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Effect on Post Office Circuits

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1 Introduction

Single phase electrified railway systems using the rails as a return path, unless equipped with suppression devices, give rise to induction effects over a wide area, and where such railways run parallel to telephone cables, noise troubles and functional interference with D.C. telephone signalling equipment are likely to occur. The British Post Office telephone system serves over 7½ million telephones connected to some 6,000 exchanges, and the density of the system, in terms of telephones per square mile is one of the highest in the world, as may be seen from Table 1.

Table 1
Telephone Densities in Telephones/Square Mile

Country	*Telephones/Square Mile*
Switzerland	87
United Kingdom	78
Federal German Republic	49
Japan	27
United States of America	21
France	16
Sweden	14
Portugal	8·8
Norway	4·3

The system has developed gradually over the last 50 years or so and includes about 20 basically different designs of exchanges using, in many cases, a number of equipments of different vintages.

The exchanges are inter-connected by an extensive network of circuits, largely in unarmoured lead-sheathed cable, of which the shorter distance circuits (called ' junction ' circuits), in general, use D.C. signalling because of its great cost advantage over A.C. There are a number of fundamentally different types of D.C. signalling systems, the principles of which have been embodied in many different designs of junction terminations to meet different service requirements and to interwork with the various types of exchanges in the network. It is estimated that there are at present over a quarter of a million junctions using several hundred different designs of D.C. signalling terminations. There are in addition many thousands of longer circuits (called ' trunk ' circuits) on a small proportion of which D.C. signalling is also employed.

It will be apparent that the electrification of the British Railways System at such a late stage in the development of the telephone network could give rise to extremely serious interference problems, unless the problem is solved in such a way as to limit the induction to values which would not give rise to noise and functional interference. This may be illustrated by reference to the electrification of the section of British Railways between Manchester and Crewe (about 40 miles) where a detailed study on a theoretical basis showed that without suppression at source some 1,600 circuits, of which 1,400 are telephone junction circuits, could be adversely affected. The difficulties which would have arisen would have been mainly due to magnetic induction, but brief reference to electric induction is made in Section 2.2.2. Examination of other parallelisms showed that the conditions of the Manchester – Crewe section arise in other areas.

In addition to the telephone trunks and junctions referred to above, other types of circuits would also be affected; these include subscribers' lines, telegraph and television circuits, and circuits leased to private renters. (Leased circuits constitute about 20 per cent. of the total circuits in trunk and junction cables.)

2 Possible Interference Effects

The following paragraphs describe the effects which could occur unless preventive measures were adopted.

2.1 *Functional Interference*

2.1.1 *Telephone Trunk and Junction Circuits*

Circuits using A.C. signalling systems are equipped with transformers which provide well-balanced earth-free terminations and are, in general, immune from the effects of 50 c/s induction. D.C. signalling equipment, on the other hand, employs the earth-connected exchange battery for line signalling and is susceptible to the effects of induced voltages. The values of induced 50 c/s voltages above which functional mis-operation may be caused are different for different D.C. signalling systems, and vary for different designs of terminations using the same signalling principles. Table 2 indicates the induced longitudinal 50 c/s voltages above which functional interference may be caused to various designs of junction signalling equipment.

Table 2

Failure points of Trunk and Junction Signalling Systems

Type of Equipment	*Longitudinal voltage above which interference may be caused (VOLTS)*	*Effect*
Loop-disconnect pulsing[1]	5	Excessive dial pulse distortion
Battery pulsing[1]	5	Excessive dial pulse distortion
Differentiated pulsing[2]	5	False switching
Double-current pulsing[3]	11	False supervision
Generator signalling, D.C. control	10	False signals
*U.A.X. signalling[4, 5]	20	False signals
Outband carrier, D.C. control[6]	5	Excessive dial pulse distortion

Note *Circuits using U.A.X. signalling, in general, also use loop-disconnect pulsing.

References

[1]S. Welch. The Fundamentals of Direct Current Impulsing in Multi-Exchange Areas, I.P.O.E.E. Printed Paper No. 184.

[2]S. Welch and C. H. J. Fleetwood. Long Distance D.C. Impulsing, I.P.O.E.E. Printed Paper No. 178.

[3]S. Welch and B. R. Horsfield. The Single Commutation Direct Current Signalling and Impulsing System, I.P.O.E.E. Journal, Vol. 44, Part 1, April 1951.

[4]C. G. Grant and E. M. Cook. The Unit Automatic Exchange No. 12, I.P.O.E.E. Journal Vol. 28, Part 2, July 1935.

[5]C. G. Grant and A. J. C. Henk. The Unit Automatic Exchange No. 13, I.P.O.E.E. Journal Vol. 29, Part 2, July 1936.

[6]B. R. Horsfield and R. W. Gibson. Signalling over Carrier Channels that provide a Built-in Out-of-Speech-Band Signalling Path, I.P.O.E.E. Journal Vol. 50, Part 2, July 1957.

Space precludes a detailed description of all the various effects listed in Table 2, but a brief reference to the dial pulse distortion problem will be made. The performance of D.C. pulse repeating equipment has been perfected over the years to reduce to a minimum the pulse distortion introduced by line plant characteristics, and other variables. Full advantage has been taken of the distortion margin between the output of the dial contacts and the requirements of the selectors, to permit the most economical planning of the telephone system both in respect of line plant and exchange equipment, and in many cases the arrangements are such that on some calls the pulses may be repeated over several junctions in tandem without correction or regeneration at tandem switching points. The oscillograms in fig.1 show the effect of induced 50 c/s voltages on loop-disconnect pulsing (the most widely used system). Each oscillogram shows a train of ten pulses (Digit ' O ') on a typical loop-disconnect junction subject to 50 c/s induction, and it will be seen that as the interfering voltage increases, the differences between the lengths of the individual pulses become increasingly pronounced. If such junctions were included in multi-link connections approaching the permitted limits of distortion there would be an increasing risk of failures as the induced voltage increased. It will also be seen that at the higher voltages the pulses are split and this would cause trouble on call routings which did not approach limiting conditions. Current developments, such as Subscriber Trunk Dialling and direct dialling into the British Telephone System from overseas countries, make it increasingly important to maintain a high standard of performance in the system.

2.1.2 *Subscribers' Lines*

Dangers of functional mis-operation due to induced 50 c/s voltages also arise on subscribers lines, and Table 3 indicates the induced longitudinal 50 c/s voltages above which functional interference with some of the more common types of subscribers' line equipment may occur.

Table 3

Failure points of Subscribers' Line Equipment

Type of Line	*Longitudinal voltage above which interference may be caused (VOLTS)*	*Effect*
Shared service[7]	25	False bell ringing
Coin box[8]	10	False release
Private metering[9] (S.T.D.)	10	Failure to operate
P.B.X.	less than 5	False engaged test

References

[7]C. J. Cameron and W. A. Humphries. Shared Service, I.P.O.E.E. Journal, Vol. 41, Part 3, October 1948.

[8]F. J. Bastow, J. D. Collingwood, E. Newell and C. K. Price. The Pay on Answer Coin Box System, I.P.O.E.E. Journal Vol. 51, Part 4, January 1959.

[9]F. Gresswell, J. L. Belk and G. A. Alderson. Subscribers Private Meter Equipment, I.P.O.E.E. Journal Vol. 51, Part 4, January 1959.

2.1.3 *Telegraph Circuits*
D.C. telegraph circuits are worked on an earth return basis and are therefore sensitive to interference from longitudinal induced voltages. Tests have shown that an induced 50 c/s voltage of 10V gives rise to an increase in signal distortion which would make it hazardous to include circuits experiencing this or higher values of induced voltages in switched telegraph networks; on point-to-point telegraph circuits, the adverse effect would still encroach on circuit margins, but such voltages could be tolerated.

2.1.4 *Leased Circuits*
Leased circuits terminate on a wide variety of signalling equipments and although these equipments must conform to certain conditions laid down for the protection of Post Office plant, full performance details of the signalling elements are not always known to the Post Office, and the degree of susceptibility of such circuits is therefore not known with certainty.

2.1.5 *Television Circuits*
Television circuits are normally transmitted on coaxial cable pairs which are inherently unbalanced with respect to earth. Signals in the video frequency range (0 – 3 Mc/s) are very sensitive to 50 c/s induction effects and even after means have been adopted to reduce the sensitivity to this type of interference by about 40 db, the maximum induced longitudinal 50 c/s voltage which can be tolerated over a six-mile section (the maximum distance between amplifiers) is approximately 2·5V.

2.2 *Noise Interference*

2.2.1 *Magnetic Induction*
The contact line current of a single-phase 50 c/s traction system feeding trains equipped with rectifiers and D.C. motors contains a large number of harmonics spread over the speech frequency range, and in consequence, induced longitudinal voltages in telecommunications circuits also contain these harmonics.

If the telecommunications circuits have a very high degree of balance, a condition which obtains with transformer-terminated A.C. signalling trunk circuits routed in cables, the transverse voltages which appear across the circuits are small, and can, in general, be ignored, although fault conditions on such circuits, which would not otherwise be serious could render the circuits unworkable, and maintenance standards must therefore be higher than would otherwise be necessary.

If, however, junction circuits with D.C. signalling are considered, even where the circuit terminations are nominally balanced, economic considerations necessitate acceptance of some unbalance due to manufacturing tolerances on the components used. In practice, the ratios of transverse to longitudinal psophometric voltages vary from about 2 per cent. (34 db.) to 0·01 per cent. (80 db.) or less, the former being applicable to a relatively unbalanced junction circuit with earth-connected terminations, and the latter to a transformer-terminated circuit. A typical unbalance distribution for junction calls routed between two Director exchanges measured at the outgoing end is given in fig.2. A reasonable limit for junction circuits, not erring on the side of caution, would appear to be about 1 per cent. (40 db.), and to meet a figure of 0·5 mV transverse psophometric voltage based on the proposed C.C.I.T.T. limits, the appropriate limit for the longitudinal psophometric voltage would be 50 mV.

2.2.2. *Electric Induction*
Experience on the Colchester – Clacton line showed that noise can also occur due to the harmonic voltages in the contact wire system; open wire subscribers' lines close to the railway were affected, the mode of coupling being capacitative. It appears that noise rather than the 50 c/s component, which in severe cases can give rise to danger, is the limiting factor for such lines, which have either been placed in a metallic-sheathed cable to give effective screening or have been diverted.

3 Estimates of Interference Voltages on Post Office Circuits in the absence of suppression at source

3.1 *Methods of assessment*
At present estimates are made on the basis that a current of 400 amps at 25 kV flows into the overhead contact system at each feeder station and persists to the mid-point track sectioning cabin between feeder stations, and that the harmonic content of this current is as shown in Table 4. This table is based on measurements made on the Lancaster – Heysham line; preliminary measurements made on the Colchester – Clacton line suggest that although the analysis may vary in some minor details, the overall effect on calculations based on these figures would not be substantial.

Table 4
Harmonic Content of Traction Current

Frequency c/s	*% of Fundamental*	*Frequency c/s*	*% of Fundamental*	*Frequency c/s*	*% of Fundamental*
50	100	950	0·65	1850	0·28
150	14·6	1050	0·55	1950	0·28
250	5·6	1150	0·46	2050	0·28
350	3·1	1250	0·41	2150	0·27
450	2·3	1350	0·37	2250	0·26
550	1·7	1450	0·33	2350	0·26
650	1·32	1550	0·31	2450	0·23
750	1·03	1650	0·3	2550	0·21
850	0·82	1750	0·29		

Using the normal Carson-Pollaczek formulae, transparent masks have been prepared suitable for use with 2½ in. scale maps, from which induced longitudinal voltages may be read off directly – interpolating where necessary. The masks have been prepared in two sets of six, one set for 50 c/s and the other for the psophometric voltage, each set covering a range of earth resistivity, the appropriate masks being chosen in the light of earth resistivity measurements made on site.

A rail screening factor of 0·5 has been assumed in each case. Cable screening factors are separately assessed as the calculation proceeds, and are based on the sheath resistance. For the psophometric voltages, a sheath resistance of one ohm/mile has been assumed in the preparation of the masks, and the voltage obtained from the mask is multiplied by the appropriate value of sheath resistance/mile. An example of a mask used for the calculation of psophometric voltage is shown in fig.3.

The assessment of cable screening factors gives rise to difficulties (1) where multi-way cable routes are concerned, and (2) where water and gas pipes are present. In some instances therefore, the assessment is a matter of judgment.

However, although the calculations are undoubtedly complex, average rather than adverse conditions are assumed throughout, and whilst no claim can be made for extreme accuracy, it would be a mistake to assume that measured values will invariably be less than those calculated.

3.2 *Estimated Values of Induced Voltage (Manchester – Crewe)*

It has been estimated, using the above techniques, that, in the absence of suppression at source, 50 c/s longitudinal voltages up to 60V could occur in the Manchester Area, the most commonly occurring value being 30V. The corresponding psophometric voltages would range up to 2V, the most common value being about 500 mV.

4 Preventive Measures

4.1 *Remedial Measures to Post Office Plant*

4.1.1 *Telephone Equipment*

Space precludes a description of the many remedial measures which have been considered with a view to overcoming the effects described in Tables 2 and 3, but since loop-disconnect pulsing is the most commonly used D.C. signalling method, a brief reference to work done on this system may be of interest. Tests have been made to determine whether longitudinal chokes could be used to improve the immunity of the system, but inductances of less than 10 Henries have not been found to have any significant effect and inductances having higher values have been found to introduce other pulsing difficulties, such as pulse splitting due to damped oscillations in the line conductors. Consideration has also been given to the use of signalling terminations embodying transformers and signal repeating relays, but this solution would involve extensive modifications to existing plant, and additional pulse distortion would still be introduced by the measures necessary to overcome noise interference.

Longitudinal chokes are useful in reducing noise interference at harmonic frequencies, but their effectiveness is limited unless accompanied by shunt paths to earth, in which case unacceptable pulse distortion is introduced, together with a transmission impairment. Transformers with signal repeating relays would probably give a somewhat greater reduction in noise levels, but would introduce additional pulse distortion and transmission losses, owing to the need for such devices at the incoming ends of junctions, where they are not at present required. Neither longitudinal chokes nor transformers with signal repeating relays would give the required degree of noise suppression on an appreciable number of circuits, and the only satisfactory solution which can at present be envisaged for such circuits is the use of highly balanced transformers free from earth connections. Such a solution would however entail the development of A.C. (or similar) signalling equipments which, to meet the wide variety of requirements in the junction network, would be numerous and complex in character, and, by virtue of the greater space required, would give rise to accommodation difficulties which would be particularly severe in the smaller exchanges.

4.1.2 *Telegraph Circuits*

To overcome the effects of interfering voltages on D.C. telegraph circuits, it would be necessary to adopt loop working with signal repeating relays, which would require twice as many cable pairs as the normal method, or to adopt voice frequency working.

4.1.3 *Television Circuits*

Where the induced 50 c/s voltage exceeded the permissible limit for video frequency transmission, frequency translating equipment would need to be provided. The provision of frequency translating equipment would add greatly to the overall costs of such circuits.

4.2 *Suppression at Source*

4.2.1 *Booster Transformers (Rail-Connected)*

The screening effect of this system[10, 11] depends on the spacing of the booster transformers and on the propagation constant γ of the rail-earth return circuit, which in turn depends on frequency and on the insulation of the rails to earth. In fig.4, the theoretical variation of rail screening factor with booster transformer spacing and frequency is shown for a value of rail insulation (viz. 1·5 ohm/mile) which extended tests have shown represents average conditions for two rails in parallel; the usual spacing at one mile intervals gives a theoretical screening factor of 0·025 at 50 c/s. As the rail screening factor without booster transformers would be 0·5, the improvement ratio due to the booster transformers is therefore 20:1. The reduction at higher frequencies is less, as shown, and hence this method is not very satisfactory for the elimination of noise due to harmonics.

In practice, however, it has been found that the presence of line-side cables can reduce the effectiveness of rail-connected booster transformers due to induced current which flows in the sheaths of such cables. This effect was observed during tests made on the Lancaster – Heysham line, and is supported by a more detailed theoretical analysis[12] in which the effect

Post Office Engineering Department—Investigation Reports of the External Plant and Protection Branch:-

[10]No.70. The characteristics of rail-earth return circuits and contact line – rail mutual impedances.

[11]No.80. Inductive screening due to end effects in rail feeding sections and the action of rail booster transformers under normal railway operating conditions.

[12]No.85. Rail booster transformer tests on the Lancaster : Morecambe – Heysham 6·6 kV railway.

of such cables is included. The measured screening factor obtained at a frequency of 50 c/s for a booster transformer spacing of 1·1 miles was 0·07, the improvement due to booster transformers being therefore only 7 : 1 instead of the theoretical 20 : 1 mentioned above. At harmonic frequencies, where a much greater proportion of the current leaves the rails due to the increase in the series impedance of the rails with increase in frequency, the current induced in the sheaths of line-side cables has very much less effect on the screening factor, and for the harmonic distribution shown earlier, the screening factor for the induced psophometric voltage is of the order of 0·15 (corresponding to an improvement due to the use of booster transformers of about 3 : 1).

4.2.2 *Booster Transformers with Return Conductor*

Consideration of the return-conductor system[13] shows that two main effects need separate treatment. The first is induction from through currents, i.e., those currents taken by trains well beyond the parallelism and confined wholly to the contact wire and return conductor, and secondly, induction due to a train in section i.e. where the train is within or near to the parallelism, and current is flowing along the rails.

For telecommunications plant well removed from the railway, i.e. for most Post Office cables, considering the first effect, the contact wire and return conductor are nearly equidistant from the cable, and the direct induction from this loop may therefore be ignored. However, the rails are not and cannot be symmetrically disposed with respect to the contact wires and return conductors, and hence an induced current flows in the rails; it is this current which causes induction in the telecommunications plant. Calculations suggest that the system screening factor for such remote cables should then be of the order of 0·025 and should be substantially independent of frequency. This represents an improvement of 20 : 1. Considering the second effect, maximum induced voltage occurs when a train is close to a booster transformer, in which event the length between the train and the strap (between rail and return conductor) to which the train current returns may be treated as being equivalent to a normal feeder section without booster transformers, for which a screening factor of 0·5 at all frequencies would be appropriate, provided the parallelism extends for about two miles or more on either side of this equivalent section.

For cables close to the railway, conditions become more complex, and fig.5 shows the screening factor appropriate to such cables in various positions where the loop effect and induced rail current have been considered. So far as induction from a train in section is concerned, the appropriate screening factor will be in the range 0·4 to 0·6.

Post Office Engineering Department—Investigation Report of the External Plant and Protection Branch:–

[13]No.93. Inductive screening of communication lines produced under normal railway operating conditions by booster transformers (current ratio 1 : 1) with return conductors.

5 Conclusions

From considerations such as have been described above, it has been concluded that the development effort, which would be necessary to make the multiplicity of Post Office circuits in the affected areas immune from the effects of induced voltages, would be so great that it would not be practicable to attempt to carry out the necessary changes. It has therefore been necessary for the Post Office to ask the Transport Commission to incorporate measures for the suppression of interference at source on those sections of the railways which would otherwise give rise to serious interference with Post Office plant. It seems likely that about one-third of the electrified route will fall within this category, and that a booster transformer system with return conductors will provide the necessary degree of protection.

6 Acknowledgment

The authors wish to thank the Engineer-in-Chief of the Post Office for permission to publish the Paper.

SUMMARY

Following a brief review of the public telephone network in the United Kingdom, the Paper describes the interference effects which could be experienced by Post Office telecommunications circuits, separate consideration being given to the problems of functional and noise interference. Telephone trunk and junction circuits are considered in some detail, and there is also mention of the effects of induced voltages on a variety of other types of circuit. The method of calculation of induced voltages is described, and the problems of modification of Post Office equipment to make it immune from the effects of such voltages, are also outlined. Finally, there is a discussion on the degree of suppression afforded by booster transformers with and without return conductors, and it is concluded that suppression of interference at source is necessary on about one third of the electrified railway route.

RÉSUMÉ

Après avoir passé brièvement en revue le réseau public de téléphones dans le Royaume-Uni, l'exposé décrit les perturbations possibles sur les circuits de télécommunications de l'Administration des Postes. On considère séparément les perturbations au fonctionnement et celles par bruits. Les circuits téléphoniques interurbains et de jonction sont traités avec quelques détails. On mentionne aussi les effets des tensions induites sur d'autres types différents de circuits. La méthode de calcul des tensions induites est décrite, et on donne un aperçu des problèmes de modification de l'équipement des Postes pour le rendre insensible aux effets des tensions induites. Finalement on discute le degré de suppression des troubles obtenue par les transformateurs-suceurs avec ou sans conducteurs de retour. La conclusion est que la suppression des troubles à leur source est nécessaire sur environ un tiers des lignes électrifiées.

ZUSAMMENFASSUNG

Einleitend wird eine kurze Uebersicht über das öffentliche Telephonnetz im Vereinigten Königreich gegeben. Der Bericht beschreibt dann die Störungen, die von der Postverwaltung in ihren Fernmeldestromkreisen bemerkt werden konnten. Besondere Bedeutung wird den Problemen der funktionellen- und Geräuschstörungen gegeben. Die Telephon Fern- und Verbindungsstromkreise werden ziemlich ausführlich erörtert und die Auswirkungen der induzierten Spannungen in einer Anzahl von andern Stromkreisarten erwähnt. Die Methode der Berechnung der induzierten Spannungen wird beschrieben und die Probleme der Abänderung der Ausrüstung, um sie immun gegen die Einwirkungen solcher Spannungen zu machen, ebenfalls angegeben. Eine Diskussion über den Grad der Unterdrückung bewirkt durch Saugtransformatoren mit oder ohne Rückleiter ist angeführt; man kommt zur Folgerung, dass Unterdrückung dieser Störspannung am Ursprung für ungefähr ein Drittel der elektrifizierten Eisenbahnlinien notwendig ist.

RÉSUMEN

Tras un breve examen de la Red de Teléfonos Públicos del Reino Unido, describe el artículo los efectos de interferencia que pueden ser experimentados por los circuitos de telecomunicaciones del Post Office, examinándose por separado los problemas de las interferencias funcionales y de parásitos. Se consideran un poco detalladamente los circuitos de enlace y de unión, mencionándose también los efectos de los voltajes inducidos sobre diversos otros tipos de circuitos. Se describe el procedimiento empleado para el cálculo de los voltajes inducidos, y asimismo se hace referencia al problema de la modificación del equipo del Post Office para hacerlo inmune a los efectos de dichos voltajes. Por fin viene tratada la medida de la supresión que se consigue con transformadores de succión con o sin cables de retorno, concluyéndose que es necesaria la supresión de la interferencia en su fuente de origen en aproximadamente un tercio de las líneas de ferrocarril electrificadas.

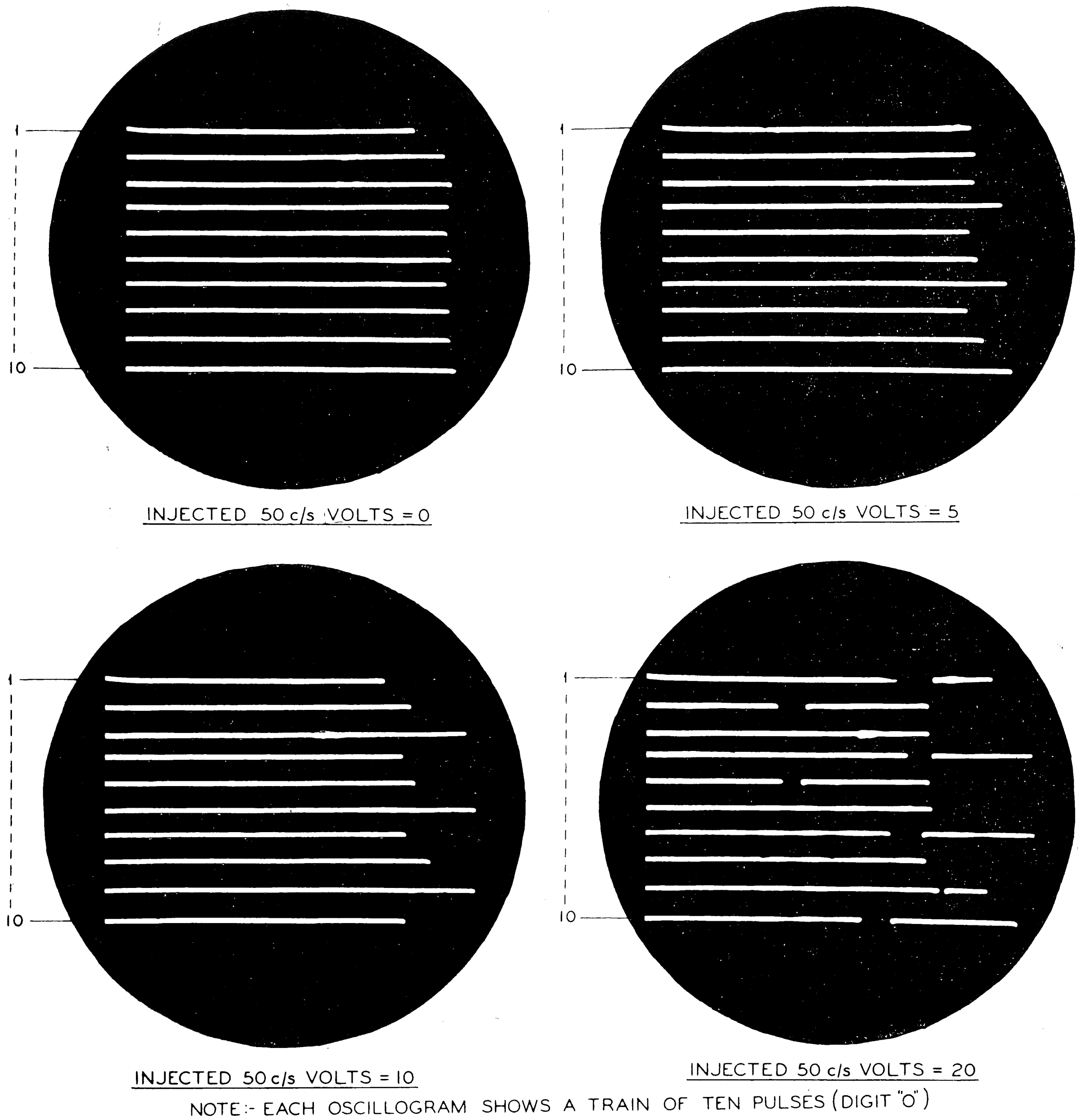


Fig.1 **Distortion and splitting of loop-disconnect pulses due to 50 c/s induction**

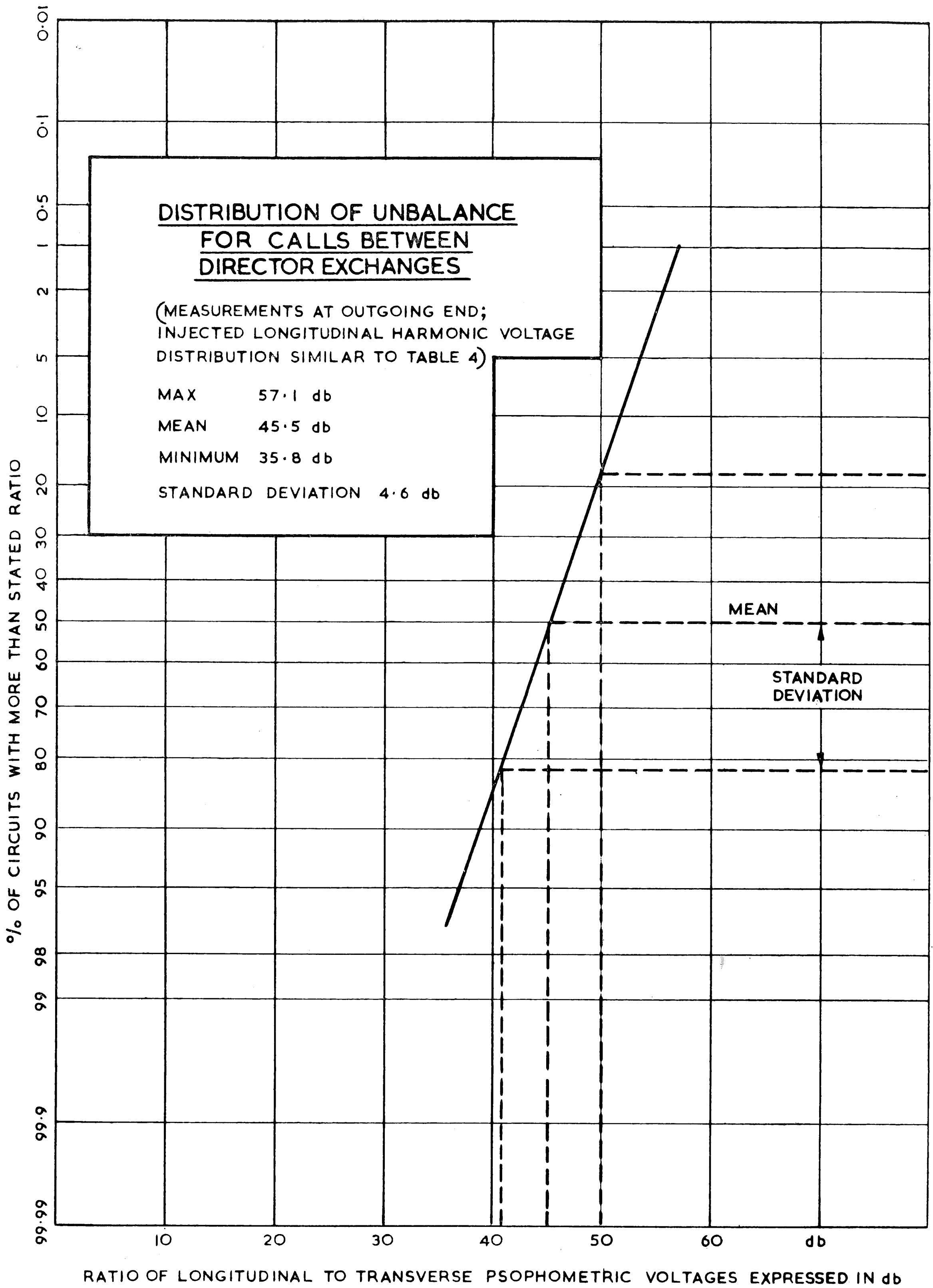


Fig.2 Distribution of unbalance for calls between director exchanges

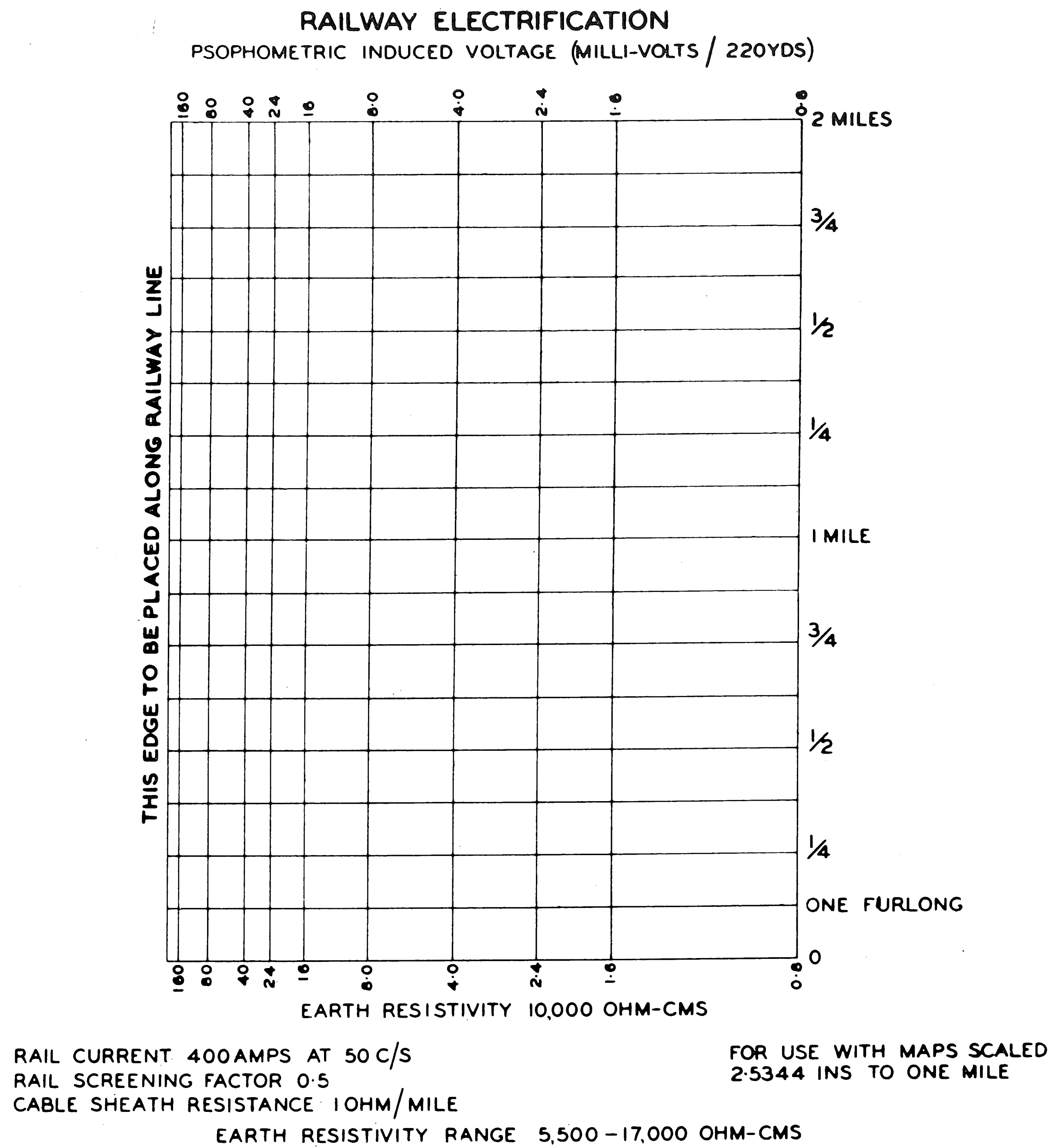


Fig.3 Typical calculating mask for induced psophometric voltage

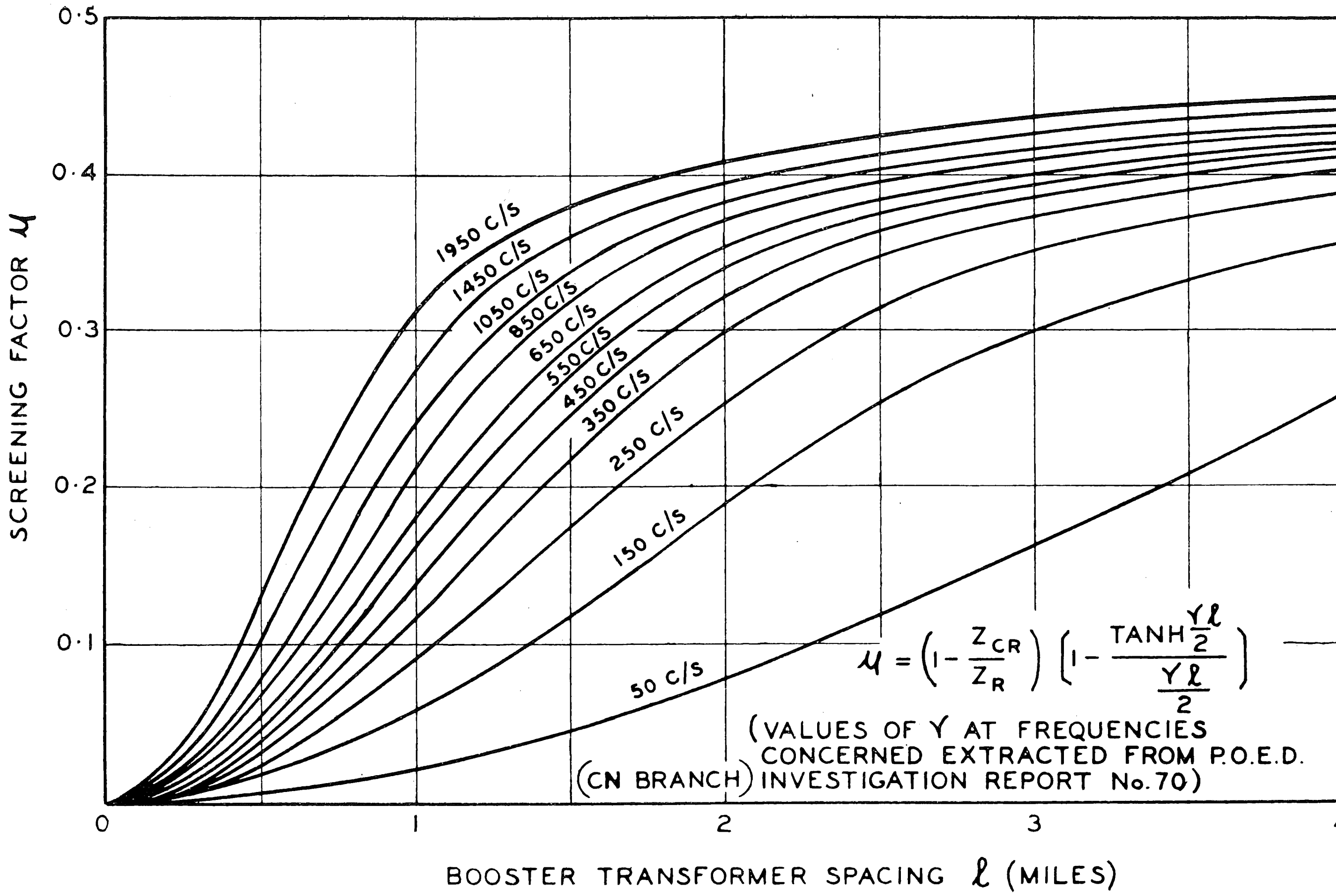
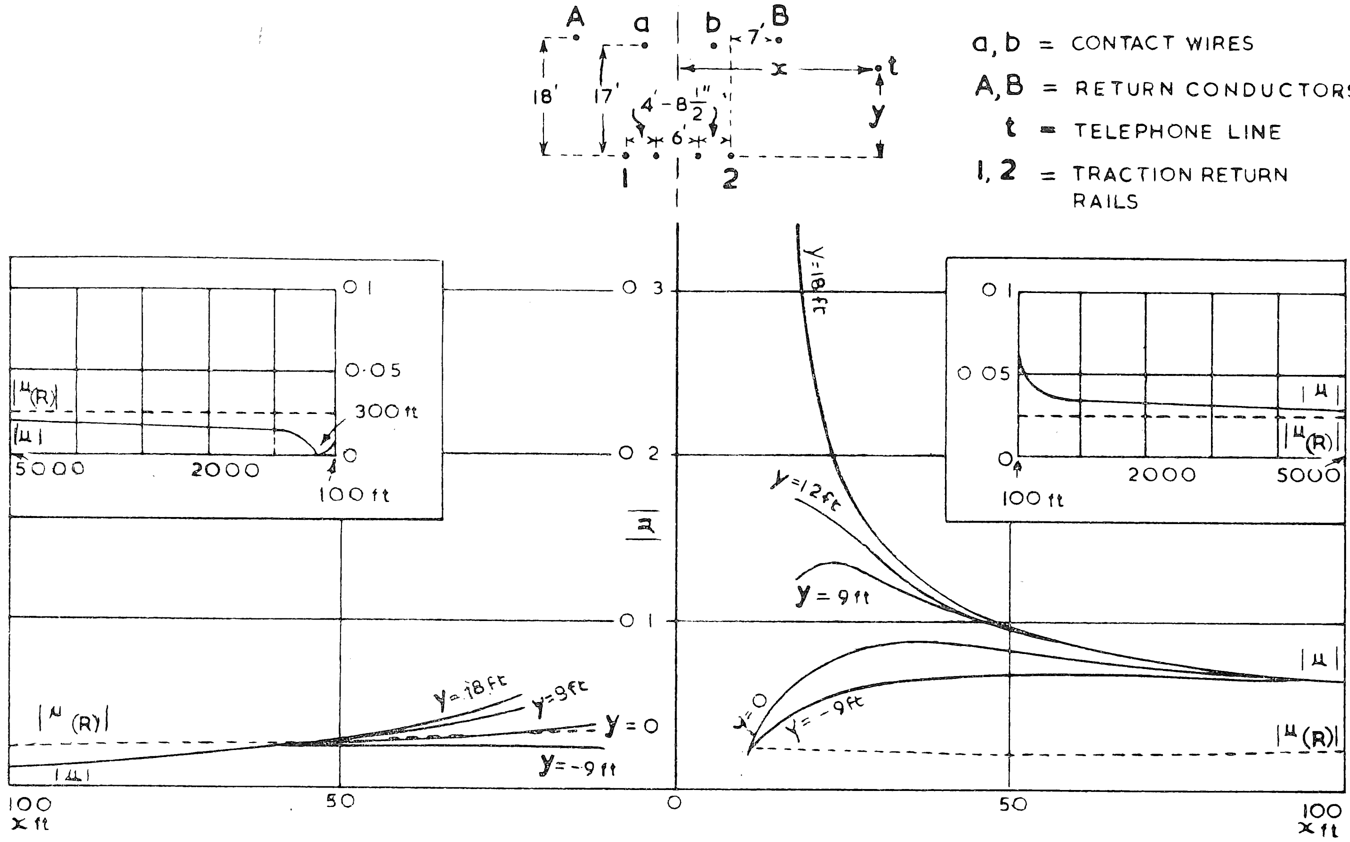
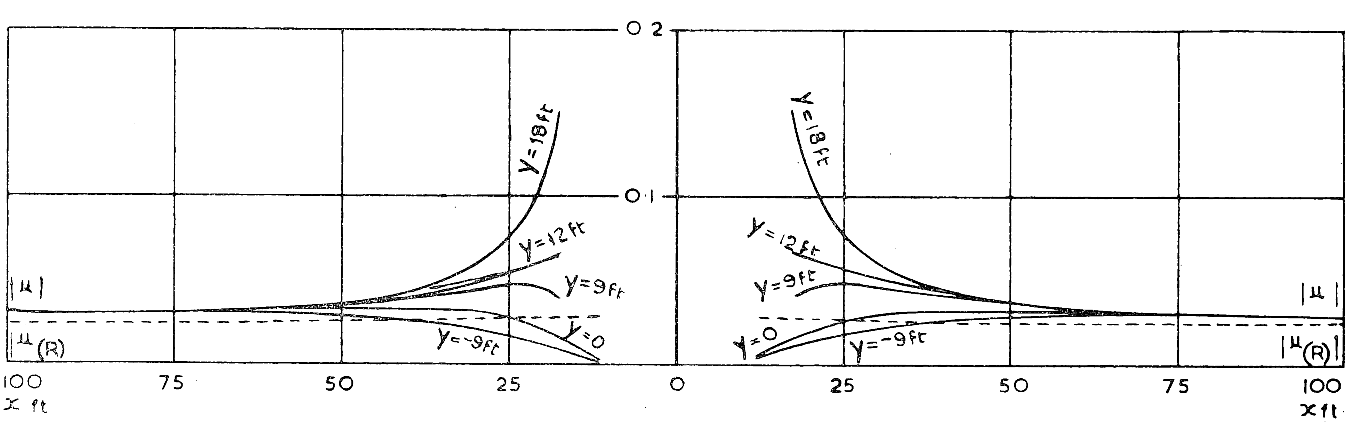


Fig.4 Screening due to rail-connected booster transformers in the absence of line-side cables (for cables approx 20 ft. or more from railway)



NOTE:— THE VALUE OF |μ| BETWEEN x = 0 & x = 300 ft SHOWN ON L.H.S. OF ABOVE FIGURE SHOULD BE REGARDED AS NEGATIVE WITH RESPECT TO THE VALUES AT GREATER SEPARATIONS ON THE L.H.S. AND THOSE AT ALL SEPARATIONS ON THE R H S

(a) WITH CURRENT ONLY IN CONTACT LINE b AND RETURN CONDUCTOR B



(b) WITH EQUAL CURRENTS IN BOTH CONTACT LINES AND RETURN CONDUCTORS

NOTE |μ(R)| IS THE COMPONENT OF THE SCREENING FACTOR DUE TO THE "INDUCED RAIL CURRENT" AND IS THE VALUE TO WHICH THE CURVES ARE ASYMPTOTIC

Fig.5 Screening factor | μ | in respect of ' through ' currents with booster transformers and return conductors

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