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Paper 9

The Interference Problem

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1 Introduction

This paper concerns principally the causes and remedies of the effects observed in light current circuits, such as those used for signalling and telecommunications, in the proximity of a railway electrified on the 50 cycle single phase overhead system. It deals particularly with the circumstances in which the British Transport Commission are placed having regard to the extensive Post Office telecommunications network described in Paper 37.

These interference effects are, of course, particular cases of the inevitable transfer of energy by induction from one circuit to another neighbouring one to an extent dependent upon a number of factors, some of which are well known, having been studied for many years. In the case of three-phase power lines, for example, the currents are normally balanced in all three phases and the resulting unbalance, which causes interference, is small. In the case of a railway using the running rails for the return of traction current, the unbalance is intrinsically high, being 100 per cent for the electric field and approximately 50 per cent for the magnetic field. The interference is much higher and being a function of the frequency is more pronounced with 50 cycles than with lower frequencies or with D.C. where only transient currents, e.g. on switching and under fault conditions set up the conditions causing interference. The special case under consideration is therefore the most severe one and, whether it be necessary for other reasons or not, prohibits the use of open wire circuits in close proximity to the catenaries.

Interference, derived from harmonic currents, may occur with both A.C. and D.C. electrification; this is a special aspect needing study to avoid undue noise in the light current circuits.

Interference at radio frequencies, to which Paper 37A particularly refers has also to be kept under control, particularly with A.C. electrification, although it may occur due to imperfect contacts with any system.

The mere statement of the problem serves to show that there is unlikely to be any universally 'best' solution and that very close co-operation is necessary between both the Signal Engineers' and the Electrical Engineers' Departments of the Railway and the Post Office and other similar authorities if the optimum result is to be achieved in each case, taking into account not only the financial factors involved but also the important though less easily quantified factor of practicability.

2 The Problem

This in brief is the achievement of the optimum solution having regard to all the factors concerned in each case.

It is obvious that the voltages induced in adjacent installations must not give rise to any risk of danger under normal service conditions or foreseeable fault conditions. Moreover, induced voltages, as well as voltages arising from conductive coupling, must not 'disturb' the operation of the other services; any deterioration of the quality of such services must remain in reasonable limits.

In Paper 10, Mr. Woodbridge defines the attitude of the Railway to the Comité Consultatif InternationalTélégraphique et Téléphonique Directives on the permissible values of disturbing voltages which he quotes.

These limits are not binding, but they are accepted by practically all telephone administrations. In consequence, the Commission works to these limits in any case for all circuits, mainly telephone circuits, which can be connected, directly or indirectly, with the Public Telephone Network operated by the British Post Office. This results in the acceptance of these limits for all telephone circuits of B.R. In addition these circuits must be properly balanced at 50 c.p.s. to avoid disturbance of ringing, dialling, etc.: the recommendations of the C.C.I.T.T. presuppose such balance without giving numerical rules.

3 Electric Induction

This paper will be mainly concerned with the effects of magnetic induction, although electric induction can produce, in a well insulated adjacent wire, a voltage of several 1,000 volts, but the current to earth is relatively small. The C.C.I.T.T. limit for this current, which might flow through the body of a linesman, is 15 milliamps. A telephone line distant 100 feet from track centre, requires a length of six miles to reach this limit, thus danger from this effect is not likely to occur. Fig.1 shows equipotential lines for a 25 kV two-track line with contact wires, catenaries and earthed return conductors. This set of curves is believed to be new and to represent the facts in such a way as to permit easy verification that no untoward effects will normally be experienced from this source of interference.

4 Magnetic Induction

This is the main cause of interference and its extent clearly depends upon the magnitude of the currents in the power circuit and the physical relationship between the high power and low power circuits, including the length of parallelism involved, in other words, on the degree of coupling of the two circuits.

4.1 *Calculation of e.m.f. induced in low power circuits*

The basic formulae are well known and may conveniently be expressed as follows:—

If several circuits 1, 2, 3, . . . ν . . . n carrying currents $I_1, I_2, \ldots I_\nu \ldots I_n$ can induce simultaneously into a circuit 'a', if the frequency is f c.p.s., $\omega = 2\pi f$ and if the relevant total coefficients of mutual induction are $M_{1a}, M_{2a}, \ldots M_{na}$, the induced e.m.f. in circuit 'a' is $e_a = -j\omega \sum_{\nu=1}^{n} M_{\nu a} I_\nu$ in which allowance must be made for the phase angles of $M_{\nu a}$ and I_ν as considered further in section (5).

In the railway case, the power currents I_ν depend not only on the characteristic of the motive power unit but also on its position on the track, i.e. I varies with the distance x of the unit from the feeder station. The current I will not in practice vary linearly with x as it will generally be the result of the differing effects due to more than one motive power unit being on the line and, in addition, there are other discontinuities due, e.g. to bonding arrangements and booster transformers (if present) which for the moment will be ignored.

Taking into account that the separation of the power circuit and of the low current circuit (a) will also vary along the track, the coefficient of mutual induction per unit length, $m_{\nu a}(x)$ must be introduced. Therefore a formula, as shown below, will ultimately permit the calculation of the instantaneous value of the induced e.m.f. for comparison with the value actually measured, e.g. by the techniques described in Paper 2.

The longitudinal induced e.m.f. (e_a) can be expressed as

$$e_a = -j\omega \sum_{\nu=1}^{n} \int_{x'}^{x''} m_{\nu a}(x)\, I_\nu(x)\, dx$$

in which the integration is to be made for an exposure between x' and x''. In calculating the coefficients of mutual induction $m_{\nu a}$ all conductors 1, 2, 3 . . . n namely, contact wires, rails, return conductors, if any, cable sheaths, waterpipes, as well as the induced conductor a are regarded as circuits with earth return.

The coefficient of mutual induction (m) between two parallel lines with earth return depends on the separation d between the lines, the frequency f and the soil conductivity σ. For lines near the surface of the earth, it is a function of the parameter $p = d\sqrt{\sigma f}$. Pollaczek, Carson and Haberland have shown independently in 1926, that m decreases slowly with increasing p as long as p is small, but quickly as $1/p^2$ when p is large. For 50 c.p.s., separations up to 100 metres and average values of σ a sufficiently accurate formula for m is:—

$$m = 1300 - 200 \ln p - j\,50\pi \quad \mu\text{H/kilometre.}$$

An approximate formula for all values of p is

$$m = 100 \ln\left(1 + \frac{6 \times 10^5}{p^2}\right) \mu\text{H/kilometre.}$$

In these formulae, the separation is measured in metres, the soil conductivity in mho/m, and 1n denotes the hyperbolic logarithm and corresponds to $\log_e$.

D. R. Turner in Paper 41 shows that this general expression can be written more conveniently as an impedance (Z_m) for frequency f:—

$$Z_m(f) = -1{\cdot}588f - j4{\cdot}66f(3{\cdot}33 - \log d\sqrt{\sigma f}) \text{ milliohm/}$$

mile, or at 50 cycles per second,

$$Z_m(50) = -79{\cdot}4 - j\,232{\cdot}8(2{\cdot}49 - \log d\sqrt{\sigma f}) \text{ milliohm/}$$

mile, the separation 'd' being measured in feet and σ in mho/m.

If the separation is measured in metres, the corresponding expressions are:—

$$Z_m(f) = -0{\cdot}987f - j\,2{\cdot}89f(2{\cdot}82 - \log d\sqrt{\sigma f}) \text{ milliohm/}$$

kilometre and for 50 c.p.s.

$$Z_m(50) = -49{\cdot}3 - j144{\cdot}7\,(1{\cdot}97 - \log d\sqrt{\sigma f}) \text{ milliohm/}$$

kilometre.

For such limiting values of soil resistivity as 20 and 2000 ohms. metre, the following values result for different separations:—

Separation (metres)	10	100	1000
Resistivity			
20 ohms. metre	230	105	8 milli ohms/km.
2000 ohms. metre	390	215	105 milli ohms/km.

Having now recalled the factors which in principle determine the magnitude of the natural disturbing effects, considerations may be given to methods of restricting them to tolerable amounts.

5 Protective measures

Protective measures are possible in principle at (*a*) the source, (*b*) in the low current circuits affected and (*c*) by screening.

The latter method will be considered first as it is nearly always present in some degree, particularly in a railway where the rails themselves in any case act in this way, as do the cable sheaths of the low current circuit. All such conductors carry currents which are partly induced and sometimes return currents. The latter are evidently about 180° out of phase with the currents in the contact lines. The phase angle of the induced currents will naturally vary with their impedance and in practice lie between 90° and 180°. The magnetic fields set up by these currents therefore cancel in some degree those set up by the main power circuit and this effect is known as screening and it becomes significant to ascertain its value for each circuit concerned in the parallelism, taking into account the interaction of all the circuits concerned.

If the suffices 1, 3 and "a" denote inducing, screening and induced circuit respectively; if R, L and m are the resistance, inductance and mutual inductance per unit length, the 'screening factor' due to circuit 3 (that is the ratio of the e.m.f.'s induced in circuit "a" with and without circuit 3) is generally

$$\frac{R_3 + j\omega(L_3 - m_{13})}{R_3 + j\omega L_3} + \frac{m_{1a} - m_{3a}}{m_{1a}} \; \frac{j\omega m_{13}}{R_3 + j\omega L_3}$$

provided that the current in the inducing circuit is not affected by the screening.

There are two important particular cases:—

(*a*) 3 is physically close to 1, so that $m_{1a} = m_{3a}$ and

(*b*) 3 is physically close to a, so that $m_{13} = m_{1a}$.

The screening factors in these two cases are:—

$$\frac{R_3 + j\omega(L_3 - m_{13})}{R_3 + j\omega L_3} \quad \text{and} \quad \frac{R_3 + j\omega(L_3 - m_{3a})}{R_3 + j\omega L_3} \quad \text{respectively.}$$

It is clear, therefore, that effective screening is only obtained when R_3 is small compared with ωL_3 i.e. either a low resistance path in the screening circuit or a high reactance in this case, as happens automatically for the higher frequencies, e.g. at 50 c.p.s. in relation to $16\frac{2}{3}$ c.p.s.

6 Screening by Cable Sheath

Because of its position, the earthed metallic sheath of a telecommunication or power cable is a particularly efficient screening conductor. The inductance L_3 of a sheath earth circuit is always equal to the mutual inductance between sheath and core. With a power cable it is $L_3 = m_{13}$; with a telecommunication cable $L_3 = m_{3a}$; the screening factor derived from the general formula already given is thus in both cases $\frac{R_3}{R_3 + j\omega L_3}$. A low value of the screening factor still clearly demands a low ratio of R_3 to ωL_3. This is attainable by a suitable choice of sheath, including non-ferrous conducting reinforcement if any, and/or by the use of steel tape armouring.

The sheath must be well earthed as the resistance of the earthing arrangements increases R_3. This can lead to difficulties if the cables are laid in trough, or have an insulating outer cover. If k_o is the screening factor of a cable with perfect earthing, if γ is the propagation constant of the actual circuit sheath/earth per unit length and if the induction is constant throughout a length of l units, the resultant screening factor is $k_o + (1 - k_o)\,\frac{\tanh \gamma l/2}{\gamma l/2}$. Thus, if γl is large due to good earthing or a long line, the second term disappears and the screening factor is relatively independent of the quality of earth. The reverse is also true and screening may be completely ineffective, if γl is small.

The reactance, and thus the screening factor of cables with steel tape armouring, depends on the magnetic excitation reaching an optimum at a certain value of the induced e.m.f. This optimum should coincide with the highest induced e.m.f. to be considered.

If several cables without steel tape armouring are near together, the induced voltage in any of these cables will be only a little higher than if all were combined to one cable with correspondingly lower sheath resistance. With steel tape armouring the cables are nearly independent magnetically and may have widely different screening factors depending on their construction. The improvement obtained by using one large cable instead of several cables is thus more if steel tape armouring is used than if it is not.

7 Induction from Power Cables

Consideration is needed to induction from single-phase power cables, which are used in connection with the power supply to single-phase railways. These are, in the British Railways' case, of the concentric type and although the current in the outer conductor and sheath may be very near to 97 per cent of that in the main core, the phase angles may be such that an effective current of 10 to 15 per cent can cause induction in adjacent circuits.

8 Screening by Rails

The rails of the railway itself form another efficient screening conductor. Perfectly insulated, they would reduce induction to that of the loop contact wire/rails. Perfectly earthed, they would have an induced current, approx. 50 per cent of the current in the contact wire for one track because the impedance of the rails is about twice the mutual impedance of the rail/overhead circuits, 60 per cent for two tracks and 70 per cent for four tracks, between load and substations, no current would flow outside. The remaining 50, 40 or 30 per cent respectively (consideration of the phase angle would increase these values somewhat) return via earth but the effect is to give screening factors of the order of ·5, ·4 and ·3 respectively. The imperfect insulation of the rails gives rise to an intermediate behaviour; an assessment can be made, however, for example, for one track the current may be taken as a constant induced current of approximately 50 per cent of the current between the load and the supply point, together with superimposed attenuated currents of 25 per cent in each direction at both ends. All these numerical values are only given to show the order of magnitude of the rail currents. The actual values in a particular case depend on size of rails, the magnetic and electric properties of the steel, the resistance of the joints and, of course, the number of rails used available for traction purposes, dependent upon the kind of track circuits used.

9 Conductive Coupling

One further source of interference remains to be mentioned in connection with effects on railway signalling circuits, namely, conductive coupling. This occurs when two circuits have a common branch. The coupling between two earth electrodes is better measured than calculated; earth electrodes for telecommunication circuits must, of course, avoid the area of high voltage gradient around an earth electrode with heavy current.

Running rails are commonly used for the return of traction current and for track circuits. The voltage drop of the traction current is superimposed to the supply for the track circuits. In assessing possible disturbance, it must be taken into account that the 'induced' fraction of the rail current does not produce a voltage drop.

Without booster transformers or if booster transformers with return conductors are used, 'return' rail current occurs only near a load (locomotive). Thus it is sufficient to consider the current consumed by one train only; about $\frac{1}{4}$ of this current can produce a disturbing voltage drop. With a rail impedance of approximately one ohm/mile, a locomotive current of 200 amps would introduce into a single-rail track circuit of 500 yards a voltage of 14 volts. During a short circuit contact wire to rail, the parasitic voltage can be more than 10 times as much, but it will exist only for about 0·2 of a second.

When booster transformers with rail return are used, the total current taken beyond a transformer leaves and enters the rails at this transformer; about half of this current gives rise to a voltage drop. In a single rail, the voltage drop due to a total current of 1000 amps would be about 150 volts for 500 yards. But in this case, double-rail track circuits will be normally used. Hence, not only the voltage drop is reduced, but only a difference between the voltage drops in both rails could give rise to a disturbance. With the unbalance encountered normally, this difference will be less than 10 volts. The track circuits must be and are designed to operate properly in spite of even higher parasitic voltages. In consequence, there is no risk of danger due to conductive coupling.

10 Choice of Protective Measures

The remainder of this paper is mainly concerned with protective measures at the source, but some reference must first be made to the possibility of remedial measures on the affected installations. These are described in more detail in Paper 10 generally, in Paper 37 as regards Post Office circuits and in Paper 41 as regards railway telecommunication circuits. Papers 38, 39 and 40 describe the arrangements made in railway signalling apparatus.

Measures such as these obviously vary with the risk to be considered. Danger due to a high induced voltage can be confined to the lines by means of isolating transformers or by coupled chokes introducing a high longitudinal impedance. These measures are effective with cables provided that their breakdown voltage is high enough. With open wire lines, the risk of danger for linesmen may enforce the use of gas discharge tubes or other devices holding the voltage to earth at all (accessible) points of a line below a certain level. Isolating transformers, although very efficient, make D.C. systems of telecommunication over the lines impossible. Longitudinal chokes allow the flow of D.C., but can distort pulses. An alternative is to handle lines and directly connected equipment as potentially dangerous and to isolate the operator from earth.

General methods against disturbance are balancing of circuits and equipment, frequency selective arrangements and increase of power level. Circuits with earth return (100 per cent unbalance), except very short ones, cannot be operated near an A.C. railway. Balanced circuits can work perfectly, even with a high voltage to earth. But improving the balance of circuits sufficiently is not always easy. Cable circuits can be perfectly balanced, open wire circuits retain always some unbalance. If the equipment is balanced or separated from the lines by isolating transformers or longitudinal chokes, the risk of disturbance of cabled circuits is small.

But the complications involved in modern automatic short and medium distance telephony make it desirable from the view point of the Post Office to leave as much freedom as possible to the circuit designer and not to bind him by the insertion of transformers, the avoidance of D.C. signalling and similar obstacles which can be overcome only by more complications. Moreover, the absence of interference has in this country permitted the development of an extremely extended network of medium distance telephone circuits which are very sensitive to induced voltages at 50 c.p.s.;

an alteration would be costly and time consuming. Thus other methods have, for practical and economic reasons, to be found to avoid disturbances in such circuits.

Long distance connections today use mostly carrier frequencies and are practically immune from disturbances. But selection is possible even for frequencies much nearer to 50 c.p.s. Track circuits can be operated with 75 c.p.s. and $83\frac{1}{3}$ c.p.s., as well as with D.C. When bi-phase relays are used, care is taken to hold the local phase free from 50 c.p.s. D.C. relays are protected against A.C. by chokes; the resulting change in the rate of rise of the D.C. here does not matter, it would be different with D.C. telegraphy.

11 The Problem Abroad

Fundamentally, the interference problem abroad is the same as in this country. It is different, however, in degree and the remedial measures necessary here may not be needed elsewhere.

In France, the circuits and cables used by the Post Office seem to be less sensitive with regard to induction than those in this country; the circuits may be less complicated. Railway signalling and telecommunication circuits and cables seem to have been adapted to the occurrence of high induced voltages. In consequence, there has been no need to employ compensation at source.

In Japan, however, it has been found that it would be very expensive to displace telecommunication lines running near an A.C. railway in a narrow valley (soil resistivity is high). There, compensation at source by means of booster transformers is being employed.

Similar differences exist between low frequency ($16\frac{2}{3}$ c.p.s.) A.C. railways. Norway and Sweden use booster transformers, the former without and the latter with return conductors, one reason being probably the high soil resistivity combined with the difficulty of replacing open wire lines by cables. In Austria, Germany and Switzerland, railway and Post Office cables and equipment have been adapted to induced voltages, and partly owing to the lower frequency compensation at source has been avoided.

It is evident that the nature of the existing public telephone network is of vital importance to the correct solution of this problem and as explained has had a pronounced bearing on the solutions adopted on the electrifications currently in hand in Great Britain.

Considering our problem purely from the point of view of railway telecommunication equipment, screening may often be the most economical solution, and further reference to recent developments in this sense is made later.

12 Screening of Cables

A heavily screened cable, e.g. aluminium sheath and four steel tapes—can have a screening factor of about 1/30, sufficient to exclude any risk of danger and most forms of disturbance. But even with such compensation, it may be impossible to operate, near the railway, circuits with earth return or with an important unbalance to earth because one may get more than five volts induced which could interfere with the operation of the telecommunication signalling system.

With medium screening, e.g. lead sheath or thin aluminium sheath and two steel tapes, or even several cables without armouring, but with heavy sheaths, near together, the screening factor might be approximately 1/5. Under British Railways' conditions the normal limits of the C.C.I.T.T. might be exceeded in all but rather short induced circuits; in such a case the equipment would have to be separated from the cable conductors by isolating transformers and be designed so that D.C. does not need to be transmitted over the cable. In exceptional cases, if that were impossible, the transformers could be bridged by relays, or replaced by longitudinal chokes.

If the telecommunication lines are already cabled but of old design, the screening will often be insufficient. Sometimes old cables can be replaced economically by new ones with improved screening, or in certain cases a heavy earthed conductor may be run near the cables to act as a screen (this expedient is being used extensively on the Eastern Region Conversion Scheme). In most cases of this kind, and especially if, in addition, there is a risk of disturbance in Post Office circuits, it becomes necessary to apply compensation at the source in the railway supply.

13 Compensation of Supply

A simple but not often applicable method is to supply the contact wire simultaneously from adjacent feeder stations. This is fully effective only if the telecommunication line is parallel with the railway, with constant induction parameters, between at least two consecutive feeder stations. If this condition is perfectly fulfilled, there remains only the longitudinal induced voltage due to the unavoidable voltage difference between the feeder substations in question which sets up a circulating current. The effects of the train currents cancel out only for the full length, and near each train the voltage conductor to sheath has a peak. Supply in this way reduces the average value of the induced voltage, but the maxima will be about equal to those with unidirectional supply because under emergency feeding arrangements the two-way feed cannot be maintained.

The amount of reduction is not so large for short railway circuits and for Post Office lines on adjacent roads.

This method is being used where it is possible to parallel adjacent feeds as described in Paper 5 on parts of the 6·25 kV network in Great Britain.

Where none of these methods is adequate, consideration must be given to a more radical compensation at the source, such as the use of booster transformers with or without return conductors in spite of the cost and complication of doing so.

14 Booster Transformers

In order to force all the return current into a 'return conductor', *booster transformers* can be used, connected between contact wire and rail(s) or between contact wire and special return conductors (fig.2). They are essentially large current transformers; the burden involved is $l(R_3 + j\omega(L_3 - m_{13}))$ where l is the length of a section, in this country one mile with connection to rail and two miles with return conductor. The burden contains the full resistance but only part of the reactance of the return conductor circuit; it can be reduced by reducing the resistance of this circuit and the separation between it and the contact wire.

British Railways have been obliged to decide to use booster transformers. They are necessary to avoid interference with Post Office lines. Generally, return conductors are used as, for example, on the Liverpool – Crewe section and on the Clacton pilot scheme, but the other pilot scheme (Manchester – Crewe) has rail connected transformers.

Booster transformers provide a very, but not fully, effective protection against magnetic induction. The uncompensated induced voltages are due to following causes:—

(*a*) The induction by the loop contact wire/rails or contact wire/return conductor is small, but not negligible, particularly as regards railway cables. With rail return, the leakage of the rails, between transformers, reduces the average rail current, especially at audio frequencies, and increases the induced voltage. For railway cables, this loss of rail current compensates partially the loop induction. With special return conductors, the loop current will induce some rail current which in turn affects other lines. Installation of the return conductor as near to the contact wire as possible reduces but cannot, for practical reasons, eliminate these effects. With two tracks and a symmetrical arrangement of the return conductors, the direct loop effect is further reduced.

(*b*) For booster transformers with return conductor, the compensation is imperfect in each booster section which contains a train; the nearer the train is to a transformer, the less perfect the compensation. This is true even with supply from both adjacent feeder stations because the currents in contact wire and return conductor are in the same direction (see fig.3). Moreover, the line impedance is discontinuous at each transformer.

It can be shown, however, that with booster transformers with rail return induction by a train between two transformers is less than that due to the same current passing over the full section.

(*c*) The magnetising current of a booster transformer always returns via the rail and earth. This can be important under overload and short circuit conditions, when the magnetising current is much more than 1 per cent of the contact wire current. The design of the transformer is an important factor and the two designs in use vary appreciably as regards the current value at which saturation begins.

The magnetising current is also generally considerably distorted and may give rise to induction in the audio frequency range; hence, low saturation is desirable. The Commission's specification for booster transformers contains stipulations to minimise the possibility of disturbance from this source. The no-load current at 50 c.p.s. and at a voltage which would drive the peak current through the relevant burden may only amount to a maximum of 7·5 amps. As the peak currents will be from 500 to 1500 amps, this limit corresponds to 1·5 to 0·5 per cent of the contact wire current. The burden specified when rail return is used is $0{\cdot}35 + j\,0{\cdot}60$ ohm, corresponding to 1·5 miles of track, so that two transformers are able to drive the current through three miles of track when the transformer between them is short-circuited by a passing train. For booster transformers used with return conductors, the burden depends on the size of the return conductor and with the two mile spacing in use in Great Britain is specified as follows:—

Cross Section sq. in.	*Burden ohm.*
0·089	$1{\cdot}3 + j\,1{\cdot}5$
0·15	$0{\cdot}8 + j\,1{\cdot}4$
0·22	$0{\cdot}5 + j\,1{\cdot}4$
0·44	$0{\cdot}25 + j\,1{\cdot}3$

It is further specified that the no-load current at 800 c.p.s. and 30 volts primary voltage should not considerably exceed 30 milliamps.

15 Effect of Booster Transformers

In assessing the compensating effect of a booster transformer installation, the sources of induction which they do not eliminate, see (14) above, must be taken into account. In addition, it must be noted that an important part of the remaining induced voltage is the small difference between large voltages induced by contact wire and return conductor current respectively. Small parasitic effects can change the expected values, e.g. additional earthed conductors or even variations of the position of the induced cable. This is a fundamental difference from the case of magnetic induction by a line with earth return. Figs.4 and 5 give calculated values of the voltages induced by a two-track railway without and with booster transformers with return conductors, under different load conditions and for different positions of the affected conductor, ignoring the effect of screening. Moreover, they show the improvement to be expected from a booster installation with closely spaced perfect transformers as the imperfections *b* and *c* are not taken into account. In practice much lower values would occur due to the screening effect of cable sheaths.

Fig.6 gives calculated values of the induced voltages in an unscreened wire, when a train taking 100 amps moves from a feeder station to a T.S.C. 15 miles distant. The calculation is made for a wire 1m below rail level and 4m or 60m from track centre, and for current in both the near and far contact wire. In addition, measured values obtained by the Eastern Region on tests on the Colchester – Clacton line are given. These show that the expected variation occurs; a better agreement cannot be expected as the position of cable and return conductor varies appreciably along the route.

For booster transformers with rail return, the voltage induced in a long cable increases practically proportionally with the length of exposure. Due to the position of the loops, the compensation for railway cables (near to the rails) is not as good as for more distant Post Office cables. The following values are calculated for *10 miles* exposure, 50 c.p.s., an average rail current of 97·5 per cent of the contact wire current, for unscreened cables in the same positions as above:—

Current in amps. in contact wire		*Volts induced in cables*	
Near	*Far*	*4 metres*	*60 metres distant*
100	0	+ 81	− 5·94
50	50	+ 52	− 5·88
0	100	+ 23	− 5·82
−50	50	− 29	+ 0·06

Minus sign for induced volts denotes preponderant induction by contact wire current; a negative value of current occurs for the fraction of the supply coming via the Track Sectioning Cabin beyond the load. The values would again be reduced by the screening factors in a practical case.

This table, compared with fig.6 suggests that booster transformers with rail return would be preferable for the protection of Post Office circuits. Unfortunately this is true only at the fundamental frequency. Paper 37 shows in detail that with audio frequency the average rail current becomes smaller, due to leakage, resulting in less effective compensation.

16 The methods of protection in use in Great Britain

Some reference has already been made herein, and in other papers, to the methods in use on the electrification schemes in progress but a summary of these will assist in explaining their differences.

(1) Manchester – Crewe ... Heavily screened railway cables, booster transformers with rail return.

(2) Colchester – Clacton ... Unarmoured aluminium sheathed railway cables. Booster transformers with return conductors.

(3) London – Tilbury – Southend
(4) Enfield – Chingford – Bishop's Stortford
(5) Chelmsford – Colchester
} Unarmoured aluminium sheathed railway cables, booster transformers with return conductors.

(6) Conversion ... ... Lead and aluminium sheathed unarmoured cable. Booster transformers with return conductor.

(7) Glasgow Suburban ... Medium screened railway cables. Booster transformers with return conductor.

(8) Crewe – Rugby ... Medium screened railway cables. Booster transformers with return conductor.

(9) Rugby – Wolverton (via Weedon). Heavily screened railway cables. No booster transformers.

The reason for these variations, which may at first sight seem to be somewhat random in character, may be classified under three headings, (*a*) either the choice was made to obtain evidence as to the efficacy of the arrangement or (*b*) the arrangements were considered to be necessary to complete the work in the time available according to the programme, or (*c*) the arrangements were necessitated by the existence of cable systems which it was not economical to replace. The method used between Manchester and Crewe falls into category (*b*) as it was vital to get the new signalling into use before a firm decision could be taken as to what was essential for interference prevention. Screening may prove to be heavier than is really necessary. The method used on the line between Colchester and Clacton is fundamentally a case of category (*a*); this was a pilot scheme and it was desired to compare the efficacy of this method with that used between Manchester and Crewe.

As regards the London, Tilbury and Southend and Enfield – Chingford lines, an early decision was necessary and the method adopted was at the time thought likely to be the most economical arrangement. Glasgow Suburban, Crewe – Liverpool and Crewe – Rugby are also in the same category.

The same arrangement is being adopted for Chelmsford to Colchester and in this case it is considered essential to instal booster transformers for the protection of Post Office cables. The arrangements made in connection with the conversion are an example of category (*c*) because the railway signalling and telecommunication cables were installed for the 1,500 volt D.C. electrification and were barely ten years old.

The decision in respect of Rugby to Wolverton is governed by the fact that protection at the source is not necessary for the Post Office and that being the case the most economical solution is the adoption of more heavily screened railway cables. This is the solution which will be generally adopted in the future whenever possible.

It must be realised that the selection of the 'best' method to avoid inductive interference requires an effective co-operation between all parties involved and that alterations in one installation can have repercussions on all the others.

SUMMARY

The paper deals first with the general aspects of interference with adjoining signalling and telecommunication circuits by electrified railways, particularly those using single phase A.C. of 50 c.p.s., and discusses the tolerable limits for different effects. It considers in some detail the calculation of induced e.m.f.'s and the screening effect of earthed conductors; discusses shortly several ways to reduce induction at the source and in detail application and effects of booster transformers, as well as the limitations inherent to this method of compensation. Diagrams are given for calculated induction with and without booster transformers.

It comments on Papers 10, 37, 37A and 41 in the above context and concludes with an explanation of the methods adopted on the British Transport Commission Electrification Schemes with particular reference to the extent to which variations are likely on future electrifications.

RÉSUMÉ

Cet exposé traite d'abord les problèmes généraux relatifs à la coexistence des lignes de signalisation et de télécommunication et des lignes des chemins de fer électrifiés, particulièrement ceux-ci électrifiés en courant alternatif monophasé 50 Hz. Les limites tolérables pour les divers effets nuisibles sont discutées. L'exposé traite en détail le calcul de la force électromotrice induite et l'effet compensateur des conducteurs mis à la terre. Il discute brièvement plusieurs méthodes de compenser l'induction à sa source et il traite plus amplement l'application et les effets des transformateurs – suceurs ainsi que les limitations inhérentes à cette méthode de compensation. Des jeux de courbes sont inclus qui donnent des valeurs calculées de la force électromotrice induite avec et sans transformateurs-suceurs.

Il commente les expositions compétentes des exposés 10, 37, 37A, et 41 et pour terminer l'auteur explique les méthodes adoptées par la British Transport Commission pour les électrifications en courant alternatif en considérant particulièrement à quel point sont probables des variations de ces méthodes pour des électrifications futures.

ZUSAMMENFASSUNG

Der Aufsatz befasst sich zunächst mit den allgemeinen Gesichtspunkten der Einwirkung elektrischer Bahnen, besonders solcher nach dem Einphasen – Wechselstromsystem mit 50 Hz, auf benachbarte Signal – und Fernmeldestromkreise, und erörtert die Grenzwerte, die bei verschiedenen Effekten zulässig sind. Die Berechnung der induzierten EMK und die Schutzwirkung geerdeter Leiter werden ausführlich behandelt. Verschiedene Verfahren, die Beeinflussung durch Massnahmen an der Bahnanlage zu verkleinern, werden kurz besprochen; die Anwendung und die Wirkungen der Saugtransformatoren sowie die Grenzen, die diesem Kompensationsverfahren eigen sind, werden genauer dargelegt. Werte der induzierten EMK ohne und mit Saugtransformatoren werden in Kurventafeln gegeben.

Die diesbezüglichen Ausführungen in den Berichten 10, 37, 37A und 41 werden herangezogen. Der Aufsatz schliesst mit einer Erklärung der Verfahren, die zum Schutze der Fernmeldeanlagen bei Bahnelektrifizierungen der B.T.C. benutzt werden, unter besonderer Berücksichtigung möglicher Aenderungen bei späteren Elektrifikationen.

RESÚMEN

El folleto se refiere en un principio, de manera general, a la interferencia en circuitos de señalizacion y telecomunicaciones debido a electrificaciones ferroviarias. En particular se refiere a las electrificaciones que utilizan corriente monofasica a 50 ciclos. Analiza tambien los limites tolerables para los distintos casos.

Estudia mas adelante metodos para calcular la fuerza electromotriz inducida asi como el efecto pantalla de los conductores a tierra. Estudia tambien varios metodos para reducir la induccion asi como la aplicacion de transformadores y las limitaciones de este sistema de compensacion. Se acompañan diagramas en los que se muestran inducciones varias con y sin transformadores compensadores.

Este folleto tambien analiza las conclusiones que sobre el mismo asunto se plantean en folletos 10, 37, 37A y 41. Finalmente se detallan los metodos adoptados por la ' British Transport Commission Electrification Schemes ' dando particular importancia a las distintas alternativas a adoptarse en electrificaciones futuras.

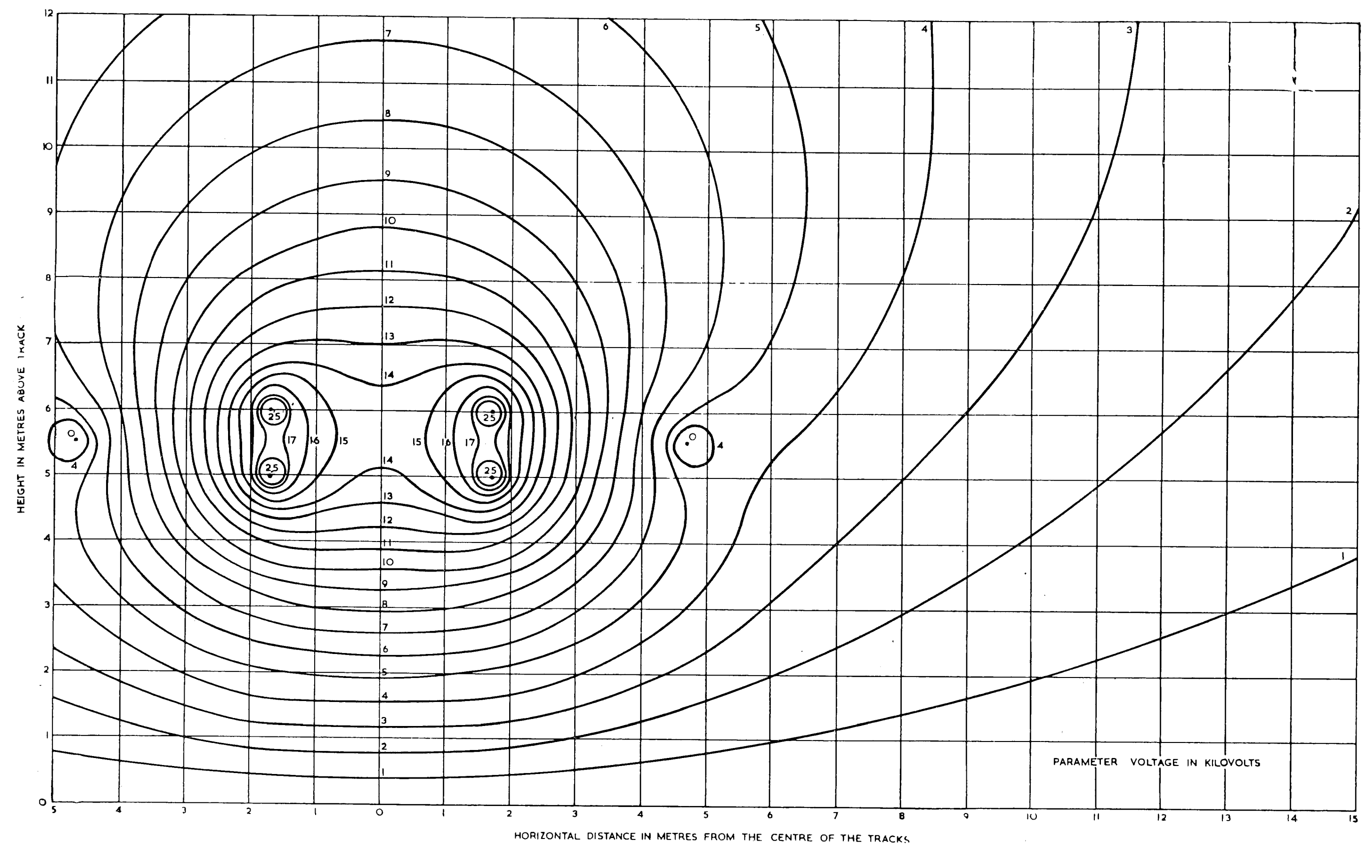


Fig.1 Electric field

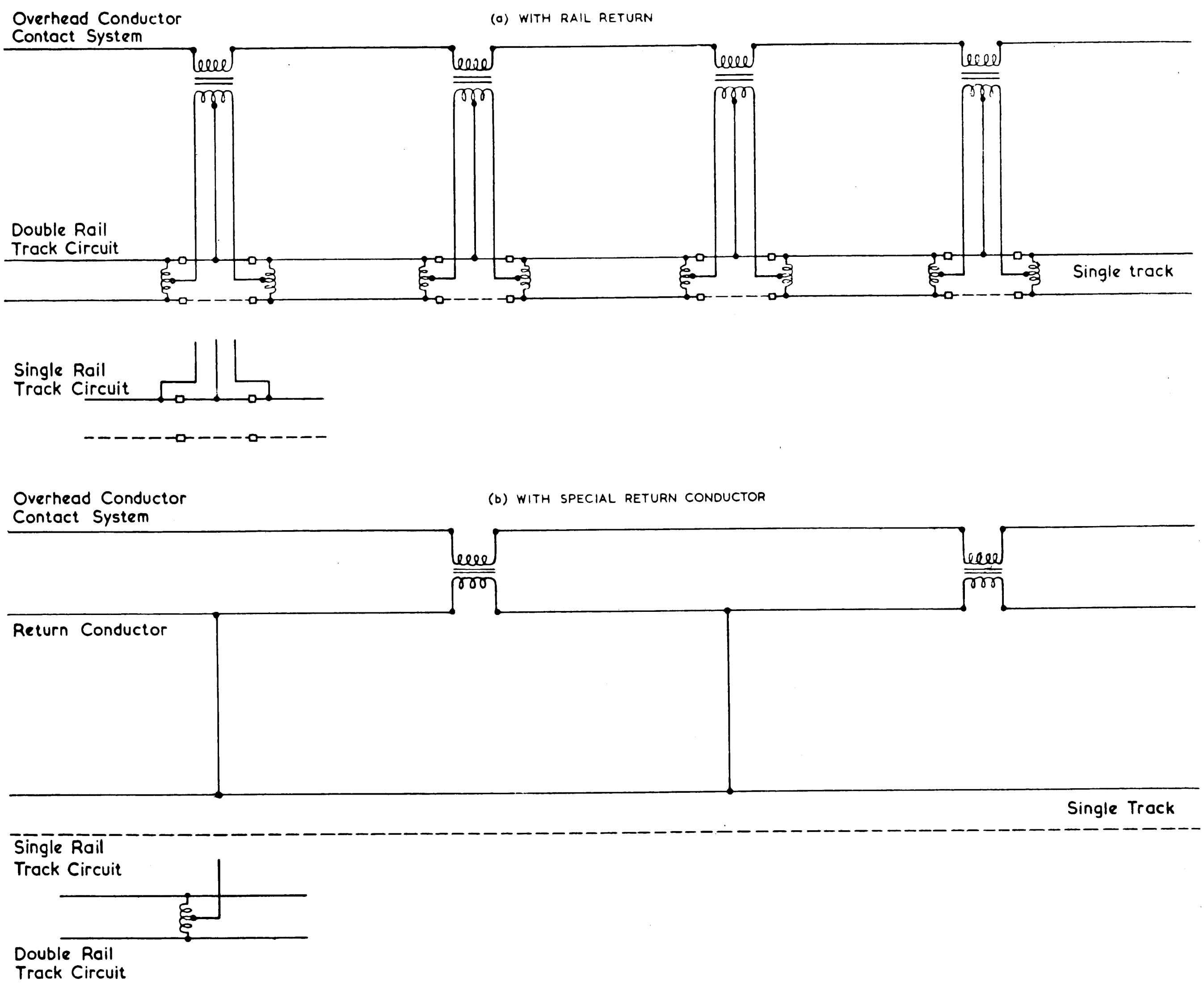


Fig.2 Booster transformer connections

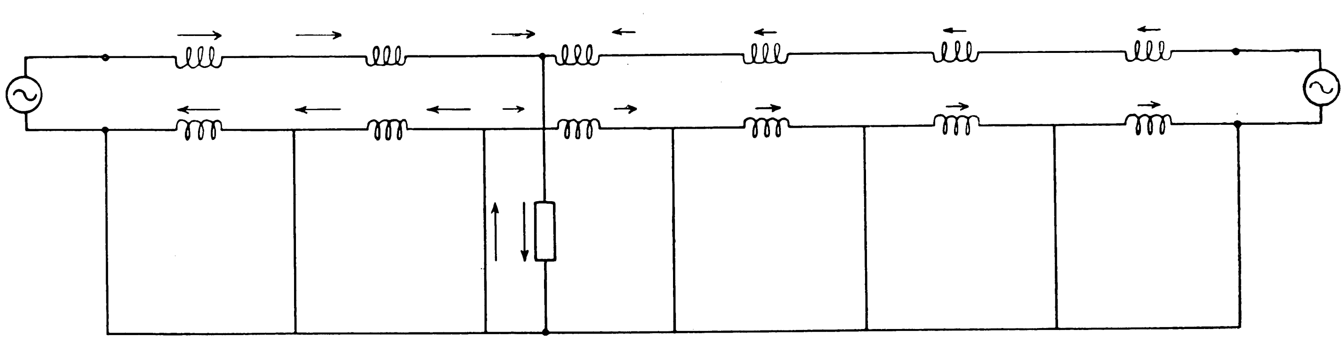


Fig.3 Current distribution in a booster section with supply from both ends

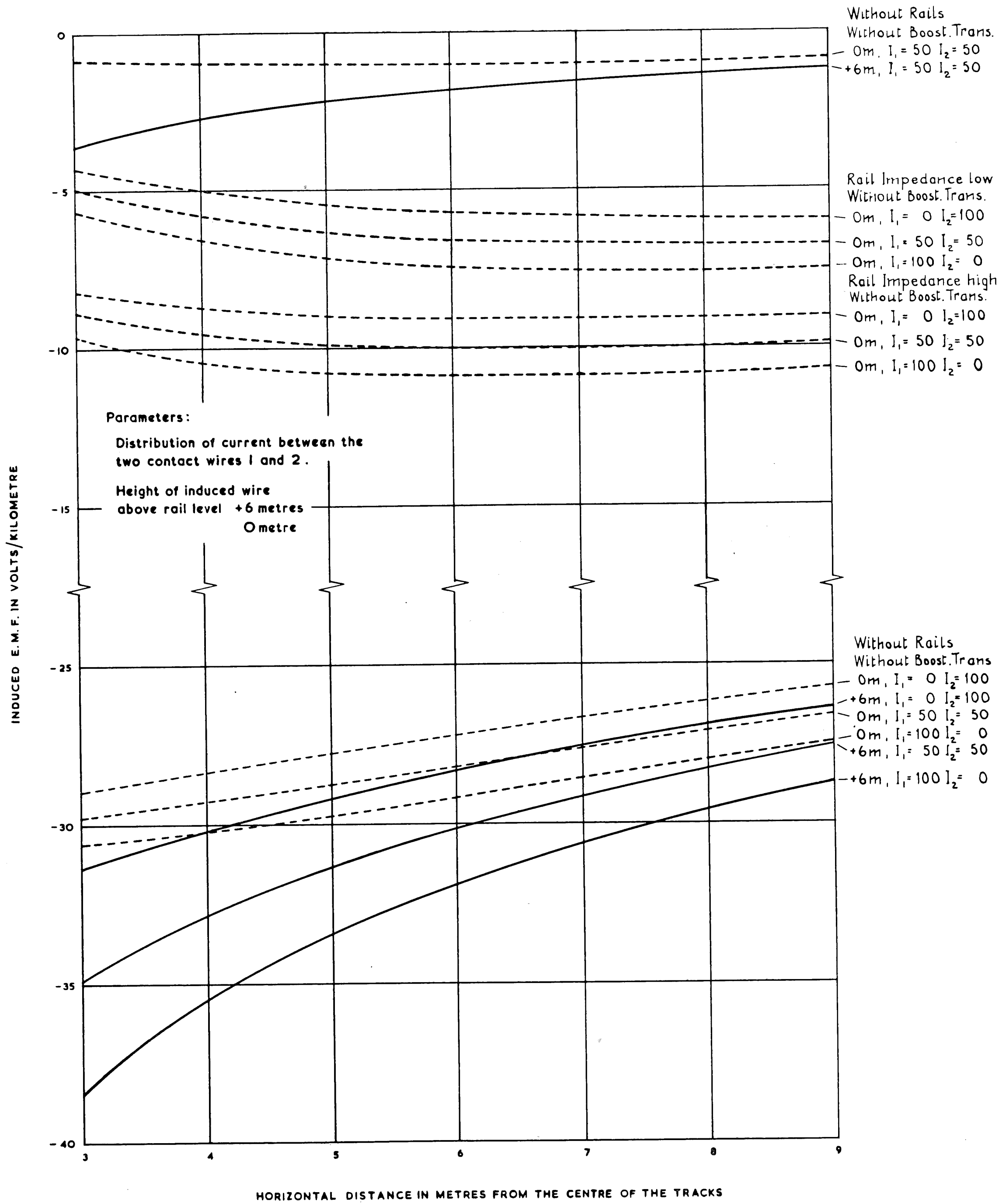


Fig.4 Calculated values of the E.M.F. induced by a two track railway without booster transformers and return conductors, and by two contact wires with earth return, in an unscreened wire on the side of track 1, in function of its horizontal distance from the centre of the two tracks.

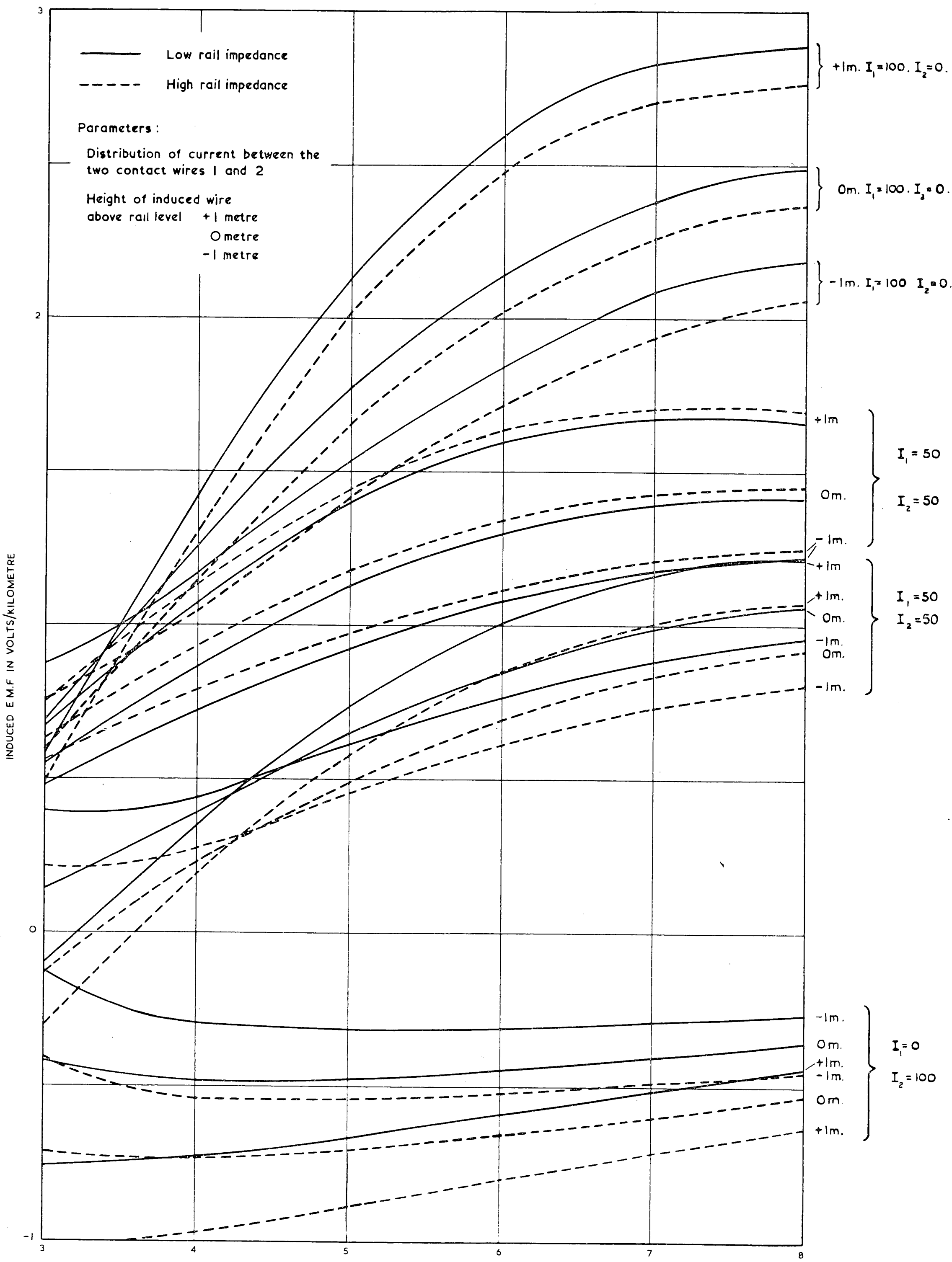
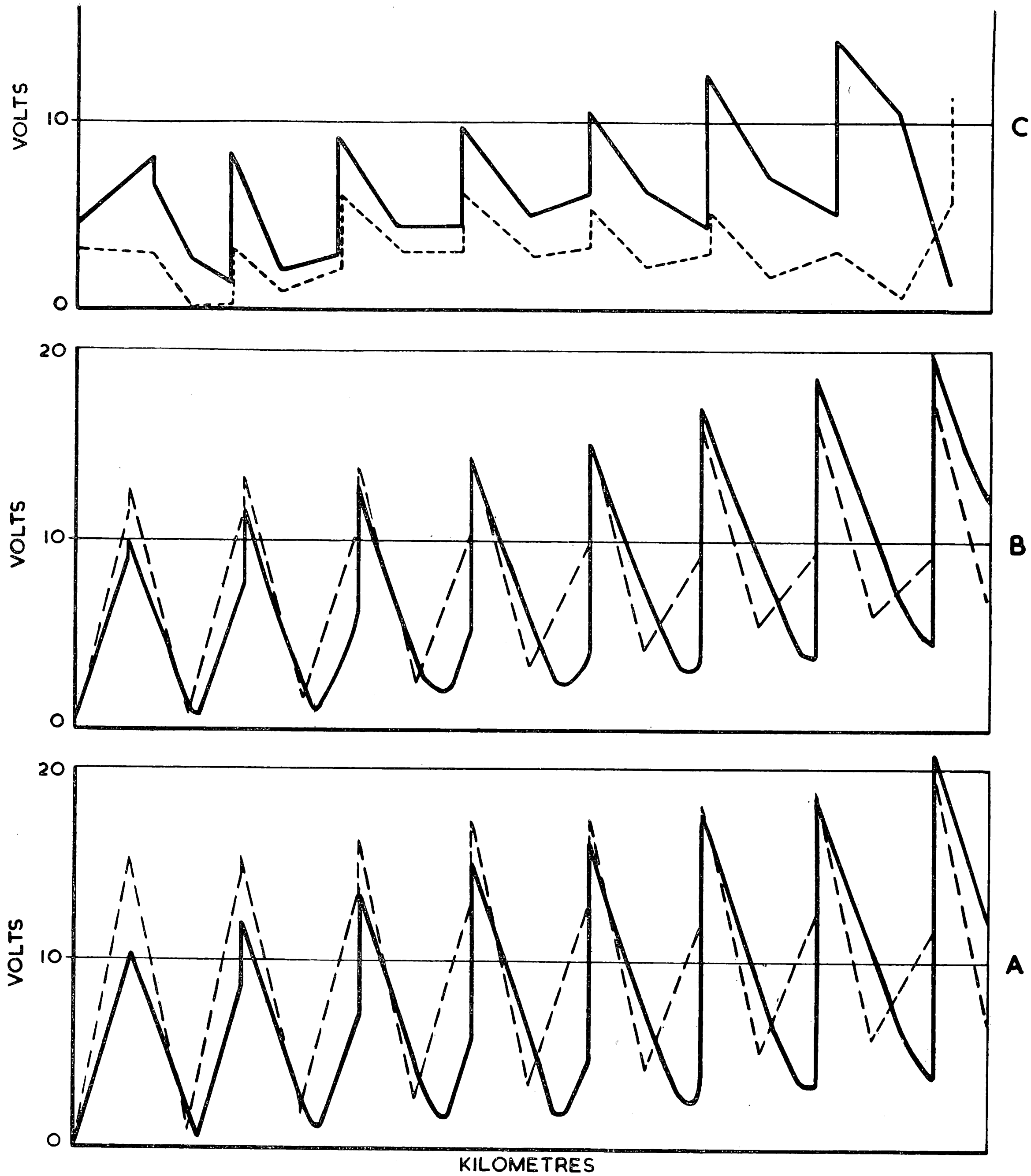


Fig.5 Calculated values of the E.M.F. induced by a two-track railway with booster transformers and return conductors in an unscreened wire on the side of track 1, in function of its horizontal distance from the centre of the two tracks



A. 100 AMPS IN NEAR CONTACT WIRE   B. 100 AMPS IN DISTANT CONTACT WIRE

– – – – 4 METRES   ———— 60 METRES FROM MID TRACK

C. VALUES MEASURED BY EASTERN REGION, WITH 100 AMPS IN UP LINE ———— OR DOWN LINE - - - - - - -

Fig.6 Induced voltage in a long unscreened wire when 100 amps are consumed at different points along a line of 24 kilometres length BT at kilometres 1·5, 4·5, 7·5 . . .; T.S.C. at kilometre 12·0 depth of wire 1 metre below rail level; separation from mid track 4 metres or 60 metres

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