint.

Compared to the coded track circuit voltage and current levels used at present by London Transport, any audio-frequency jointless track circuit would provide very low values at the relay end of a track circuit. Relay end rail current could be as low as one hundred to a few hundred milliamp., which was very small when related to the 4 amp. used by London Transport today. The power available from the pick-up coil on a train for operating train-carried safety equipment would, with audio-frequency jointless track circuits, be measured in microwatts; he could not give an exact figure.

Crosstalk between adjacent tracks and between adjacent track roads was a more severe problem with jointless audio-frequency track circuits than with commercial-frequency conventional track circuits. Satisfactory operation of the Aster style 'U' and the American Mini-Bond equipment indicated that the problem of crosstalk could be overcome. He had a personal reservation in respect of using audio-frequency equipment at point layouts, and until he knew more he would prefer to use conventional lower-frequency track circuits at points for train detection and to use coded audio-frequency current in cable layed in the trackway if train commands were required in an overall audio-frequency cab signalling system.

In the context of train shunt values, he agreed with Mr. Dell that a full knowledge of wheel/rail contact conditions was vital. With the advent of audio-frequency jointless track circuits, it would seem that the time was ripe for a review of the whole train shunt problem.

Mr. V. H. Smith joined with Mr. Dell in thanking Mr. Duckitt for his interesting paper and also for showing the Expo film. At the end of the film, Mr. Duckitt had revealed a secret. If he might reveal another one, when the train was running in automatic on test, the gentleman on the front said " It seems to be all right". What the film did not tell the audience was that the train was proceeding towards the terminal station which had the buffer stops immediately at the end of the platform, so that if it didn't stop . . . . ! Incidentally the relay room was built immediately beyond the buffer stops. He could only say it was " built-in suicide".

He was particularly interested in the portion of the paper devoted to jointless track circuits, having recently had the opportunity of inspecting audio-frequency track circuits installed in North America. These at the moment were being installed in Chicago and New York and it was proposed to use them in the near future in Boston. The only actual installation in work that he saw was on the automatic train mentioned in connection with Expo '67. The Mini-Bond to which Mr. Duckitt had referred, forming in these installations an impedance bond, was, of course, in itself an attractive piece of equipment from a size point of view for railways which used the running rails for the return traction path. On the elevated railway in Chicago all the tuning circuits were contained in a box mounted in the 4 ft. way. One might almost write a paper on the merits of putting the tuning circuits there, or putting them in the relay room.

He felt the reliability of the signalling system could be greatly improved if blockjoints could be reduced in number, or better still entirely eliminated. When he saw Expo they had got blockjoints in at the crossing, so he rather thought Mr. Duckitt's American colleagues had had second and perhaps later thoughts. However, in considering proposals for alternative track circuits one must be assured of the reliability of the new proposal. He did not think it difficult to make the circuits reliable functionally, but was concerned about the possibility of false operation.

They had already talked about the shunt value of 0.06Ω obtained, which was quite acceptable to their American colleagues. Mr. Dell also talked of the tests carried out on a limited number of trains in which they found on one train a rail/wheel, wheel/rail resistance of 0.6Ω. This was quite alarming ; admittedly in the particular test we took this axle was right in the middle of the train, which would not be too dangerous on its own, but one had to remember that if the end axle was the high resistance one, then one had still to detect this when it was the last wheel or the first wheel standing on the track circuit.

The tests giving this value of 0.6Ω were carried out using d.c. and 50 c/s. In fact, using 50 c/s, obviously one was measuring the impedance and there was no appreciable difference, which no doubt was what one would expect. But he also wondered what happened when one started using audio-frequencies, and whether the inductance of this contact became important, in which case the impedance was now producing the shunt and not the resistance, and the resulting impedance would be higher.

Another disturbing feature to his mind was that as the train entered the track circuit at the relay end, it short-circuited the track feed voltage and the relay, but as the train proceeded along the track circuit, whilst it maintained a short circuit on the track feed voltage, it would no longer effectively shunt the relay since from the relay terminals the effective shunt was now the train shunt plus the impedance of the rails from the rail connection to the train position. He believed the impedance of 1 000 ft. of track at 2 kc/s was something in the order of 7 Ω so that when the train was 1 000 ft. away from the relay connections the shunt it was offering to the actual relay was of the order of 7 Ω. He agreed that it was producing a very much lower shunt to the feed voltage, but it was no longer maintaining a short circuit on the relay, and therefore, the relay could now respond to any false voltages which happened to be around. He accepted that with the system Mr. Duckitt had talked about, these false voltages had got to be at the same frequency or somewhere near it presumably to get through the filter circuits. Also in the American installations, as he gathered, the feed voltage would be in the order of 3 or 4 volts, whereas the voltage at the relay end of the rails would be in the order of 2 or 3 mV, which meant to say, and he was talking from the point of view of the rail connections, the sensitivity at the relay end was very high and it would not, therefore, take a very high leakage current to operate it.

He was also not very happy with the arrangement of the one track feed in the middle of two track circuits, because one now got the track circuit arranged so that the train entered at the feeding end and not at the relay end and for the point he had just outlined one did not produce a short-circuit on the relay at the time of the train entering. The American signal engineers and Mr. Duckitt said they did not put coded signals on to their tracks until the track circuit was shunted, and they thought they obtained some safety from this, which he supposed they did from the fact that they were not putting coded track signals on unless actually required. If the train failed to shunt the track circuit it got no code, and if the code was made to work the train, or work into the braking system, which would seem to be the practice outside of Expo, the train came to a stop. But, of course, the track circuit not shunted did not offer protection to the train from a following train running into it.

The equipment in America used on Expo and, he thought, on the other sites was being provided with adjusting facilities for the tuning circuits, and the transmitting track feed amplifier was provided with a variable gain control; this, he thought, was very alarming because alteration to this gain control had two effects. Firstly, it would permit the track circuit to be over-energised, thereby affecting the value of the shunt at which it would be de-energised; and secondly, it extended the area over which the track circuit would be shunted by a train because more volts were being put on the rail.

In the solid state circuits as they were, there was no visual indication whatsoever for the maintainer to know whether he had adjusted the track circuit correctly or not, and if he touched this knob, which was no more than the volume control on a radio set, he twisted it and turned it and did not know what he had done. With their conventional track circuits there was the pointer on the a.c. relay to show that the track circuits were correctly adjusted; or in a d.c. track circuit one could put a voltmeter on the relay and take a reading. One could not put a voltmeter on the track circuits they were discussing because there were a lot of other voltages around. The adjacent track circuit was bound to be producing volts and the coding features were producing volts, so to check a track circuit one had to disconnect everything else in the vicinity. It was not something that could be done very easily or very readily and was something he feared would not be done—they would just turn the knob and hope they had got it right. This was something else he thought a little disturbing from a maintenance point of view.

He was sorry to have been so critical, but he believed that this was something they had got to pursue because it was all-important and he was sure if they adopted these circuits they would be friends with the Civil Engineer once again in eliminating blockjoints, and he would wish to examine and proceed with further experiments on the lines of this equipment.

Mr. H. Duckitt replied that in theory the impedance of the wheel/axle circuit path was less than 0.02 Ω at 3 kc/s so that the effect was negligible in considering train shunt values. However, he would refer to Mr. Dell's comment that a full knowledge of wheel/rail contact impedance was necessary, and it was in this context that train shunts with audio-frequency track circuits should be studied.

Mr. Smith had given a clear picture of the safety problem of ensuring an adequate shunt at all positions within a track circuit section. His comments emphasised the fact that an audio-frequency track circuit system must be designed to deal with crosstalk between adjacent tracks and adjacent track roads.

He was in full agreement with Mr. Smith that adjustable controls of the type he mentioned on the American equipment were not consistent with the standard that would be set in this country for the reliability and integrity of vital signalling equipment.

In his view the essential reason for switching coded current to give train commands only when a track section was occupied, was to provide a clean cab command transfer and avoid a momentary mixed code at the junction of two audio-frequency tracks in a jointless track circuit system.

Mr. B. H. Grose said that the gap which Mr. Duckitt had referred to as existing between the terminations of adjacent jointless track circuits of the new Aster type, would not exist. This would be because there would be sufficient current to work the receiver after the first wheels of the train passed the tuning unit. This must be so because there would be ample current at the transmitter end of the circuit, and the receiver must be sensitive enough to function when it was at the far end of the track circuit. So if one accepted that one was going to put in the facility which Expo '67 had, it seemed to him that one got over the trouble caused by mangled code.

Furthermore, the Mini-Bond circuit used two distinct frequencies as carriers for the modulation and these were separated in the trainborne equipment by two separate receivers. The same thing could be achieved with the Aster track circuit, since there were two frequencies per track and, therefore, if one put in two receivers, each tuned to the appropriate carrier frequency, these could be easily distinguished. Mr. Duckitt had referred to certain weaknesses in the Mini-Bond track circuit which he had not dwelt on, with regard to the mumber of frequencies which he thought might have to be provided when there was a number of tracks.

Mr. Duckitt, he believed, had mentioned that he had not so far considered crosstalk very much with the Mini-Bond equipment, but on British Railways they were very interested in crosstalk because all their track circuits on a.c. electrified lines were completely unbalanced. One rail on each side of the track was joined to the structures on that side of the track, and hence constituted a very pronounced unbalanced situation. This meant that even with a two-road stretch of track, one was forced to have four frequencies whether one used a Mini-Bond system or any other type of audio-frequency track circuit. When they came to a four-track section, which was by no means unusual, they looked forward to having eight frequencies in use.

As a further observation, he had always understood that the 0.06 Ω train shunt tradition in America was based on the idea that the train was an immeasurably low short circuit, and this resistance was put in simply to allow for bonding of turnouts. This was quite sensible, since if there was a train just occupying a turnout, something must be allowed for the resistance of the bonding and this was the figure adopted.

He would like to join with the author in a plea for a review of the train shunt figures which were now generally accepted. It seemed to him that these figures had been endowed with a certain magic over the years so that if there was better than $\frac{1}{2}$ Ω (or 1 Ω on London Transport), all was assumed to be well. It seemed to him that what was of more consequence was the potential between the rails, and it was this, he believed, that determined whether the track circuit shunted or not. Therefore, the numerical value of the measured train shunt should only be regarded as a yardstick for the maintenance forces to ensure that the track circuit was not too sensitive, and hence liable to fail with the first bad weather experienced.

The utility of the track circuit as a train detector, he felt, would be decided simply by the state of the rail head and an adequate number of axles to prevent complete loss of shunt due to the live nature of the axle loads presented by a train. He had not thought much about this until he had to deal with some trouble with Lucas track circuits, and during the discussion it emerged that in this equipment there was a transistor output stage in which, to preserve the life of the transistors by reducing heating, the length of the impulse delivered to the track was considerably shortened. While all was well the track circuit gave a train shunt of about 1 Ω or more. Now, if this cut-off circuit went wrong, much longer impulses were developed, but they were still of about 40 volts, the normal voltage which this system provided; but they were so much longer that the energisation of the relay was increased to such an extent that the train shunt dropped to about 0.3 Ω. At first sight this might seem a poor track circuit, since failure of a piece of electronic trickery reduced the train shunt seriously. However, he would feel a lot safer travelling on that 40 V track circuit despite its low train shunt, than he would on a 1 V track circuit shunting at about 10 Ω, simply because there were still 40 volts available to break down any rail head contamination.

The opposite point of view might be taken. They were all quite familiar with marshalling yards where much trouble was taken to produce rail circuits having a very high shunting value—to say they shunted at 10 Ω was no exaggeration. It was well known that such track circuits had to be appreciably slugged because they completely lost shunt, and that was the other point of his argument that the numerical value was not sufficient to show that a track circuit was going to work. One needed to know that there was sufficient voltage between the rails to break down any contamination, and that the wheels were going to stay in contact with the rails.

He could go better than London Transport with regard to high measured train shunts, and although British Railways had not gone to great lengths to measure the actual resistances of axles, they did know from results of numerous tests that two-axled vehicles went from nothing to infinity. They had proved this abundantly because they were always being asked by the Civil Engineer, " could he run his two-axled track maintenance vehicles about under the protection of the signalling without having a possession ?" and they invariably say ' no'. They had done this test so many times it was a waste of time doing it again, but it always cropped up. So those were his two arguments—voltage all the time, and sufficient axles to ensure that one at least was in contact with the rails at all times; numerical value was really only to guide the technician in ensuring that the track circuit was not too sensitive.

There was another factor, namely, that various authorities used different values of train shunt—0.06 Ω in America, 0.03 Ω in France and on British Railways, 0.5 Ω on British Railways again, and 1 Ω on London Transport; these were all used in very widely-separated parts of the world and he was not aware of any body of information to say that one was better than another. So the only conclusion he could draw was that they were pretty arbitrary, and if they were arbitrary, and they could advance signal engineering by changing an arbitrary standard, he agreed with Mr. Duckitt and said they should.

Mr. H. Duckitt replied that Mr. Grose had made some important statements with regard to audio-frequency track circuits, crosstalk and the unbalanced nature of British track circuits. The use of distinctive frequencies allocated to each track road was important in preventing crosstalk in relation to track circuits when used for train detection. However, when coded commands were added to co-operate with train-carried equipment, the design engineer was faced with a severe crosstalk problem since a train must not pick up a command from an adjacent track road and yet the train must be capable of running on any track road and must only receive the command present in the rails of the road it was running on at a particular time.

He believed that Mr. Grose and he thought on similar lines in regard to the problem of train shunt. Like Mr. Grose he considered that, if train shunt conditions were difficult due to poor wheel/rail contact, then high track voltage and a slow pick-up track relay or repeater provided the best solution. If wheel/rail contact conditions were good, then the minimum train shunt could be permitted to be much lower than the 0.5 Ω of present practice.

Mr. B. D. Heard wished to bring a period of calm to the meeting, and lay off train shunts for the moment. Regarding Fig. 10, he was not happy as to why the voltage added in the local part of that circuit should not be coupled back into the B winding and thus produce equal ampere-turns in the decoder. Secondly, one had coded track circuits. Mr. Duckitt talked of the reversible track circuit. Would it be possible to remove one fixed end of the coding and, instead, fix it on the train so that the train, during the off-periods of the codes on the track, could add its own code, and perhaps add information that might be useful at the lineside. Thirdly, as to pick-up coils, he was not sure if these were iron-cored. Was there any trouble with saturation due to traction currents flowing underneath them. Lastly, in Fig. 20 (the Mini-Bond system) he got the impression that either there seemed to be twice as many code injection points as were really necessary, or else each of these half tracks in fact represented one signal section.

Mr. H. Duckitt in reply explained that the phase-sensitive circuit of Fig. 10 operated as follows: During the "off" period in a code cycle the local supply fed into winding A of the decoding transformer, but there was some local current fed round *via* the input transformer into winding B of the decoding transformer. The trick was to make the track source impedance, as looked back into from the input transformer, much lower than the impedance of the windings A and B of the decoding transformer. This ensured that the nett ampere-turns were predominantly those from winding A. Subsequently, during the "on" period of a code cycle, the current in winding B became predominant as explained in the paper and this ensured switching of the decoding transformer flux condition.

He doubted whether low-frequency coded currents could be transmitted efficiently from a train back to the track. This seemed to be a case for using coding with higher frequency carrier currents in the range above the audio-frequency band.

A train pick-up system could be saturated and rendered momentarily non-responsive to code if there was interference from traction current having a high a.c. content. However, such occurrences were usually of short duration at positions where traction cables crossed under the track and the time was insufficient to drop out any train-carried code relay which should remain energised at that time.

In Fig. 20 each half of a centre-fed circuit was a separate track circuit, and therefore, for train commands each Mini-Bond must have a feeding point.

Mr. H. H. Ogilvy remarked that in Paragraph 7 of the paper the author referred to future systems of automatic train control and suggested, for example, that perhaps nine separate commands would be sufficient. This was not in accordance with the conclusions reached by the O.R.E. committee investigating the problem in relation to main line trains, the number of possible instructions being at least one order of magnitude greater. In fact, Mr. Duckitt had just suggested it might be 150. Furthermore, future developments at present being considered by U.I.C. suggested that a very much greater information capacity would be required—hence the decision to eliminate the rail bond transmission link for train control. How did the author reconcile U.I.C. views with his own, and what system had he in mind for future developments if coded tracks proved to be inadequate?

Regarding separation of safety and control information—if that was really the meaning—he was in complete agreement with Mr. Duckitt and hoped the final O.R.E. recommendations would be submitted with this in mind. Nevertheless, to provide all the safety information needed for communication to trains operating on main lines, such trains having widely varying characteristics, a large number of separate instructions were necessary—of the order of 150. These specified gradients, signal aspects, speed restrictions (temporary and permanent), distance to such features and so on.

When such information was available on the train, the calculation of a safety curve (which was a function of the braking characteristic) became possible and from this the train-borne equipment could decide whether emergency braking action was called for at any stage. Thus, he thought a more elegant communication medium than that offered by the track circuit was essential; furthermore, this should have sufficient capacity for future expansion to allow for transmission of non-safety (i.e. control) information, in both directions.

Mr. H. Duckitt noted Mr. Ogilvy's remarks with interest. His own view of automatic train operation was that safety of train movement was the prime consideration. Whilst a large number of train commands might be involved in an automated system, he contended that certain commands, which in his view need not exceed 12, should be the ones which give permission for the allowable maximum speed in each section of track. This safety command system should be electrically separate from the remaining command system and should be of a type satisfying signalling safety principles. This basic structure should apply whether the track currents were in the rails or in a specially-laid. trackway cable system. If the safety functions were separated in the way he had mentioned, then railway engineers and the Ministry of Transport had a clear picture of where the safety lay in an otherwise complex overall automatic control system. To him, this establishment of the safety factor was a vital element in an automated train control system.

Mr. M. E. Leach congratulated Mr. Duckitt on the very comprehensive way in which he had brought the Institution up-to-date on the subject of coded track circuits. It was something like twenty years since there was a paper before the Institution on this subject and Mr. Duckitt's paper showed how much advance had been made in this particular field in that time. He would, however, confine his remarks to what might be called the "steam" version of coded track circuits.

The Western Region first became interested in coded track circuits of the more conventional type in 1948 when there was a call for long track circuits in connection with the introduction of intermediate block section signalling. The former Great Western Railway adopted a very difficult form of track construction from the track circuiting point of view, with through-bolted fastenings which very effectively put the rails in direct contact with the ballast and led to extremely low ballast resistances which, of course, limited the length of track circuits which could be worked with orthodox equipment. They therefore went in for coded tracks really to exploit the prevent shunt characteristics of this equipment.

They very soon ran into troubles with transformer decoding because of code distortion. The author had mentioned storage battery effect. That, of course, was not the only feature which produced code distortion. The code-following relay was in parallel with the rails and therefore subject to slugging by the effect of the ballast resistance. They found that the only way to overcome the delayed release of the relay caused by this and the storage battery effect, was to reverse the polarity of the feed on the track during the nominal "off" periods of the code. This made use of the polarised feature of the code-following relay and actually drove it down instead of allowing it to release normally.

Transformer decoding has been found particularly sensitive to code distortion; in fact, with a nominal 50/50 code with the current on for 50% of the time and off for 50% of the time, as soon as the code became distorted to 30/70 or 70/30, as a result of slugging or storage battery effect, the system failed. He asked whether in fact the more sophisticated techniques using solid state devices were subject to the same sort of difficulty with code distortion.

Later on they made use of the much simpler pulse type of track circuit which used the condenser decoding arrangements described in the paper. They called it a "spoon and bucket" circuit by the analogy of one condenser which "spooned" charge into another "bucket" condenser, which kept the relay up. They found this very effective, less costly, and not so subject to code distortion.

This led to the thought that if they could design an acceptable form of decoding circuit to prove that the relay was following code properly, it would be possible to use a second-order, or non-safety, type relay directly across the track to reduce the cost still further. This development, which was the subject of a patent application, in fact used a

Post Office type relay as a code-following relay directly across the track with a rather sophisticated form of decoding circuit designed to detect welded contacts. A prototype version of this equipment was in service and performed some 160 000 000 operations without failure before being taken out of use.

Finally, another difficulty found with the transformer decoding circuit was that it gave trouble from television interference. People living alongside the line complained bitterly of white lines coming out on their television screens, and also of a clicking noise on the audio circuits. Did this trouble still occur with the more sophisticated and elegant type of decoding arrangements ?

Mr. H. Duckitt replied that with the low code frequencies used to date, the problem presented by code distortion was important and solid-state equipment had the same problems as earlier forms of coding equipment. He would agree that failure was likely to occur if a normal 50/50 code was distorted to a 30/70 relationship by the time the coded signal arrived at the decoder.

Because there was no contact arcing with a solid-state coding system, the problem of interference with adjacent television receivers did not arise.

Mr. D. S. Jewell said he did not want to enlarge the argument about safety and command systems, but commented that in his opinion there would be very little difference between safety and control in any sophisticated system of the future. This was simply because the whole system would have to be so reliable that nothing was ever going to fail.

His interest in the paper was primarily concerned with transmitting information. Mr. Duckitt had suggested that this could be done by coded track circuits, either for detecting the presence of trains or for transmitting information to trains. In the introduction to his paper he made brief reference to the other method of providing the channel of transmission, namely the provision of track conductors. No doubt the author would agree that one could not ignore the cable. In fact, it had already been referred to in the discussion, since, when one got into difficulty with coded track circuits in points or crossings, it was necessary to lay a cable.

The position on the kind of line that British Railways was concerned with was rather different from a rapid transit line, and he thought the author would agree that they would have to face a very much increased range of information for all purposes—and it was not going to be a question of 4 or 9 or 150 codes. He seemed to remember one document which even quoted 600. The position on British Railways, as Mr. Grose had said, was immeasurably more difficult if they were going to have electric traction, because one rail would inevitably be earthed. He thought he was right in saying that this was the position when Hainault/Woodford was started, but he understood that both roads had had to be made free of earth. They must not forget cables, therefore, and he would refer to this again later. Regarding Montreal, however, for the command system was there one set of carriers for the up line and one set for the down : was it the same set, and if so, how was the crosstalk between the two tracks covered? As far as he knew the coefficient of coupling between two parallel tracks was of the order of 0.025.

The author had fears about parallel tracks and obviously the coded track circuit system had its difficulties in this respect. The worst case would seem to be four tracks where there were two ups and two downs and it would appear traditionally that there was one set of carriers for the up line and one for the down. More vital, however, was the fact that if coded track circuits were used as a means of transmitting information, then the system was a discrete one.

Safety in the future would not be just a question of stopping a train—not just a question of tripping the brakes if there was a signal at danger. At higher speeds and higher loads, it was going to be a question of supervising and checking the braking curve throughout its full extent. If one used coded track circuits it seemed that one could only make a check at each track circuit termination, where the code changed, and he did not think that the length of a coded track circuit would be reduced merely to give more checking points. On the other hand, if a track cable was provided there could be a phase inversion point every 50 or every 100 yd. This was a big difference between the two systems in the vital matter of supervising the safety curve. Track cables, as they knew, could be kept entirely separate from the rails—free from harmonics generated by thyristors and anything else the traction current could produce.

Lastly, track conductors had an advantage which might be theoretical for the moment, but could be important. When using currents in the rails the pick-up coils required to be horizontally polarised, but with track conductors they could be vertically polarised : also, in the first case the coils must be ahead of the first axle, but in the second case they could be mounted under the centre of the vehicle, where there would be less interference. In a world in which everyone was using electricity to a growing extent, interference could well be the deciding factor.

Mr. H. Duckitt replied that he could not say much more about crosstalk than in his replies to Mr. Dell, Mr. Smith and Mr. Grose. The use by British Railways of audio-frequency jointless track circuits would undoubtedly, with time, increase knowledge of the crosstalk problem. He had the feeling that so far as track-to-train communication with audio or higher frequency coded currents was concerned, the use of a trackway cable in the centre of the track might well be the best solution to the crosstalk problem. His earlier reply to Mr. Ogilvy that " isolation of safety commands from all other commands is an essential factor," applied to Mr. Jewell's comments on braking curves. Perhaps all their problems might be solved some day if a " fail safe " time division multiplex transmission system could be developed.

The President, Mr. H. W. Hadaway, said in closing the meeting that he believed the paper given by Mr. Duckitt would stand for many years as a reference on this subject of coded track circuits. He confessed that in the film show his heart missed a beat because when they were shown the link between the control room and the train he understood the man on the train to say he had arrived at the wrong station. When he heard it at a recount, it was " La Ronde station". Here again it was a question of difficulty of communication. He again thanked Mr. Duckitt for his most interesting paper and asked the Members to show their appreciation in the usual way.

Provincial Meeting of the Institution of Railway Signal Engineers

held at

BIRMINGHAM

on Wednesday, April 3rd, 1968

The President (Mr. H. W. HADAWAY) in the chair, was supported by the Senior Vice-President, Mr. B. Reynolds and the Honorary General Secretary, Mr. R. L. Weedon.

Mr. H. Duckitt read his paper on " Coded Track Circuits".

DISCUSSION

Mr. B. Reynolds, who opened the discussion, mentioned references in Mr. Duckitt's paper to the finding in Spain of a d.c. voltage between rails on plain track and stated that he, too, had experienced this in many parts of the British Isles when carrying out testing. It was usual, he said, to discover a " battery effect " voltage between rails at almost any location and he would like to ask Mr. Duckitt for further details of what he had found in Spain.

Mr. Duckitt agreed that voltages of 0.2 to 0.3V could normally be found in Britain where the track used wooden sleepers standing on normal ballast. In Spain, however, the circumstances were different in that this effect was more marked, showing up even more towards the end of the night when moisture condensing on the sleepers would give this effect, as would also moisture present in the ballast bed between the rails. If, as in Spain, the track circuits were of the coded d.c. type, the battery effect built up when the polarity was such as to assist potential storage and was quite troublesome when the track circuit had to be normalised or reversed. With long track circuits (and some of these were 15 000 ft. long) this took quite a time.

Mr. Oakes recalled that Mr. Duckitt's paper had made several references to jointless tracks. When changing over to circuits of this kind it seemed to him that there must sometimes occur lengths of bonded track which had to have jointless track circuiting equipment installed in readiness for a changeover to long welded rail. Would it be possible to leave this equipment undisturbed when the changeover to long welded rails took place ?

Mr. Duckitt answered that this had been done already in many instances where rails were temporary, and had proved quite satisfactory. The bond impedance would be very small at the frequencies used and no difficulty would be expected from that point of view.

Mr. Oakes then asked whether the time would ever come when a train would be able to send a signal in advance of itself ?

Mr. Duckitt said in reply that this was tied up with train identification—and train description systems could also be used for this purpose. A difficulty arose, however, when mixed freight and passenger trains occupied the same track. He thought routing by train description or by some other automatic means was bound to come ; this had certainly been used successfully in the United States. It was recommended, however, that when such systems were developed, the track circuit was retained for safety purposes, leaving the cab signalling impulses to be fed along the track in a separate cable, probably laid in the 4-ft. way.

Mr. Hadaway remarked that in Fig. 16 of the paper Mr. Duckitt referred to a shunting zone between two track circuits. This could be looked at in two ways. There was the shunting zone defined by the wheels and the axles of the train and, in addition, there were shunting zones as defined by the Signal Engineer. This difference, it would appear, must be resolved before the Signal Engineer could decide precisely where was the equivalent of his normal block joint.

Also, he would like to ask Mr. Duckitt if he could see any way in the future whereby the stringent requirements of the Signal Engineer in wanting a 1 ohm train shunt could be met without the extension of this shunting zone between track circuits.

Mr. Duckitt replied that the standard British Railways train shunt for non-impedance bond track circuits was 0.5 ohm and for impedance bond track circuits 0.3 ohm. It was known that under certain conditions a shunt of 0.2 ohm could be admissible. With respect to the actual Z-bond position as shown in Fig. 16, the train shunt varied from a high value as it approached the leading end Z-bond to near zero after passing clear of the bond. At the bond itself, with normal ballast conditions, the train shunt would normally be of the order of 0.2 to 0.5 ohm.

But Mr. Hadaway had raised the question of a 1 ohm train shunt. The Aster track circuit was the only type of track circuit he knew of where there was an apparent increase in the impedance looked at from the rails into a train shunt. It was this raising of the impedance which permitted a reasonably close demarcation of the effective train shunt position and yet raised the train shunt at the same time. So far as the 1 ohm was concerned, the natural tuning of the bond imposed some restriction and it was not possible to improve the train shunt to 1 ohm at the present moment.

Mr. Hadaway said that the question of whether or not it was reasonable to ask for 1 ohm, on London Transport they had carried out tests which clearly showed that a single pair of wheels on a train gave a rail-to-rail resistance of 0.6 ohm. They knew that front wheels were important, and back wheels equally important, and it followed that at some stage in the train journey a front pair of wheels or a last pair of wheels could play a vital part. If 0.6 ohm should be present in that pair of wheels, obviously a track circuit with a shunt value of less than that was not going to operate properly. This appeared to be the current difficulty with the jointless track circuit. He would certainly like to see this type of track circuit in more general use, but so long as there was a problem of track circuit shunting it would not suit London Transport requirements.

Mr. Duckitt replied that, as he had said, the natural tuning governed the train shunt and he did not see how they could raise the impedance of the rails any further.

Mr. Reynolds said that, looking at Fig. 16 Mr. Hadaway's problem seemed to be that if he was required to replace his signal precisely within 30 ft, where was he to position it ? Taking a zero ohm train shunt, he would suggest that it would be replaced perhaps 5 or 6 ft before the centre-point of the Z-bond.

When discussing Fig. 16 Mr. Duckitt mentioned the question of the frequency of the Aster track circuit. At the moment a Z-bond length of 95 ft shown in Fig. 15, was correct for the frequencies used, striking a neat mean between the length of the Z-bond and the maximum impedance to be won from the rails for tuning purposes. If lower frequencies were used, longer track circuits would be possible but the Z-bond would need to be increased proportionately and with Z-bonds 200 to 250 ft long, demarcation would be a difficulty, not to mention cost. Conversely, if, to obtain sharp demarcation, much higher frequencies were used, the impedance of the rails at these frequencies would enforce much shorter track circuits and, therefore, many more of them would be required to the mile, which would not be economic. So here were two limiting factors which more or less settled the frequencies used as around the 2 000 Hz mark.

Mr. P. E. Powell recalled that the

President had mentioned a test on one pair of wheels which gave a measurement of 0.6 ohm. He was rather interested in the conditions under which this 0.6 ohm was given.

Mr. Hadaway replied that the tests in question were made under running conditions with trains running at various speeds and in various weather conditions. Oscilloscope photographs were taken during the tests and from the results so recorded they were able to identify the voltages and current obtaining at the time. From these the resistance was calculated. The answer was not a question of rust on rails—the rails used for the test were in use continuously. It was a question entirely of wheel-to-rail profile and the tests showed the tremendous importance of having a proper mating profile between the wheel and the rail. It seemed that the way in which one stock as compared with another developed wear on the profile of the wheels could cause it to have a different contact effect on the rails. When one brought on a piece of new stock of which the wheels were in a clean condition and to the right profile, these did not match up with the point at which other stock had produced the brightest spot on the rails. The answer was a question of proper profile, wheel and rail. This was the key to the whole matter.

Mr. Duckitt said he would imagine from what the President had said that these tests were taken at a fairly high voltage. He had already stated that they were taken under dynamic conditions. In any case, the relay of a coded track circuit was rather sluggish in re-energisation and would not be likely to pick up under the last wheels of a train. Typical figures would be a drop-away of a coded track circuit relay in one second, and a pick-up of the same relay in one-and-a-half seconds.

Mr. Hadaway referred again to Fig. 16 in the paper, which related to the Aster Track Circuit Style U, and suggested that the filter at the extreme right of the diagram, which Mr. Duckitt explained was to prevent frequency f3 going off in the wrong direction, would surely, if it became disconnected, permit this frequency to travel as far as it wanted to go ?

Mr. Duckitt replied that the filter unit mentioned by Mr. Hadaway acted as a low impedance device to frequency f3 and prevented its further transmission outide the confines of the track circuit. If it became disconnected from the rails this terminating effect would no longer be present and the frequency would be free to wander down the track. It would not get very far, however, because of rail attenuation—certainly not as far as the next track circuit of corresponding frequency.

Mr. Parker asked if he could speak as a Traffic man ? They on the Traffic side of the Birmingham Division stood in awe at technological achievements. Mr. Duckitt had spoken about driverless trains. At the moment only one new line was being built and that was on London Transport. Might he ask an elementary question ? What was there in all these technological improvements for the operators of the railways ?

Mr. Duckitt said he thought that in most cases this was a reasonable commercial point of view. The type of automatic train they were looking at, and the coded type of track circuits that had been described, were at the present time commercially more applicable to city transport systems than to main line railways. Cab signalling might come first. They might in any case be forced to do something shortly due to talk of high speed trains on existing lines. Something must be done to permit trains to exceed 100 m.p.h. When going beyond these speeds some special information must be given to allow them to operate at these higher speeds.

Mr. Parker asked whether coded track circuits would help them to get a cheaper figure for operational purposes, to which **Mr. Duckitt** replied in the negative.

Mr. Hadaway followed up Mr. Duckitt's reply by stating his opinion that the benefit in the ultimate would be tremendous, because when the railway reached the stage of making full use of automatic information it would be operated entirely without any operating staff at all. Everything would be completely automatic—no drivers, no signalmen and all decisions pre-prepared. As he saw it, as an Operating Manager he would have an Operating Department of ONE !

Mr. Reynolds pursued the line of thought set up by Mr. Parker, saying that there seemed to be three clear advantages arising from what Mr. Duckitt had explained. Firstly, there would be better train running due to the trains running entirely under automatic control. Secondly, safety of the trains would be guaranteed by the equipment and would no longer be in the care of human hands. Thirdly, automatic routing of trains would become quite feasible and even commonplace.

Mr. Duckitt said he thought Mr. Parker was looking at the future a little too far ahead. But in any case great benefits for other people were on the way, following on from the use of both coded tracks and jointless tracks. Probably Mr. Newens would be overjoyed to get more and more jointless track. These benefits seemed to be available immediately from the long-term objectives. Mass production, too, produced equipment which, though mass produced, still maintained its inherent safety. This could be used for coded track circuits. They no longer had to go in for big, heavy, costly signalling safety relays. These had been drastically cut down in size, and this definitely led to a cheapening which from the long-term viewpoint counteracted inflation.

Mr. Newens assured the meeting as a Civil Engineer that they really did want jointless track circuits—because of high speed lines in particular. When Aster track circuits were proposed a few years ago for use on the London Midland Region it was intended to install some of them on the Midland line at Northampton. When he saw the installation diagrams, though, he had to call a halt and he would make this plea—that in their future designs they did not arrange their equipment so that it was vulnerable to the Civil Engineer's machines, on which they depended entirely. The cabling indicated in the diagrams would be very vulnerable to tamping machines and it was difficult for them to have to miss a single sleeper and then go back and pack it manually.

Mr. Duckitt replied that Mr. Newens would be happier with the new Aster jointless track circuit equipment. This would be located at one side of the track and not in the four-foot way at all.

The President then closed the discussion, thanking Mr. Duckitt for presenting such an excellent paper, which had been based on a world-wide survey of coded track circuit practice.