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On cover: Inside view of a workshop department at LM Ericsson's factory at Midsommarkransen, Stockholm: adjustment of telephone relays

Distribution System in Local Telephone Networks with Through-Connected Basic Load

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The LM Ericsson network construction system is based on the distribution principle. Compared with other systems, a network built on this principle presents many advantages including simple cabling and clear cable record, thus facilitating extension, operation and maintenance to a high degree. Nevertheless, there is one disadvantage that may justifiably be mentioned, and that is the extra expense in this system for the cable distribution cabinets and their terminal boxes. Efforts have been made for many years to bringing down this expense while retaining all the good features of the distribution system. In this article is presented a system designated *distribution system with through-connected basic load*, constituting in this respect a development of LM Ericsson's present network construction system, an account of which is first given briefly.

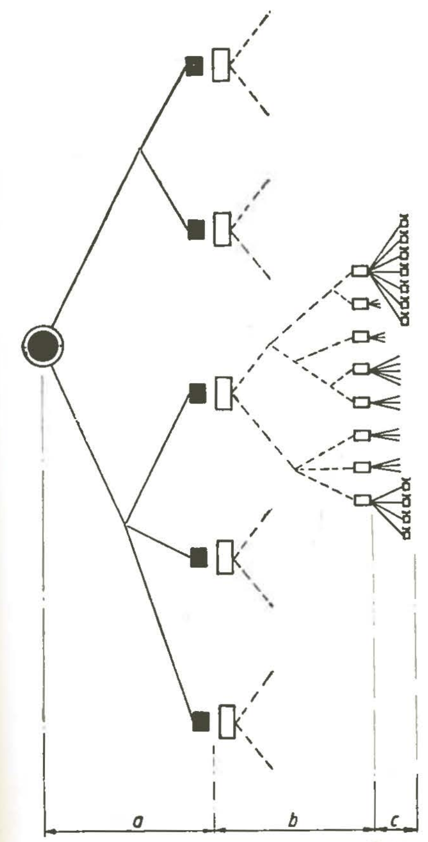
I. L M Ericsson's Actual Network System: the Distribution System

As the name implies, this system is based on the distribution principle. In accordance with this, the area in which the network is to be constructed is divided into a number of distribution districts independent of each other. In each of these districts a *distribution cabinet* is set up. The cabinets are central points around which the network is subsequently built up. From the telephone exchange to the distribution cabinets there are drawn cable lines constituting the *primary cable network*. From each distribution cabinet there are in turn drawn cable lines to various dispersion points, these lines constituting the *secondary cable network*.

Both the primary and the secondary cables are terminated and sealed, each one separately, in cable boxes mounted inside the distribution cabinet. Between the terminal screws of the primary cable boxes and the secondary cable boxes jumpering is then done for each individual subscriber line by means of insulated wire. At the dispersion points the secondary cables are terminated and sealed in boxes of essentially the same design as the boxes used in the distribution cabinets. The lines then go out from the dispersion points to the subscribers in the form of nailed single-pair cable or P.V.C. insulated wire, freely suspended bare wire, self-supporting single-pair cable or self-supporting insulated wire (drop wire), these lines constituting the *dispersion network*.

The lay-out system may be seen from the diagram of Fig. 1.

The characteristic features of the distribution system are as follows:



X 4484
X 9112

Fig. 1
Skeleton diagram of L M Ericsson's distribution system

- exchange
- cable dispersion cabinet
- dispersion box
- telephone instrument
- *a* primary network
- *b* secondary network
- *c* dispersion network

1. *Simplicity of Operation*

a) The quality of operation in the network should be such that a subscriber may obtain a telephone at any spot whatever in the network area in a very short time, for a limited urban area usually within 72 hours. To make this possible there must always be available spare lines in sufficient numbers at certain points in the network, so that the section of the subscriber line that requires to be drawn anew to the subscriber will be as short as possible.

In a network laid out on the LM Ericsson distribution system, spare lines are laid in both the primary and the secondary cables. Consequently the work for the installation of a subscriber line is confined to executing a jumpering in the cable distribution cabinet and mounting a new dispersion line from the distribution box to the location of the new subscriber. As the dispersion boxes are very near each other, this line will most often be extremely short. Moreover as the percentage of spares in the secondary cable network, that is also in the dispersion boxes, is high there is extremely small risk of there being no free pair in the nearest dispersion box.

In the removal of a subscriber instrument from one place to another the procedure will be equally simple. If the subscriber only moves within the distribution cabinet district, there is not even need to change the old pair in the primary cable.

Lines for extension instruments, not near enough to the main instrument to be drawn direct to it, may conveniently be connected on via the dispersion boxes and the distribution cabinet. This applies to all extensions located in the same building as the main instrument, as well as to most outdoor extensions, as these are generally situated in the same cabinet area as the main instrument.

Thus the installation work for the subscriber lines may be done with particular rapidity and in normal times no difficulty arises in keeping the times for installation within the stipulated 72 hours.

b) Further, a network must be so laid out that large or small extensions can easily be made at any point, e. g., for feeding newly erected buildings. For this purpose a suitable number of cables or cable pairs must be laid as reserve or in other manner, e. g., by the introduction of jumpering points, arrange in such a way that extensions can be made without it being necessary to draw new cable for each new building right to the telephone exchange. In this conjunction, the network should be so laid out that expensive relaying and splicing of cables is avoided to the greatest extent possible.

In a network laid out on the LM Ericsson's distribution system the work on local extension will be particularly simple, as new cables (secondary cables) need only be laid to the cable distribution cabinet. The primary cables usually do not need disturbing at all. Extension of these is only required if new lines are required for the cabinet district as a whole.

c) Finally to ensure simplicity of operation a network must be easy to overlook. For this reason the cable lay out must be simple without complicated branch splices and the cable record must be logical and easy to understand.

In an LM Ericsson network both cable lay out and cable record are the simplest possible and installation of new subscriber's lines as well as local extensions of the network are therefore easy to execute.

As regards numbering and cable record, decimal division is used throughout the network, both for cables and for the cabinets and dispersion boxes. The cable record of the network will be seen from Fig. 2.

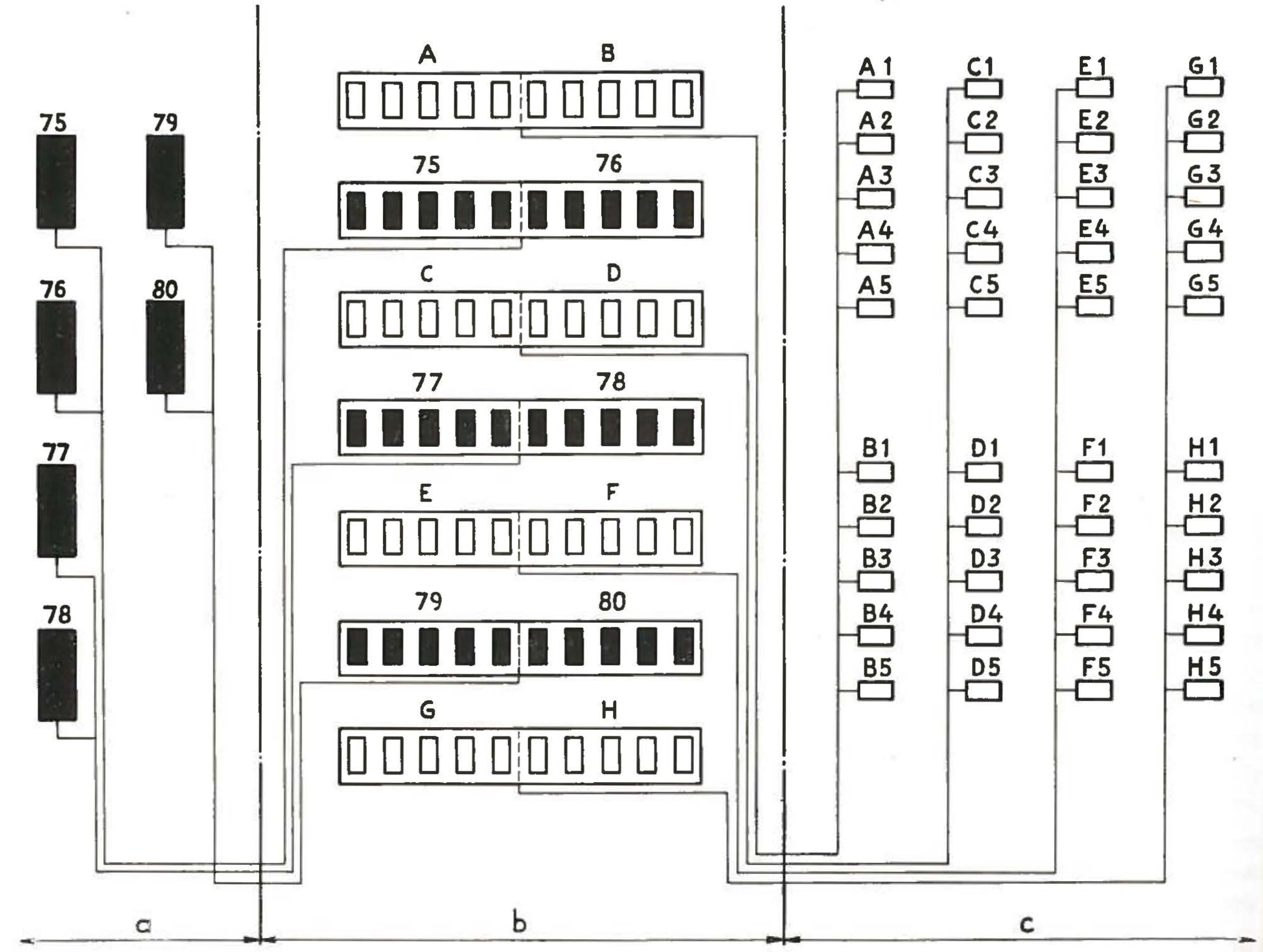


Fig. 2 X 7346
Recording in L M Ericsson's distribution system

- a exchange
- b cabel distribution cabinets
- c dispersion

2. *Low Maintenance Costs*

As regards maintenance, a network must be laid out so that faults on the lines are kept down to a minimum. The demand usually imposed is that faults on a subscriber line should not exceed 0.2—0.5 faults per annum, i. e., that a fault may arise once every fifth to second year. Faults in the telephone instruments are not included in the figures.

According to statistics available the percentage of faults in the dispersion lines reckoned per pair km is incomparably greater than in the primary or secondary cables. This is due partly to the material and partly to the method of laying and also because the dispersion lines are more exposed to damage. Owing to the dispersion lines being very short in the distribution system, the risk of fault is reduced considerably.

The primary and secondary lines are cabled and for the great part laid in conduits. This ensures effective protection of the lines, so that there exists no difficulty in keeping faults within the stipulated limits.

3. *Good Economy*

In respect of the cost of a network, it should be so constructed that the present value of all costs for laying, operation and maintenance will be a minimum. Particularly as regards costs of laying, these comprise both the laying of

initial and subsequent stages of construction together with progressive future local extensions for newly erected or reconstructed buildings as also the installation costs for new subscriber lines.

The factors which contribute above all to make a network laid out on the LM Ericsson system cheap in cost are the following:

a) By the introduction of cable distribution cabinets the primary cable network and the secondary cable network may be laid in separate stages. In this way a higher grade of utilization may be ensured in the primary cables (the longest section of the subscriber line) than in the secondary cables.

b) The division of the exchange area into cabinet districts makes possible future inexpensive increases of the secondary cable network.

c) As each cabinet controls a relatively large area, the utilization of the primary cables may be kept at a high level, which means an appreciable saving, as these cables are long and provided on the exchange side with expensive protector strips.

d) The relatively short and therefore inexpensive secondary cables may be laid with abundant reserves in cable pairs, so that the number of dispersion boxes will be large. In this way the rather expensive dispersion lines are shortened and installation is facilitated greatly, which means cheap new installations and removals both of subscriber's main station and of extensions.

The capital-saving factors advanced above are, however, counter-balanced to a certain extent by the cost of the addition of the cabinets and their cable boxes. Moreover it might be claimed that the work of installation would be greatly facilitated if the subscriber line lay ready connected right up to the dispersion box, thus avoiding the necessity of executing jumpering in the cabinet for each subscriber line. We shall return to these factors below.

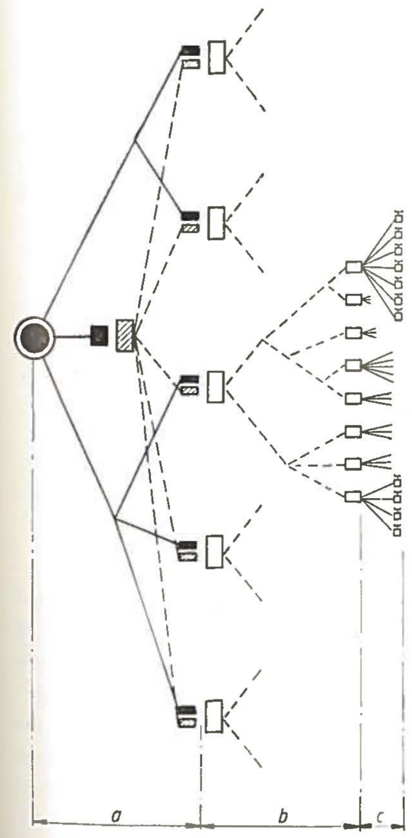


Fig. 3 X 4485 X 9113
Skeleton diagram of the buffer system

- exchange
- buffer cabinet
- cable distribution cabinet
- dispersion box
- telephone instrument
- *a* primary network
- *b* secondary network
- *c* dispersion network

II. Distribution System with Through-Connected Basic Load

As has been shown above, LM Ericsson's distribution system fulfils in an excellent manner the demands that may be put on a telephone network. The constant aim, however, has been to strive to improve it where possible. Efforts have been devoted for many years to *making it even more advantageous in economic respects while retaining all the benefits of the distribution system.*

A step in this direction was the introduction of the *buffer system,* described in an article in Ericsson Review No. 1, 1937, later also reproduced in a number of foreign trade journals. The method has come into use to a large extent both in the LM Ericsson concession undertakings and in the networks of the Swedish Telegraph Administration. This system consisted of simply setting up what are called *buffer cabinets* at those points of the network at which primary cables from a number of distribution cabinets meet. The majority of the primary cables from the distribution cabinets subordinate to this buffer cabinet are drawn direct to the exchange, while a small number of the primary cables are connected via the buffer cabinet. The method will be seen in diagram in Fig. 3. The result is a saving in cable pairs between the exchange and the buffer point. The grade of utilization may be brought up by the employment of buffer cabinets to about 85 %, as against an average of 70 to 75 % for the primary cables in a network laid out on the LM Ericsson distribution system.

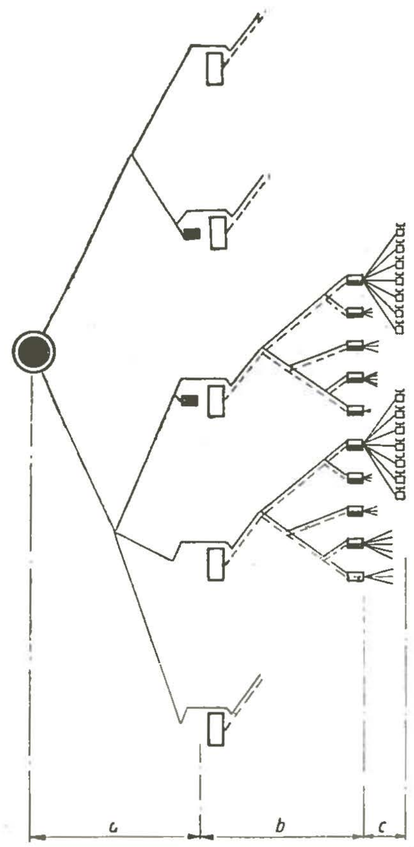


Fig. 4 X 4486 X 8114
Skeleton diagram of distribution system with through-connected basic load

- exchange
- cable distribution cabinet without exchange lines
- cable distribution cabinet with a few exchange lines
- distribution box with 5 exchange lines and 5 cabinet lines
- telephone instrument
- *a* primary network
- *b* secondary network
- *c* dispersion network

This raising of the grade of utilization obviously means an appreciable saving, not merely in the costs of the cables themselves but also in the costs of conduits and of protector strips at the exchange. On the other hand there is a supplementary cost for the buffer cabinets with their cable manholes and the expense connected with the insertion of a further connecting point for those subscribers connected over the buffer cabinet. If these additional costs are weighed against the savings made it will be found that the gain is the greater the farther the buffer point is situated from the exchange. For the area nearest the exchange it seldom pays to put up buffer cabinets.

Efforts have therefore been concentrated on a more general modernizing of the distribution system with a view to saving of capital. It must first be stated on what points any appreciable financial savings are possible. The factors thus stated as involving appreciable supplementary costs compared with other network systems are the following:

1. Extra cost for the relatively expensive cabinets with the necessary manholes. These costs are accompanied by the extra outlays occasionally involved in the form of annual rent paid to property owners concerned for permission to set up the cabinets.

2. Extra cost for the large number of cable boxes in the distribution cabinets.

3. Extra cost for jumpering in the distribution cabinet on setting up a subscriber line.

With the object of bringing down these costs, while still retaining the many great advantages of the distribution system, there has been worked out a *distribution system with through-connected basic load*, particulars of which will be given below.

The fundamental principles, as seen on Fig. 4, are as follows:

1. The network is laid out on the whole like the distribution system.

2. From each dispersion box for 10 pairs, however, there are connected 5 pairs (one line of terminals) directly to the exchange, while the remaining 5 pairs are connected to the distribution cabinet.

Similarly, from dispersion boxes for 20 pairs the half or 10 pairs are connected to the exchange and 10 pairs to the distribution cabinet. As is known, all LM Ericsson's terminal boxes are built up of uniform 10-pair blocks. Consequently a 20 pair box is provided with two such blocks. In the system with through-connected basic load there are always connected in the dispersion boxes the one row of terminals in *each* block to the exchange and the other to the cabinet. In this way jumpering can easily be done by a bare wire between a terminal screw in one row and the screw standing right opposite in the other. The work of jumpering that requires to be done as described below is thereby facilitated greatly.

3. The by-passing of the distribution cabinet may as regards cable lead-in be executed in two manners:

a) Either each secondary cable is branch spliced with half the number of cable pairs to the exchange and half the number of cable pairs to a terminal box in the cabinet. The old terminal boxes with one cable lead-in may then be employed, see Fig. 5.

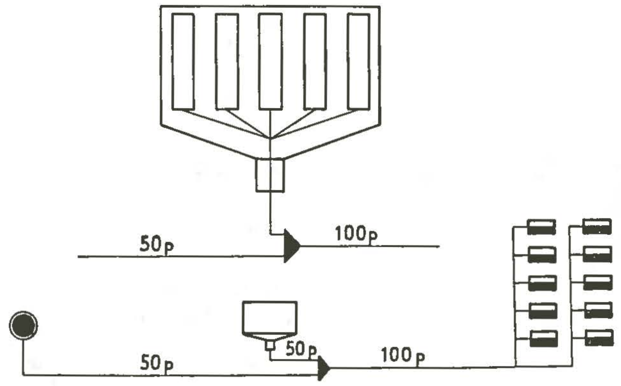


Fig. 5 X 6253
Principle of through-connecting
Cabinet box with one cable lead-in

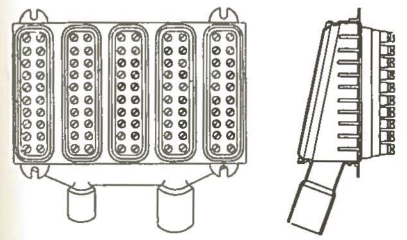


Fig. 6 X 4490
Cabinet box with *two* cable lead-ins

b) Or there may be employed a new type of terminal box having two cable lead-ins, of which boxes it is the intention to introduce two sizes, one provided with five 10-pair blocks (50-pair box, see Fig. 6) and the other with ten such blocks (100-pair box). Here we will describe the employment of the 50-pair box, see Fig. 7. To the one lead-in of this box 50 pairs are led in from the exchange, to the other are led 100 pairs from the secondary network. The 50 pairs from the exchange are »by-pass spliced», i. e., spliced direct to the equivalent number of pairs in the outgoing secondary cables. The remaining 50 pairs from the secondary cable are connected in the usual manner to soldering tags in the box. Thus each such 50-pair box will contain 5 pairs from the soldering tags in the box to each of 10 dispersion boxes and in addition will be passed by 5 pairs exchange lines to each of those 10 boxes.

At first sight one may ask why exchange lines should be brought in and out of a cable box, when these lines are not connected to tags in the box and thus are in no way accessible in the box. Nevertheless, in this way there is avoided all branch splicing of the cables and the cable lay out will be exactly the same as in the usual distribution system.

4. The cable record also will be largely the same as in the former distribution system with retention of the decimal graduation. The only difference is that each dispersion box will have five pairs with the exchange's strip number and five pairs with the secondary network's letter designation, e. g., 75 1-5, A 1-5 (see also Fig. 8).

5. If on the first construction the mean load per dispersion box is less than 5 subscribers, then one or two pairs from a convenient number of dispersion boxes may be return connected to the cabinet, to be employed for those dispersion boxes which, owing to uneven load, have already received more than 5 subscribers in the first stage of construction.

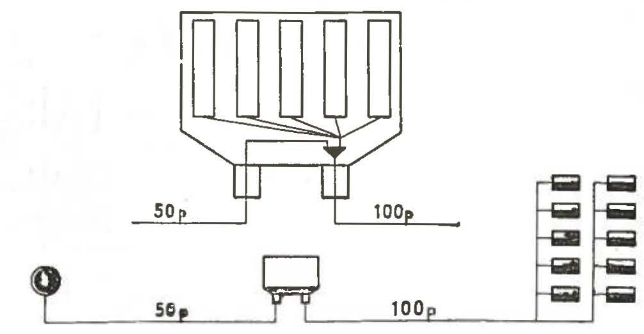


Fig. 7 X 6254
Principle of through-connecting
Cabinet box with two cable lead-ins

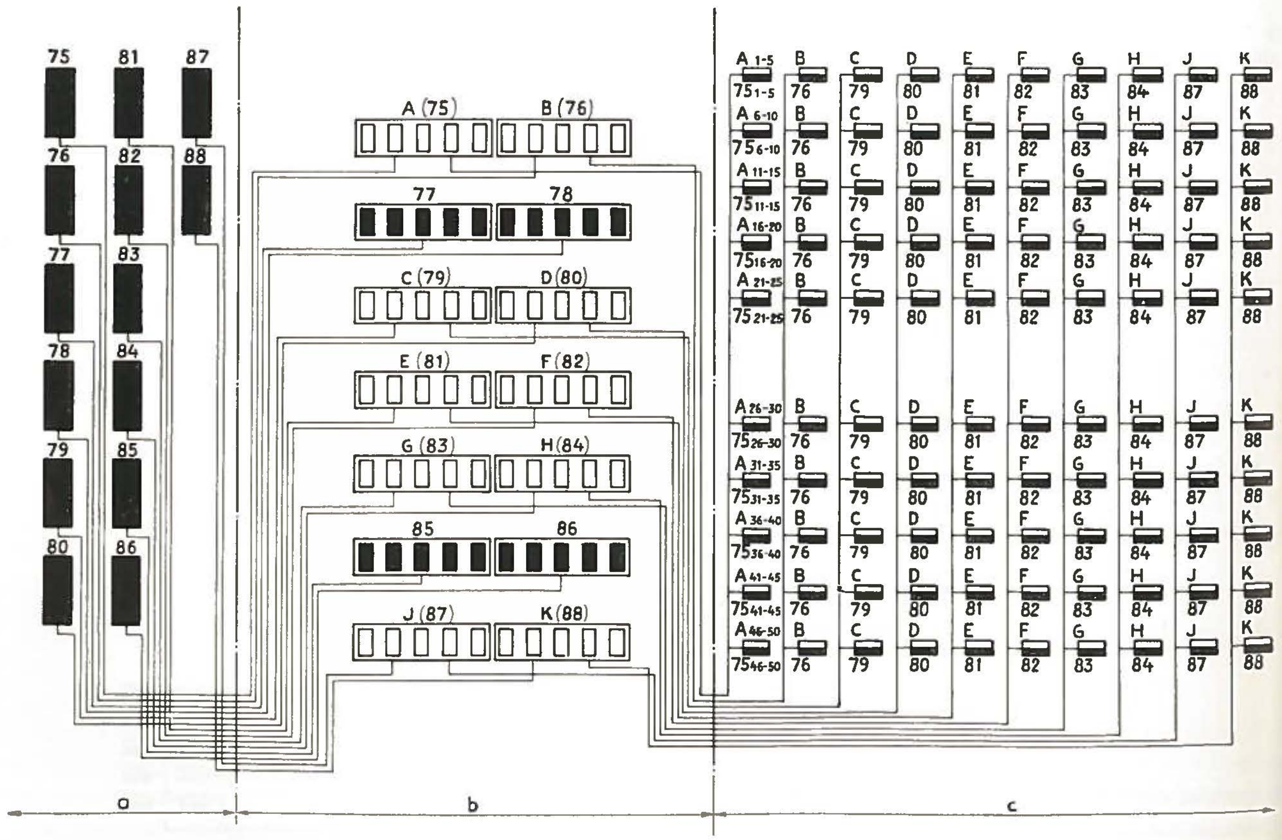
6. All cable reserves laid in the secondary cable network for future local increment may also when needed be return connected to the cabinet. This, of course, is easily possible, as each secondary cable is made up of half direct drawn pairs from the exchange and half pairs from the cabinet. Consequently the ends of the cable conductors of the direct drawn pairs require only to be twisted together with the cabinet pairs.

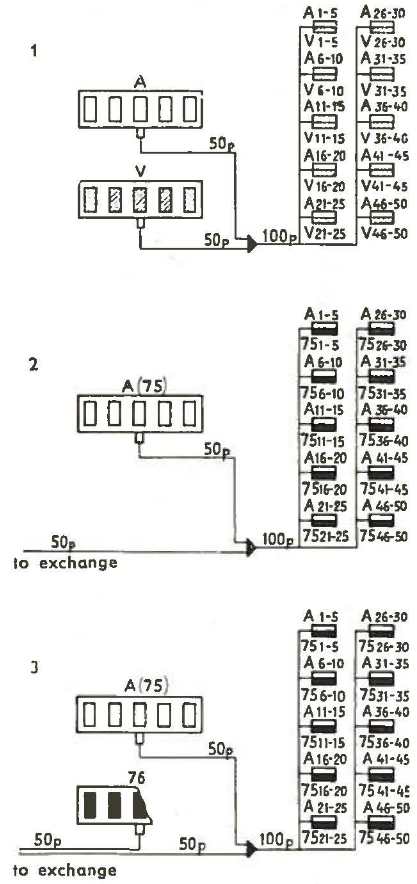
7. All spares return connected in this way to the cabinet from a dispersion point or from a reserve cable will automatically come in the correct number place in the cabinet concerned, which besides corresponding in its letter designation with certain 10 dispersion boxes, e. g., A in Fig. 8, is also marked with the strip numbers feeding those same dispersion boxes with direct lines from the exchange. For example, if there be return connected the direct line pair strip 75 pair 5 to the cabinet, this is always done over the secondary pair A 5, which in the cabinet box always represents strip 75 pair 5 when this is return connected. Even in case of return connecting, the cable record is kept orderly and accessible. Nevertheless if return connecting of several pairs is done at one time this should be indicated in some way in the cabinet.

8. If the mean load is exceptionally low, a suitable number of dispersion boxes may in the initial construction be put up at the start without direct drawn exchange lines, these only being connected when the load demands it. As regards the drawing of the cables this may be done in two ways according to whether cabinet boxes with one or two lead-ins are used.

a) If cabinet boxes with a single lead-in are used, procedure is as shown on Fig. 9. As may be seen, to avoid future re-splicing, those dispersion boxes which on initial construction are not to have any direct lines to the exchange are connected totally to the cabinet. In the cabinet the real secondary pairs, 5 pairs from each dispersion box, are connected in the ordinary way to their cabinet boxes, marked A in Fig. 9, while the other 5 pairs from each dispersion box, which in the future are to be connected to the exchange, are provisionally terminated in an auxiliary box, marked V in Fig. 9.

Fig. 8 X 7437
Recording in the distribution system with through-connected basic load





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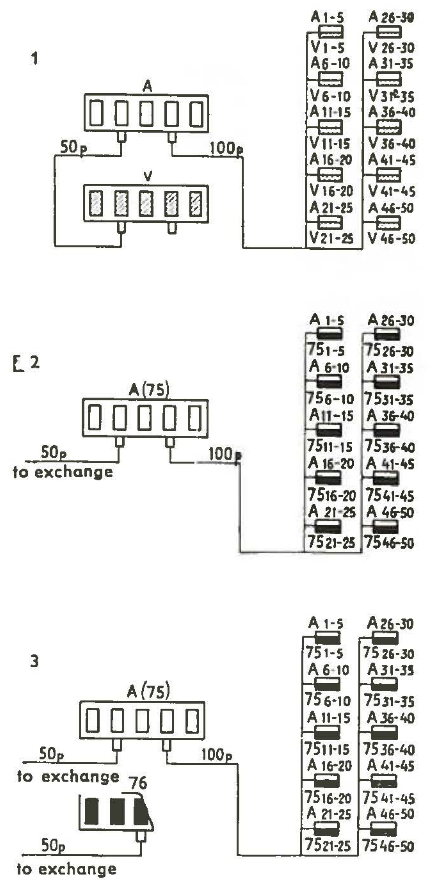

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Fig. 9 X 4487
Various stages of extension in the distribution system with through-connected basic load

Cabinet boxes with *one* cable lead-in

1 Mean load less than 5 subscribers per dispersion box. (Some of the dispersion boxes have then, as shown in the fig., no direct lines to the exchange.)
2 Mean load 5 subscribers per dispersion box
3 Mean load more than 5 subscribers per dispersion box

Fig. 10 X 4488
Various stages of extension in the distribution system with through-connected basic load

Cabinet boxes with *two* cable lead-ins

1 Mean load less than 5 subscribers per dispersion box. (Some of the dispersion boxes have then, as shown in the fig., no direct lines to the exchange.)
2 Mean load 5 subscribers per dispersion box
3 Mean load more than 5 subscribers per dispersion box

Later, when the mean load grows, the cable to the auxiliary box is cut and the butt is instead connected to a fresh cable from the exchange. In this way the dispersion boxes receive their 5 direct-drawn pairs.

b) Where cabinet boxes with two lead-ins are used, the procedure is as shown by Fig. 10. Likewise to avoid re-jointing in the future, the cable butt that is later to be connected to a cable from the exchange is provisionally connected on the initial construction to an auxiliary box which is later disconnected. The cable drawing is seen entirely in the figure.

9. When the mean load of the network later rises above 5 subscribers, a suitable number of direct-drawn primary cable pairs is drawn to the cabinet, where they are jumpered to the secondary side by means of insulated wire in the usual manner. This will be seen in the third stage of extension in Fig. 9 and 10.

The result of the measures indicated above will be that, in the distribution system with through-connected basic load, it will be possible greatly to reduce the number of terminal boxes in the cabinets. In this way the cabinets for the same capacity as formerly in the ordinary distribution system can be made appreciably smaller. A comparative table of cabinet capacity for the ordinary types of cabinets when used in the old distribution system and in the new is given below.

type of cabinet	possible cabinet capacity (in numbers of cable pairs)					
	in old distribution system			in distribution system with through-connected basic load		
	primary	secondary	total	primary*	secondary	total
NBD 1025	100	150	250	250 (50)	400	650
NBD 1030	100	200	300	300 (100)	400	700
NBD 1050	200	300	500	500 (150)	700	1200
NBD 1070	300	400	700	700 (200)	1000	1700
NBD 1140	600	800	1400	1400 (400)	2000	3400

* The figures in brackets represent the number of primary pairs not through-connected, e. g., for NBD 1070 there are 500 primary pairs through-connected and 200 primary pairs terminated in the cabinet.

As may be seen, an ordinary 700 pair cabinet NBD 1070 is for example replaced by a 300 pair cabinet, NBD 1030. How the extension of such a cabinet proceeds in different stages, namely 100/200, 100/300, 150/300, 200/300 and 300/400 pairs primary to secondary, is shown in Fig. 11.

Owing to the small size of the 300 pair cabinets they require no special conduit manhole, but may easily be set up on a wall or a pole. Consequently the trouble in getting permission to set up the cabinet is partly done away with. The cost for cabinets and boxes will therefore be appreciably reduced in the distribution system with through-connected basic load.

As in this system half the primary cables pass out direct to the dispersion boxes, there is also saved the greater part of the jumpering work for the individual subscriber lines in the cabinets. The direct lines in each dispersion box are of course used first and only afterwards direct lines from other dispersion boxes or possibly from the cabinet are taken. Return connections made in the dispersion boxes to the cabinet, may be done by means of a bit of bare line wire or by a small connecting tab, thus considerably facilitating this work of connection.

III. Application of the Distribution System with Through-Connected Basic Load to Distribution Networks Already Constructed

In distribution networks that have been in service for many years it happens sooner or later that the cabinets become fully occupied. Formerly, to provide for further increment in the network, it has been necessary to replace the cabinet by a larger one or to divide up the cabinet area. This has often in-

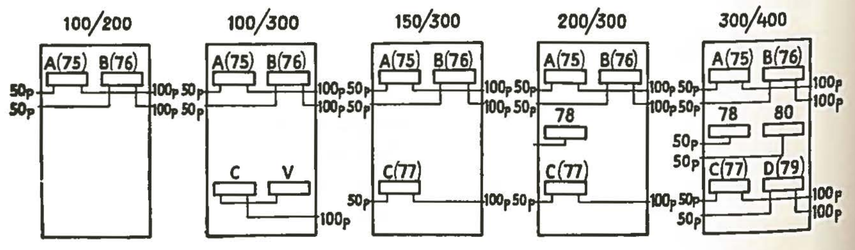
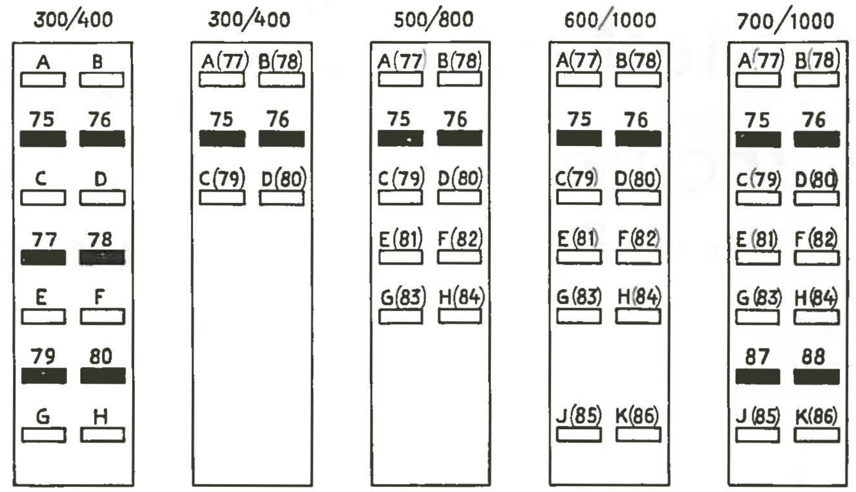


Fig. 11 X 6255
Extension of a 300-pair cabinet (100/200) to a final capacity of 700 pairs (300/400)

Fig. 12 X 6256
Re-connecting of a fully occupied 700-pair cabinet (300/400) and progressive extension of the cabinet capacity to 1700 pairs (700/1000)



volved expensive relaying and splicing of the cables, especially if the cable lay-out was not suitably planned at the start or if entirely unforeseen rebuilding of property or of whole quarters had taken place.

A very great advantage of the distribution system with through-connected basic load is that it can be applied with particular flexibility to an old network, enabling the cabinet capacity to be increased to more than double. In such an employment of the system there is required no change whatever in the cable lay-out, both the primary and the secondary networks being retained unaltered. Nor need replacement of either dispersion boxes or cable cabinets be made.

The work required is confined to re-connecting of a number of the cabinet boxes together with the re-connection of an equivalent number of subscriber lines. The re-connecting of the cabinet boxes can be done to the extent that is considered necessary. How such a re-connection should be done is shown in Fig. 12 which indicates the re-connecting of a fully occupied 700-pair cabinet with 300 pairs primary and 400 pairs secondary, as also progressive increase of the capacity in various stages up to 1700 pairs with 700 pairs primary and 1000 pairs secondary.

As in the case of the initial construction of a network, two different procedures may be employed, either branch splicing in the cabinet manhole or replacing the old cabinet boxes by new ones with two cable lead-ins.

IV. Concluding Remarks

The aim in introducing the distribution system with through-connected basic load was to bring down the lay-out costs of the network by reducing the costs for cabinets and their terminal boxes and to bring down the expense of installation work by decreasing the number of jumperings in the cabinets.

As will have been seen, this may be done without the great advantages of the distribution system being in any way impaired. Moreover as the new system is particularly well adapted for application to networks already existing, to avoid costly relaying and re-splicing, the system should find great employment in the future.

A Method for Computing Track Circuits

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U.D.C. 656.259.12

In railway signalling, track circuits are employed to a large extent for remote signalling of the presence of trains on a track. Present-day signalling plants comprise track circuits both in the station areas and in block signal plants and their purpose is to prevent the admittance of two trains simultaneously on the same track section with consequent risk of collision.

Track circuits are of very old date. The first track circuit was installed in USA in 1872[1] and was of D. C. type. Both D. C. and A. C. track circuits are employed nowadays. In view of the great magnitude and variation of the ballast leakage the track circuit is unquestionably quite a peculiar circuit and the computation of track circuits presents an interesting and rather complicated problem.

As far as the author is aware, no exact method of computing track circuits for A. C. has been brought out. Below is presented a method of computing A. C. track circuits with two-phase relays, account being taken of variations in leakage.

In a subsequent article the method will be extended to comprise also variations in supply voltage and it will also be shown how it may be applied to single-phase and D. C. track circuits. In addition, practical examples will be submitted and improved facilities for designing of track circuits offered by the method will be discussed.

Generally a track circuit consists of a track relay R of two-phase induction type, see Fig. 1, a current source E_L for the »local phase», a current source E which feeds the »track phase» of the relay over the track T insulated at both ends, a »feed impedance» Z_T, a »feed transformer» TrT and a »relay transformer» TrR. The length of the insulated track is s km.

If the track is free of trains the relay should be energized at any possible value of leakage between the rails and of the voltages E and E_L. If the rails are more or less shortcircuited by an incoming vehicle, the relay should be released with certainty under all circumstances.

Frequently the feed impedance lies between the feed transformer and the track. This case is dealt with below in section A V.

[1] According to *McReady:* Alternating Current Signaling. Swissvale USA 1915.

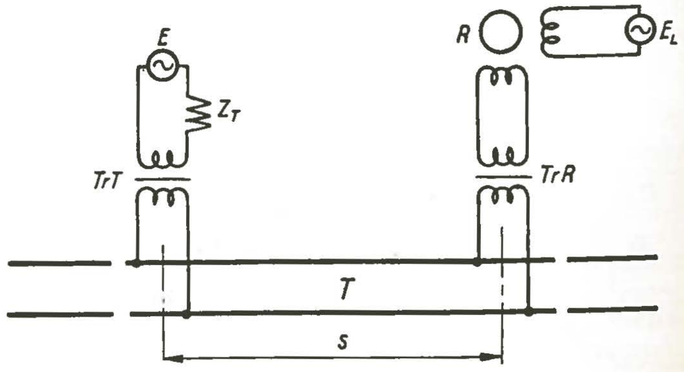


Fig. 1
Skeleton diagram of track circuit

X 6257

- E current source for the track phase
- E_L current source for the local phase
- R two-phase track relay
- s length of the track circuit
- T track circuit
- TrR relay transformer
- TrT feed transformer
- Z_T feed impedance

The Track Relay

First a brief description of the relays employed in track circuits.

The two phase (two element) relay now mostly used consists of a rotary metal disc or cylinder traversed by two alternating fluxes, viz. the local flux and the track flux. Each flux generates a current in the rotor and each current, when acting on the other flux, gives a driving moment to the rotor.

The driving moment turns the rotor a certain angle and thus actuates contacts, the making or breaking of which in turn actuates signals or other elements in an interlocking plant. The driving moment on the rotor equals the vector product of the two currents, i. e. it is proportional to the magnitudes of each current in the two phases and to the sine of the phase angle between them.

Consequently the direction of the turning moment depends upon the sign of this angle. In passing we may mention that if the frequencies of the local and track currents differ from each other, the moment will periodically alter direction and the rotor will oscillate with a frequency which is equal to the difference of the current frequencies. The greater this frequency difference, the smaller will be the angle of deflection made by the rotor, this on account of its inertia, and above a certain value of this frequency difference the rotor will be practically at a standstill. This property is utilized to make the relay frequency selective. The local phase is then fed with the desired frequency. The rotor makes constant deflection for this same frequency in the track phase, but it oscillates if the track frequency deviates a small amount from the local frequency. If however the frequency deviation exceeds a certain limit the relay will not be influenced by the deviating current. The greater the inertia in the rotor the narrower the limits within which the relay will be disturbed by a current of deviating frequency, but also the slower will be the relay's operating speed.

As the moment in the two-phase relay is proportional to the sine of the phase angle between the currents, the least current product will be required for energizing if the phase angle is 90°. To make the relay sensitive it is usual to have the local phase current as great as the heating of the rotor allows. The track current required for the operation of the relay thus may be decreased to a corresponding extent. The local current source E_L and the track current source E must be synchronous and so linked to each other that the phase angle between them is constant. The operating value of the relay is measured and stated always for 90 degree angle between the relay phase tensions, usually the same as the angle between the phase currents. Operating values for other angles, however, may then easily be computed through division by the sine of these angles.

In the single-phase (»single element») relay there is only one current producing magnetic fluxes which in one way or another actuates a moveable device; likewise in the D.C. relay. Thus the single-phase relay is not in itself frequency selective.

A. A.C. Track Circuits with Two-phase Relays

As the safety against accidents in an interlocking plant with track circuits is dependent on the functioning of the circuit, i. e., that the track relay releases on the entrance of a vehicle on the track circuit, it is necessary to be able to compute the resistance between the rails (the train shunt) for which the relay releases. If this resistance proves to be less than what the vehicle on contact with the rails can produce, an alteration of the component parts must be made.

If the angle between the phase currents of the relay remained constant when trains »shunt» the relay, the computation would be simple. Owing to the

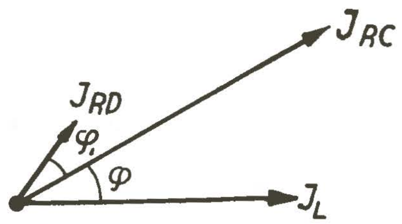


Fig. 2 X 4401
Vector diagram for the relay currents

I_L local current vector
I_{RC} track current vector, relay attracted
I_{RD} same, relay released

fact that all track circuit components are more or less reactive, however, this phase angle varies not only with train shunting, but also with variations of the leakage, and this appreciably complicates the computations.

Previous Methods of Procedure

The computation of the train shunt for which the relay just drops has previously been done according to three methods, two of which involve step by step approximation. One of these latter has been described by *Hård*[1] in this journal. A third method, direct but graphic, has been indicated by *Gall*[2].

Method of Computing Train Shunt, Phase Angles and Feed Tension

Briefly the method is based on determining first the operating and release currents of the relay at different phase angles and then the current which the relay receives from shunted and open track at different leakages and feed voltages. The results are presented in diagrams which when laid one on the other directly give the train shunt and the requisite phase angle between the local and the track phase currents at a certain leakage.

I. Operating Conditions of the Two-phase Induction Relay

If the local current is taken as reference phase, there will prevail the following relation between the operating lifting force q_c of the relay and the track phase operating current:

$$q_C = k \cdot |I_L| \cdot |I_{RC}| \cdot \sin\varphi$$

where $|I_{RC}|$ and φ are the $r \cdot m \cdot s \cdot$ value and the phase angle respectively of the operating current, the vector of which is written

$$I_{RC} = |I_{RC}|\, e^{j\varphi}$$

$|I_L|$ is the local phase current $r \cdot m \cdot s \cdot$ value and k a relay constant. If the relay shall release, the current through the track phase must be altered as to magnitude and/or direction so that the lifting force is decreased to the release value q_D. This is expressed by the relation

$$q_D = k_1 |I_L| \cdot |I_{RD}| \sin(\varphi + \varphi_1)$$

where $|I_{RD}|$ is the release current $r \cdot m \cdot s \cdot$ value and φ_1 is the change in phase angle of the current, see Fig. 2. k_1 is a constant which, depending on the design of the relay, may be equal to or differ from k.

The release current vector is

$$I_{RD} = |I_{RD}|\, e^{j(\varphi + \varphi_1)}$$

The ratio between the lifting forces

$$\frac{q_C}{q_D} = \frac{k}{k_1} \cdot \frac{|I_{RC}| \sin\varphi}{|I_{RD}| \sin(\varphi + \varphi_1)}$$

is a constant depending on the design of the relay. If we put

$$\frac{q_C}{q_D} \cdot \frac{k_1}{k} = f$$

then

$$\frac{|I_{RC}|}{|I_{RD}|} \cdot \frac{1}{f} = \frac{\sin(\varphi + \varphi_1)}{\sin\varphi} = \cos\varphi_1 + \cot\varphi \sin\varphi_1 \quad \ldots\ldots\ldots (1)$$

In the following, however, the ratio between the vectors is of interest.

$$\frac{I_{RC}}{I_{RD}} = \frac{|I_{RC}|\, e^{j\varphi}}{|I_{RD}|\, e^{j(\varphi + \varphi_1)}} = \frac{|I_{RC}|}{|I_{RD}|} e^{-j\varphi_1} = \frac{|I_{RC}|}{|I_{RD}|} (\cos\varphi_1 - j \sin\varphi_1)$$

[1] *Hård:* On the Computation of Track Circuits. LME Review No. 4—6, 1928
[2] *Gall:* Railway Track Circuits. London, Sir Isac Pitman & Sons, 1933.

Put this ratio equal to $h + jk$

$$\because h = \frac{|I_{RC}|}{|I_{RD}|} \cos\varphi_1 \quad \text{or} \quad \cos\varphi_1 = h \cdot \frac{|I_{RD}|}{|I_{RC}|}$$

$$k = -\frac{|I_{RC}|}{|I_{RD}|} \sin\varphi_1 \quad \text{or} \quad \sin\varphi_1 = -k \frac{|I_{RD}|}{|I_{RC}|}$$

$$h^2 + k^2 = \left(\frac{|I_{RC}|}{|I_{RD}|}\right)^2 \quad \text{or} \quad \frac{|I_{RC}|}{|I_{RD}|} = \sqrt{h^2 + k^2}$$

Inserting these expressions in equation (1), we get

$$\frac{1}{f}\sqrt{h^2 + k^2} = h \cdot \frac{1}{\sqrt{h^2 + k^2}} - \cot\varphi\, k \frac{1}{\sqrt{h^2 + k^2}} \quad \text{or}$$

$$h^2 + k^2 - hf + kf\cot\varphi = 0$$

If the squares are supplemented by increase of both members by $\left(\frac{f}{2}\right)^2 + \left(\frac{f}{2}\cot\varphi\right)^2$ we get

$$\left(h - \frac{f}{2}\right)^2 + \left(k + \frac{f}{2}\cot\varphi\right)^2 = \left(\frac{f}{2}\sqrt{1 + \cot^2\varphi}\right)^2$$

which is the equation of a circle in the complex $h\,k$ plane with the centre in the point

$$h = \frac{f}{2} \quad k = -\frac{f}{2}\cot\varphi$$

and with the radius

$$\frac{f}{2}\sqrt{1 + \cot^2\varphi}$$

The circle intersects the real axis in the origin and in $h = f$, Fig. 3.

The centre falls below the h axis if φ is in the first or the third quadrant and above the h axis if φ is in the second or the fourth quadrant. If φ is 90° or 270° the centre lies on the h axis and/or $\varphi = 0$ or 180° the centre lies infinitely below or above the h axis but always on the line $h = \frac{f}{2}$.

The length of the vector $\frac{I_{RC}}{I_{RD}}$ therefore constitutes the ratio between the operating current and the release current, the former measured at the angle φ and the latter at the angle $\varphi + \varphi_1$ from the local current.

If the relay current is reduced below the release value the relay will fall with certainty. The vector ratio between the operating current and this smaller current is greater than the circle requires. In other words, if the current ratio vector terminates outside the circle, the relay will release, but not if the vector terminates within the circle.

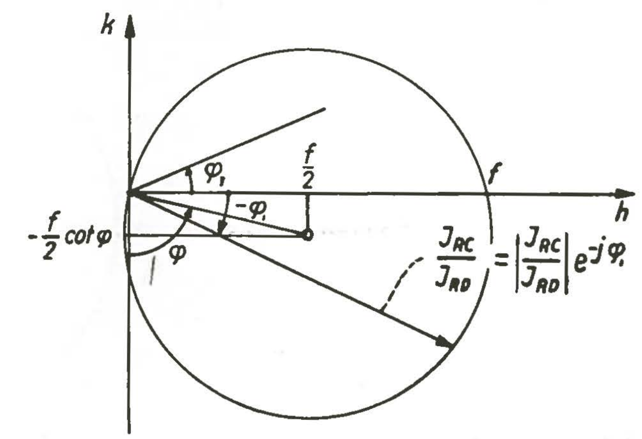


Fig. 3 X 6256
Circle diagram for the release conditions of a two-phase relay

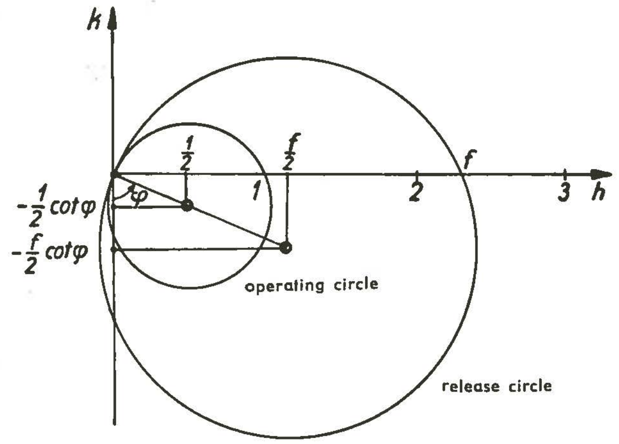


Fig. 4 X 6259
Circle diagram of the operating and release conditions of a two-phase relay

The relay constant f is determined by measurement of the operating and release currents, retaining the angle between the track and the local currents, usually at 90°.

The circle is hereafter designated the *release circle* (the drop circle), as it indicates how much the relay current is to be altered as regards magnitude and phase angle from a given operating value in order that the relay shall release (drop).

A track relay, however, must be able to operate under all conditions when the vehicle leaves the track. That is even if the leakage and consequently the phase angle for the relay current vary. If, therefore, the current after an angular change φ_2 is written $I'_{RC} = |I'_{RC}|\, e^{j(\varphi+\varphi_2)}$ the condition for the relay just operating, i. e., for the lifting force to be the same before and after the change of angle, is expressed by the equation

$$q_C = k\,|I_L|\,|I'_{RC}|\sin(\varphi+\varphi_2) = k\,|I_L|\,|I_{RC}|\sin\varphi$$

or

$$\frac{|I_{RC}|}{|I'_{RC}|} = \frac{\sin(\varphi+\varphi_2)}{\sin\varphi} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

This expression differs from equ. (1) only by f being replaced by 1 and φ_1 by φ_2. The vector ratio I_{RC}/I'_{RC} can therefore be represented by a circle with radius $\frac{1}{2}\sqrt{1+\cot^2\varphi}$ instead of $\frac{f}{2}\sqrt{1+\cot^2\varphi}$ and the condition for the relay operating with certainty for a given current is that the vector for the ratio between the operating current I_{RC} and the current in question I'_{RC}, falls *within*

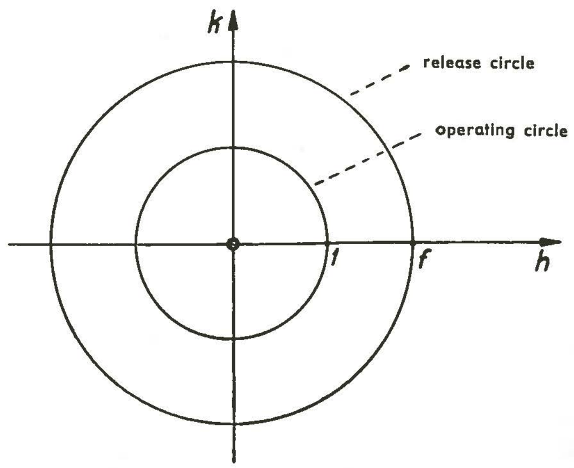


Fig. 5 X 6260
Circle diagram of the operating and release conditions of a single-phase relay

that circle. The circle will hereafter be designated the operating circle because it indicates how much the relay current may be altered (in respect of magnitude and phase angle) from a given operating value without the relay's next operation being endangered. The operation circle will thus have its centre at the point

$$h = \frac{1}{2} \quad k = -\frac{1}{2}\cot\varphi$$

and the radius

$$\frac{1}{2}\sqrt{1+\cot^2\varphi}$$

In Fig. 4 there is shown an operating circle and its associated release circle.

For the sake of comparison let us now consider a single-phase relay. The ratio between the operating and release currents is independent of their phase angles and the release circle of the relay will have its centre in the origin and the radius equal to f, see Fig. 5. The operating circle will likewise have its centre in the origin but its radius equal to 1.

In the next section there will be shown the convenience of expressing the operating and release conditions as the ratio between two currents. Here we will merely point out that this ratio may have an infinite number of values for each value of φ and that in addition an infinite number of release and operating circles may be drawn, one for each value of φ.

In the circle diagram, φ is given as an angle reckoned from the negative k axis to the junction line between the origin and the centres of the circles.

If the release current leads the operating current, i. e., if φ_1 is positive, the current ratio vector will lie below the h axis, otherwise above it, see Fig. 3, where φ_1 is assumed to be positive.

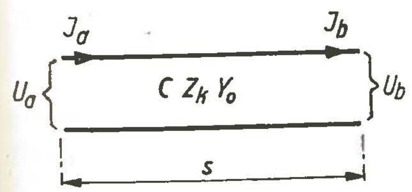


Fig. 6 X 4492
Skeleton diagram for symmetrical transmission line

- C line constant
- I_a current at input end
- I_b current at output end
- s length of line
- U_a voltage at input end
- U_b voltage at output end
- Z_k short-circuit impedance of the line
- Y_0 no-load admittance of the line

II. Current Supplied to the Relay by the Track under Different Circumstances

In the following the track is regarded as a homogeneous symmetrical two wire transmission line with an evenly distributed leakage of $(g + j\omega c)$ mho per km and an evenly distributed impedance $Z_r = |Z_r|\, e^{j\varphi_r}$ ohm per km. From this is computed in the usual manner for a track length s the short-circuit impedance reckoned from the one terminal point

$$Z_k = Z \operatorname{tgh} \gamma s$$

and the no-load admittance

$$Y_0 = \frac{1}{Z} \operatorname{tgh} \gamma s$$

as also the circuit constant

$$C = \cos h\, \gamma s = \frac{1}{\sqrt{1 - Y_0 Z_k}}$$

where $Z = \sqrt{\frac{Z_r}{g + j\omega c}}$ is the characteristic impedance of the line and $\gamma = \sqrt{Z_r(g + j\omega c)}$ is the complex attenuation exponent of the line.

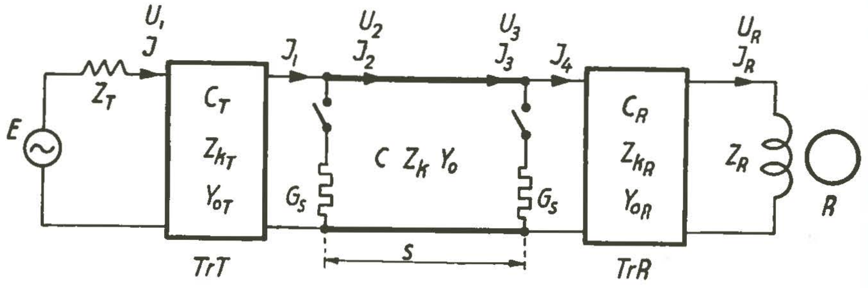
For the equation between currents and tensions in the two ends of the line as per Fig. 6 there applies, as known from the theory of alternating currents on long lines,

$$\left.\begin{aligned} U_a &= C\,(U_b + Z_k I_b) \\ I_a &= C\,(I_b + Y_0 U_b) \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

Fig. 7 X 6261

Substitute diagram for track circuit

E	feed tension
G_s	requisite train shunt conductance
I	primary current in TrT
I_1	secondary current in TrT
I_2	track current in feed end
I_3	track current in relay end
I_4	primary current in TrR
I_R	relay track phase current
R	track relay (local phase winding left out)
s	length of track
TrR	relay transformer
TrT	feed transformer
U_1	primary voltage on TrT
U_2	secondary voltage on TrT
U_3	primary voltage on TrR
U_R	voltage on R
Z_R	relay impedance
Z_T	feed impedance
C, Z_k, Y_0	characteristic constants for the track
C_R, Z_{kR}, Y_{0R}	characteristic constants for TrR
C_T, Z_{kT}, Y_{0T}	characteristic constants for TrT
G_s	may be applied alternatively to the feed end or the relay end of the track circuit



Analogous equations are known to apply to any symmetrical quadrupole, say for instance the relay transformer in Fig. 1. If the short-circuit impedance Z_{kR} and the no-load admittance Y_{0R} are known for the transformer there is first computed

$$C_R = \frac{1}{\sqrt{1 - Y_{0R} Z_{kR}}}$$

after which the relations between the primary and the secondary currents and voltages are expressed by the equations

$$U_p = C_R (U_s + Z_{kR} \cdot I_s)$$
$$I_p = C_R (I_s + Y_{0R} U_s)$$

where the indices p and s indicate the primary and secondary sides. (The transformer ratio assumed to be 1/1.)

The diagram of Fig. 1 is replaced by the diagram in Fig. 7, with designations as below

E = the feed voltage
U_1 = the primary voltage on the feed transformer TrT
I = the primary current in TrT
C_T, Z_{kT} and Y_{0T} are characteristic constants as above for TrT
U_2 = secondary voltage on TrT
I_1 = secondary current in TrT
G_s = requisite train shunt conductance
I_2 = track current in the feed end
C, Z_k and Y_0 are characteristic constants for the track section
s = length of the track section
I_3 = track current in the relay end
I_4 = primary current in the relay transformer TrR
U_3 = primary voltage on TrR
C_R, Z_{kR} and Y_{0R} are characteristic constants for the transformer TrR
I_R = current through track phase of the relay R
U_R = voltage over R
Z_R = relay impedance
G_s may be applied alternatively to the feed end or the relay end of the track circuit.

The ratios of the transformers are assumed to be 1/1. Otherwise the circuits connected opposite to their track windings must be reduced to the track side.

Starting at the relay end we may deduce the following equations for currents and voltages in different points of the track circuit.

$$U_3 = C_R (U_R + Z_{kR} I_R) = C_R Z_{Ra} I_R$$
$$I_4 = C_R (I_R + Y_{0R} U_R) = C_R B I_R$$

where $\left.\begin{array}{l} Z_{Ra} = Z_R + Z_{kR} \\ \text{and} \quad B = 1 + Y_{0R} Z_R \end{array}\right\}$

In practice Z_{Ra} differs but little from Z_R and B but little from 1.

If the shunt is applied in the relay end, then

$$I_3 = I_4 + G_s U_3 = C_R I_R (B + G_s Z_{Ra})$$
$$U_2 = C (U_3 + Z_k I_3) = C C_R I_R (Z_{Ra} + B Z_k + G_s Z_k Z_{Ra})$$
$$I_2 = C (I_3 + Y_0 U_3) = C C_R I_R (B + Y_0 Z_{Ra} + G_s Z_{Ra})$$
$$I_1 = I_2$$
$$U_1 = C_T (U_2 + Z_{kT} I_1) = $$
$$= C_T C C_R I_R [Z_{Ra} + B Z_k + Z_{kT} (B + Y_0 Z_{Ra}) + G_s Z_{Ra} (Z_k + Z_{kT})]$$
$$I = C_T (I_1 + Y_{0T} U_2) =$$
$$= C_T C C_R I_R [B + Y_0 Z_{Ra} + Y_{0T} (Z_{Ra} + B Z_k) + G_s Z_{Ra} (1 + Y_{0T} Z_k)]$$
$$E = U_1 + Z_T I =$$
$$= C_T C C_R I_R [A (Z_{Ra} + B Z_k) + Z_{Ta} (B + Y_0 Z_{Ra}) + G_s Z_{Ra} (Z_{Ta} + A Z_k)] \quad (4)$$

where $\left.\begin{array}{l} A = 1 + Y_{0T} Z_T \\ \text{and} \quad Z_{Ta} = Z_T + Z_{kT} \end{array}\right\}$

If the shunt is applied in the feed end of the track then

$$I_3 = I_4$$
$$U_2 = C C_R I_R (Z_{Ra} + B Z_k)$$
$$I_2 = C C_R I_R (B + Y_0 Z_{Ra})$$
$$I_1 = I_2 + G_s U_2 = C C_R I_R [B + Y_0 Z_{Ra} + G_s (Z_{Ra} + B Z_k)]$$
$$U_1 = C_T C C_R I_R [Z_{Ra} + B Z_k + Z_{kT} (B + Y_0 Z_{Ra}) + G_s Z_{kT} (Z_{Ra} + B Z_k)]$$
$$I = C_T C C_R I_R [B + Y_0 Z_{Ra} + Y_{0T} (Z_{Ra} + B Z_k) + G_s (Z_{Ra} + B Z_k)]$$
$$E = C_T C C_R I_R [A (Z_{Ra} + B Z_k) + Z_{Ta} (B + Y_0 Z_{Ra}) +$$
$$+ G_s Z_{Ta} (Z_{Ra} + B Z_k) \ldots\ldots \quad (5)$$

For an unoccupied track the relation between I_R and E is obtained from (4) or (5) by inserting $G_s = 0$.

$$E = C_T C C_R I_R [A (Z_{Ra} + B Z_k) + Z_{Ta} (B + Y_0 Z_{Ra})] \ldots\ldots \quad (6)$$

III. Computation of Shunt Value and Feed Tension at Constant Leakage

When the track is unoccupied the relay should just operate, i. e., I_R should be equal to I_{RC} and when the track is shunted the relay should just release, i. e., I_R should be equal to I_{RD}. If I_{RC} were known, E might be computed from (6) and, if I_{RD} were known, G_s might be determined from (4) or (5). The values of I_{RC} and I_{RD}, however, are not explicitly determined; both are dependent on φ but in addition I_{RD} is dependent on φ_1, i. e., indirectly on G_s, the magnitude of which was to be determined from I_{RD}. Above is stated, however, that the ratio I_{RC}/I_{RD} is represented by a vector terminating on a release circle. We therefore form this ratio by division of (4) by (6) or (5) by (6) after insertion of I_{RD} instead of I_R in (4) and (5) and I_{RC} instead of I_R in (6).

$$\frac{I_{RC}}{I_{RD}} = 1 + G_s \cdot \frac{Z_{Ra} (Z_{Ta} + A Z_k)}{A (Z_{Ra} + B Z_k) + Z_{Ta} (B + Y_0 Z_{Ra})} \ldots\ldots \quad (7)$$

if the shunt is applied in the relay end, and

$$\frac{I_{RC}}{I_{RD}} = 1 + G_s \cdot \frac{Z_{Ta} (Z_{Ra} + B Z_k)}{A (Z_{Ra} + B Z_k) + Z_{Ta} (B + Y_0 Z_{Ra})} \ldots\ldots \quad (8)$$

if the shunt is in the feed end.

Assuming that G_s is real, i. e., that the shunting resistance is purely resistive, these equations represent straight lines in the complex hk plane. Only the positive G_s values are of interest. Therefore the lines begin in the point $h = 1$ on the real axis and incline towards the h axis with the phase angle of the

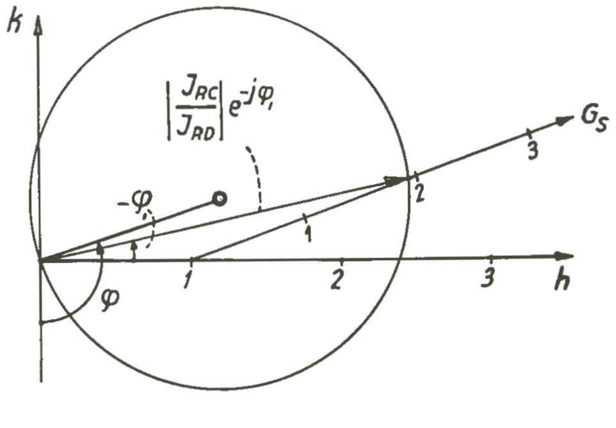


Fig. 8 X 6262
Graphic solution of the problem of determining the requisite shunt conductance and the relay current phase angle change φ_1

complex factor for G_s, see Fig. 8. If the line is divided into lengths each corresponding to $G_s = 1$, there is obtained a »shunt line», on which may be read the shunt value required to give the ratio I_{RC}/I_{RD} the desired value.

If there be drawn a release circle with arbitrary φ, then the point of intersection between the shunt line and the circle will represent that value of G which will bring the relay to release if it operates for $G_s = 0$. In the diagram the value of φ_1 may also be measured. In the fictive example of Fig. 8 $-\varphi_1$ is positive, i. e., φ_1 is negative. Thus on shunting the vector of the relay current I_R has been turned back in time.

Is it obvious that an infinite number of shunt values may be obtained if φ may be given any arbitrary value. If there is no other condition determining φ, this angle may conveniently be chosen as 90°, as I_{RC} will then have its lowest value as also E and the requisite power. With I_{RC} known E is computed directly from (6). If the feed tension available does not agree with that thus computed, it is only necessary to make the ratio of the feed transformer equal to the ratio between the available and the computed voltage. No account need than be taken of voltage drop in the transformer as this has already been done when deducing the formula.

IV. Computation of the Shunt Value and the Feed Voltage at Variable Leakage

In actual practice the leakage varies between a greatest and a smallest value. The relay therefore must not only release with certainty on shunting, but it must also operate with certainty at different values of the leakage when the track is free. Consequently φ cannot as in the preceding section be chosen as 90° without further consideration, but an investigation of the relay's operating properties must precede the selection of φ. This investigation is carried out with the aid of the operating circle and equation (6) in the following manner.

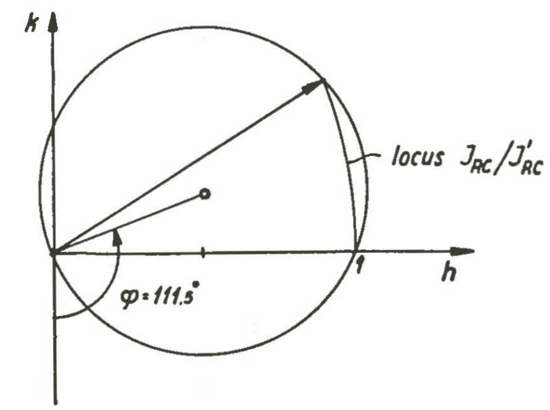


Fig. 9 X 6263
Graphic determination of the phase angle between the track and local phase currents at the basic value of leakage between the rails

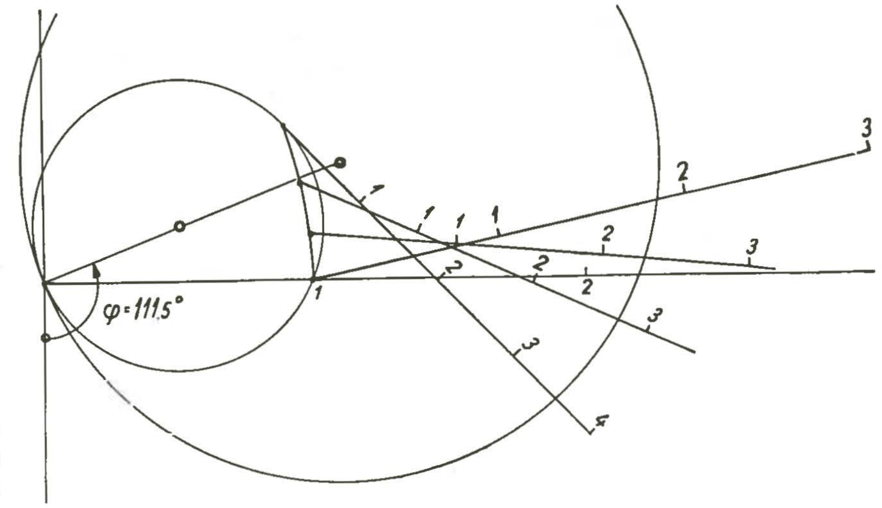


Fig. 10 X 6264
Graphic determination of the requisite shunt conductance for different leakages

If for a certain value of the leakage, »the basic value», the relay operating current is designated I_{RC} and the track section constants C, Y_0 and Z_k and for another value of the leakage I'_{RC}, C', Y'_0 and Z_k, there is obtained from equ. (6) the following relations between E, I_{RC} and I'_{RC}

$$E = C_T C' C_R I'_{RC} [A (Z_{Ra} + B Z'_k) + Z_{Ta} (B + Y'_0 Z_{Ra})] \dots \quad (6\text{ a})$$

$$E = C_T C C_R I_{RC} [A (Z_{RA} + B Z_k) + Z_{Ta} (B + Y_0 Z_{Ra})] \dots \quad (6\text{ b})$$

the ratio I_{RC}/I'_{RC} is a vector in the complex plane with the equation

$$\frac{I_{RC}}{I'_{RC}} = \frac{C'}{C} \cdot \frac{A (Z_{Ra} + B Z'_k) + Z_{Ta} (B + Y'_0 Z_{Ra})}{A (Z_{Ra} + B Z_k) + Z_{Ta} (B + Y_0 Z_{Ra})} \dots\dots \quad (9)$$

which should terminate on or within an operating circle if the relay is to operate also for this new leakage.

The vector I_{RC}/I'_{RC} should be computed for a number of leakages taken sufficiently close together to make it possible to draw a vector point curve in the complex plane, after which an operating circle is drawn with its periphery entirely outside the vector point curve. In Fig. 9 the locus for the vector I_{RC}/I'_{RC} has been drawn for leakages varying from the basic value to a limit value and an operating circle has been drawn which lies outside all vector points for intermediate leakages. In this case all operating circles with φ between 111.5° and 180°, (thus not 90°) would satisfy the condition, but in order not to unnecessarily increase the power consumption of the relay the circle with the φ value nearest to 90° is chosen.

After φ has thus been determined the release circle is drawn and shunt lines will be inserted for the different leakages. The equations for these lines are obtained in the same way as in the preceding section by division of (4) by (6) or (5) by (6).

The equation for a shunt line, when the shunt is placed at the relay end, is thus

$$\frac{I_{RC}}{I'_{RD}} = \frac{C'}{C} \cdot \frac{A (Z_{Ra} + B Z'_k) + Z_{Ta} (B + Y'_0 Z_{Ra}) + G_s Z_{Ra} (Z_{Ta} + A Z'_k)}{A (Z_{Ra} + B Z_k) + Z_{Ta} (B + Y_0 Z_{Ra})} \quad (10)$$

and when the shunt is placed at the feed end

$$\frac{I_{RC}}{I'_{RD}} = \frac{C'}{C} \cdot \frac{A (Z_{Ra} + B Z'_k) + Z_{Ta} (B + Y'_0 Z_{Ra}) + G_s Z_{Ta} (Z_{Ra} + B Z'_k)}{A (Z_{Ra} + B Z_k) + Z_{Ta} (B + Y_0 Z_{Ra})} \quad (11)$$

These shunt lines begin in the points where $G_s = 0$, which points are identical with the points of the vectors I_{RC}/I'_{RC}. Assuming as before that G_s is real, the lines are straight with an inclination to the h axis, which is determined by the factor for G_s.

On these shunt lines are read the release shunt values for the different leakages in the points of intersection with the release circle. On the shunt lines, whose starting points lie inside the operating circle, it is also possible to read the shunt values for which the relay operates at different leakages (»the operating shunt values»). In Fig. 10 there are shown release and operating circles and 4 shunt lines in a fictive example.

The relay's f as may be seen has been assumed as 2.2, φ has been fixed at 111.5°. For the leakage at which the angle between the track and local currents is 111.5°, the basic value, there is read the shunt value 1.8 mho, i. e., a shunt resistance of $1/1.8 = 0.55$ ohm. When the leakage varies towards the limit value the release shunt conductance is successively increased to 2.3, 2.8 and 3.5. On the intermediate shunt lines there are read the operating shunt values app. 0.1 and app. 0.15 mho.

Whether the leakage in the example increases or decreases when it varies from the basic value to the limit value cannot be told from the displacing of the shunt lines, as this is dependent not only on the variation of the leakage but also on the magnitudes and angles of Z_T and Z_R.

Measurement of pH and Redox Potentials

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U.D.C. 621.317.39: 545.371

The determination of pH and redox potentials has in recent years assumed growing importance, not only in chemical laboratories but also in various branches of medicine, foodstuff industry, metal production, pulp and paper industry, water and sewage treatment, steam power generation etc. In the article below is given a survey of the principles for such measurements and a description of the measuring accessories. A subsequent article will describe two pH meters which are manufactured by L M Ericssons Mätinstrument AB, Ulvsunda.

Definition of pH

The term pH was defined in 1909 by *Sørensen* as the negative logarithm of the hydrogen ion concentration:

$$\mathrm{pH} = -{}_{10}\log c_{\mathrm{H}^+}$$

Later it has been found more adequate to understand by pH the negative logarithm of the activity of the hydrogen ions, the activity being obtained as the product of the concentration and the activity factor f. It has also been found that the hydrogen ion in aqueous solutions is associated with a water molecule, forming the hydronium ion H_3O^+. The modern definition consequently runs:

$$\mathrm{pH} = -{}_{10}\log a_{\mathrm{H_3O}^+} = -{}_{10}\log (f_{\mathrm{H_3O}^+} \cdot c_{\mathrm{H_3O}^+})$$

The value of the activity factor depends upon the concentration of the hydrogen ions as well as the concentration of other molecules and ions present in the solution. The value of f is generally about 1 and approaches 1 when the concentration of the solution decreases. It is therefore often possible in approximate calculations, particularly when dealing with dilute solutions, to assume that the activity and the concentations are equal, in which case Sørensen's original definition may be used.

The pH values of aqueous solutions almost always lie between the values *0* and *14*. Fig. 1 gives the pH scale with the pH values of some characteristic solutions indicated.

It should be noted that a large hydrogen ion concentration (large degree of acidity) corresponds to a low pH value and that an *increase* of the hydrogen ion concentration is expressed as a *decrease* of the pH value.

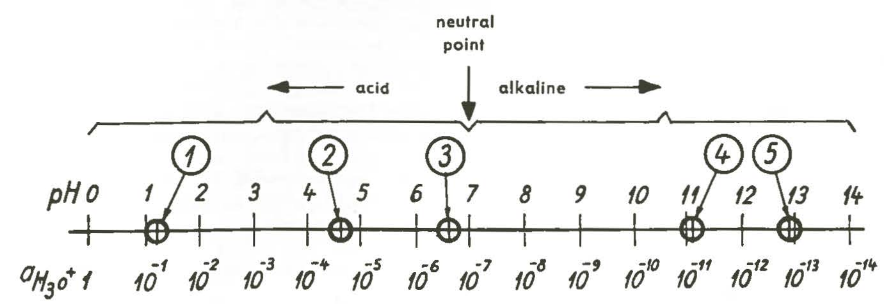


Fig. 1 X 6272
pH scale
1 0.1n hydrochloric acid pH 1.1
2 acetate buffer (0.1n HAc + 0.1n NaAc) pH 4.67
3 phosphate buffer (0.1 m KH_2PO_4 + 0.1 m K_2HPO_4) pH 6.68
4 0.1n ammonia pH 11.1
5 0.1n sodium hydrate pH 12.9

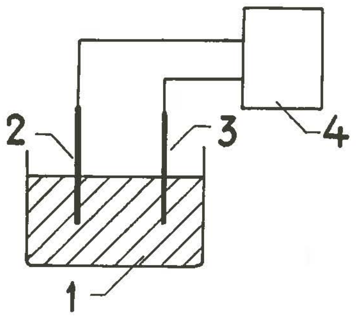


Fig. 2 x 4493

Principle of electrometric pH measurement

1 solution to be measured
2 pH sensitive electrode
3 reference electrode
4 measuring apparatus

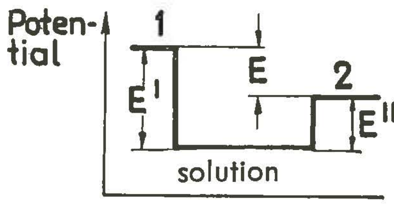


Fig. 3 x 4494

Potential conditions at electrometric pH measurement

1 pH sensitive electrode
2 reference electrode

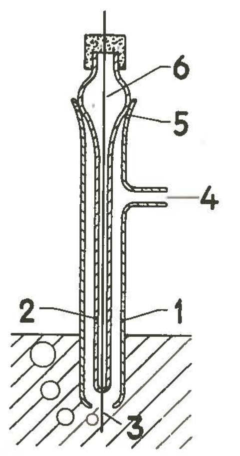


Fig. 4 a x 4495

Hydrogen electrode

1 outer glass tube
2 inner glass tube
3 platinum wire
4 hydrogen inlet
5 ground-glass joint
6 electrical connection

Electrometric Determination of pH

By far the most important method for determining pH is the electrometric one, Fig. 2. By electrometric determinations greater accuracy is obtained than by other methods, and with appropriate measuring technique (particularly suitably selected electrodes) the results are independent of other substances that may be present in the solutions and are not affected by colour or turbidity of the solutions.

The electrometric method is based on the measurement of the EMF of a galvanic cell consisting of two electrodes which are immersed in the solution to be measured. One electrode, the *pH sensitive electrode,* is such that the potential of this electrode is determined by the pH value of the solution, while the other electrode, the *reference electrode,* has constant potential independent of pH. When the pH sensitive electrode is of one of the usual types, the potential drop at this electrode (in volts) is given by

$$E' = E_0' - 1.983 \cdot 10^{-4} \cdot T \cdot \mathrm{pH} \qquad (1)$$

where E_0' = a characteristic constant of the electrode
T = the absolute temperature.

If the potential of the reference electrode is designated by $E'' = E_0''$ (= const.) the EMF of the cell, see Fig. 3, is given by:

$$E = E' - E'' = E_0' - E_0'' - 1.983 \cdot 10^{-4} \cdot T \cdot \mathrm{pH} \qquad (2)$$

or at room temperature (20° C):

$$E = E_0' - E_0'' - 0.0581 \cdot \mathrm{pH} \qquad (3)$$

Table I

E_0-values for electrodes at 20° C

electrode	E_0, volts
pH sensitive electrodes	
Hydrogen electrode[1]	0.000
Glass electrode[2]	+ 0.406
Quinhydrone electrode	+ 0.703
Antimony electrode	+ app. 0.275
Reference electrodes	
Saturated calomel electrode	+ 0.250
0.1-*n* calomel electrode	+ 0.338

[1] Hydrogen pressure 1 atm.
[2] Inner solution pH 2.0. Inner electrode Ag/AgCl with $c_{Cl} = 0.1$.

In Table I are given the E_0 values for the most common types of pH sensitive electrodes and reference electrodes. From the values given in the table the EMF of for instance a cell, consisting of a quinhydrone electrode and a saturated calomel electrode, is calculated, at 20° C, to

$$E = 0.453 - 0.0581 \cdot \mathrm{pH}$$

It may be remarked that it is connected with considerable difficulties to determine experimentally the absolute value of a single electrode potential. For this reason the electrochemical potentials are given in a scale, whose zero point consists of the so-called *normal hydrogen electrode.* This electrode, which is a hydrogen electrode with a hydrogen pressure of 1 atm., dipping in a solution of pH 0, is assumed to have zero potential at all temperatures. Because the EMF of a galvanic cell is the difference of two single potentials, it is evidently without influence on the EMF if the single electrode potentials should in reality differ by a certain amount from the values thus assumed, i. e. if the normal hydrogen electrode should in reality not have the zero potential assigned to it. In fact, recent investigations seem to indicate that the absolute potential of the normal hydrogen electrode is about + 0.28 V. If such is the case, the values of the single electrode potentials will have to be increased by this amount, the values of the EMFs of the galvanic cells, however, remaining unaffected.

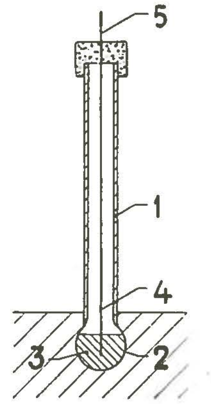


Fig. 4 b x 4496

Glass electrode

1 glass tube
2 thin-walled glass bulb
3 inner solution
4 chlorinated silver wire
5 electrical connection

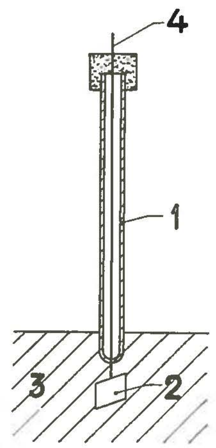


Fig. 4 c x 4497

Quinhydrone electrode

1 glass tube
2 platinum foil
3 solution to be measured, with quinhydrone added
4 electrical connection

pH sensitive Electrodes

A description is given below of the common types of pH sensitive electrodes.

The *hydrogen electrode,* Fig. 4 a, consists of a foil (or wire) of platinum which is exposed to hydrogen gas and is at the same time in contact with the solution whose pH is to be determined. Before the measurements the platinum foil is coated with a layer of finely divided platinum (platinum black) by making the electrode the cathode in a platinum chloride solution and electrolysing for some minutes with suitable current density. The hydrogen electrode is usable over the whole pH range, from 0 to 14, giving an exactly linear relation between pH and electrode potential in the entire range. It is noteworthy that the electrode ceases function (»is poisoned») if exposed to certain substances, particularly those having the character of physiological poisons, such as cyanides, sulphides, alkaloids, amines etc. A poisoned hydrogen electrode is made serviceable again by removing the deposited platinum layer and providing the electrode with a fresh coating. Except in solutions which contain substances acting as electrode poisons, the hydrogen electrode can not be used in the presence of substances which react chemically with hydrogen gas, such as oxidizing agents and certain metallic salts. Nor is it advisable to use the hydrogen electrode when the solution contains dissolved gases, which may be carried away by the hydrogen stream and in this way alter the pH of the solution. The hydrogen electrode has nowadays chiefly the character of a standard electrode, which is used to calibrate other electrodes and in scientific measurements. For practical pH measurements it has almost entirely been replaced by other electrodes, mainly the glass electrode.

The *glass electrode* is the pH sensitive electrode most used. In the form of construction shown in Fig. 4 b it consists of a glass tube, which at one end is blown out to form a thin-walled glass bulb. The bulb contains a solution of fixed pH value, the contact between this solution and the electrical connection lead of the electrode being established by a metal electrode, usually a chlorinated silver wire, which is inserted in the bulb. When the glass electrode is immersed in the solution whose pH value is to be measured, there arises between the inside and outside surface of the glass bulb a potential difference which is proportional to the difference in pH between the outside and inside solution. By making the bulb of a special glass, the change of potential with pH can be made the same as for the hydrogen electrode, viz: 58.1 millivolt per pH unit at 20° C.

The glass electrode attains its potential rather quickly and the electrode shows — with the exceptions to be mentioned — no disturbances in solutions where the hydrogen electrode is unusable. It is not affected by poisons, oxidizing agents or metallic salts and may equally well be used in solutions containing dispersed solid or liquid substances, in pastes etc. The use of the glass electrode, however, is mainly limited to pH values below 9. Above this value the potential no longer varies linearly with pH and is moreover influenced by Na^+ ions existing in the solution. Above pH 11 to 12 the electrode becomes entirely unserviceable owing to the attack of the alkaline solution on the glass. It should be observed at the measurements that a potential difference, known as the »asymetry potential», usually exists between the inside and outside of the glass bulb, even when the inside and outside solutions have the same pH. The value of this potential, which may amount to some tens of millivolts, depends on the earlier treatment of the glass etc. and may vary slightly from day to day.

Because of the glass membrane a galvanic cell which contains a glass electrode has a high internal resistance, in general between 10^7 and 10^8 ohms. Consequently the glass electrode can only be used in connection with measuring apparatus that are specially designed to enable accurate measurements even in systems of such high resistance (see below). A consequence of the high resistance is also that the glass electrode is sensitive to electrostatic disturbances such as spark formation in switches, electric motors etc. in the vicinity. By enclosing the whole galvanic cell in an earthed metal casing or, more simply,

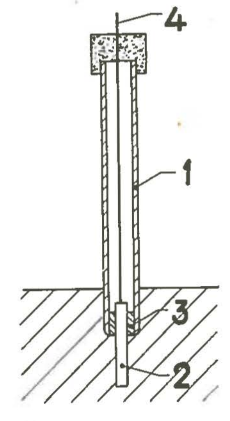


Fig. 4 d
Antimony electrode
1 glass tube
2 antimony rod
3 cement
4 electrical connection

X 4498

by using a special screened type of glass electrode, these disturbances are eliminated.

As the wall of the bulb has a thickness of only some tenths of a millimetre, it may easily be injured by knocks, jars etc. It is therefore necessary to handle the glass electrode with care at transport and measurements.

For certain kinds of pH measurements it is custom to use the so-called *quinhydrone electrode*. An organic substance, quinhydrone, is added to the solution whose pH is to be determined, and a bright platinum foil is immersed in the solution, Fig. 4 c. This type of electrode is specially suited for the measurement of pH in extremely small quantities of liquids, as in microchemistry and some kinds of biological work. As the quinhydrone electrode has low resistance it imposes no particular demands on the measuring apparatus. It cannot be used for pH values above 8 to 9, as the quinhydrone is attacked by alkaline solutions, nor can it be employed in solutions containing substances (e. g. oxidizing agents) which react chemically with the quinhydrone.

The *antimony electrode*, Fig. 4 d, is rather well adapted to some techniacl pH measurements, as it is low ohmic and may be constructed fairly rugged. It may be utilized over practically the whole pH range, at least between 1 and 13. The accuracy of the antimony electrode is lower than with other electrodes and the potential is affected by the oxygen content and stirring of the solution, as well as by the surface conditions of the electrode. Metallic salts, complex forming substances, etc. produce disturbances which in aggravated cases may render employment of the electrode impossible.

In conclusion it may be said that there is no pH sensitive electrode which may be used with advantage in all cases. The type of pH sensitive electrode to be used should be selected with regard to the conditions of each case. In many cases, however, the glass electrode may be regarded as a rather universal electrode.

Reference Electrodes

The reference electrode which is most frequently used is the *calomel electrode*, of which a suitable design is shown by Fig. 5. The electrode consists of a glass vessel on the bottom of which is placed a layer of mercury covered by a layer of mercurous chloride (calomel), after which the vessel is filled with potassium chloride solution. Depending on the concentration of the potassium chloride solution the electrode is named »0.1 normal», »saturated» etc. The most common type of calomel electrode is the saturated one.

The interface between the potassium chloride solution and the solution to be measured is the seat of a *diffusion* (or *liquid-junction*) *potential* which adds itself to the electrode potentials. The diffusion potential should be kept as low as possible, which is attained partly by high concentration of the potassium chloride solution and partly by a well-defined form of the boundary surface. In order to attain the latter a drop of potassium chloride solution should be run out of the connecting tube, when the solution to be tested is changed, in this way causing a renewal of the interface.

Definition of Redox Potential

The term »redox», while not yet generally adopted in English and American literature, has been used since a long time in Swedish and German literature. Being conveniently short and, as far as the author knows, not giving rise to any misunderstanding, this term will be used here instead of the longer word »oxidation-reduction».

The redox potential of a solution is identical to the potential of a bright platinum foil, which is immersed in the solution. As the potential of the platinum electrode is produced by the exchange of electrons between the metal on one hand and oxidizing and reducing substances in the solution on the other, it is possible from the value of the potential to draw conclusions concerning the sort of oxidizing and reducing substances present in the solution and their concentrations.

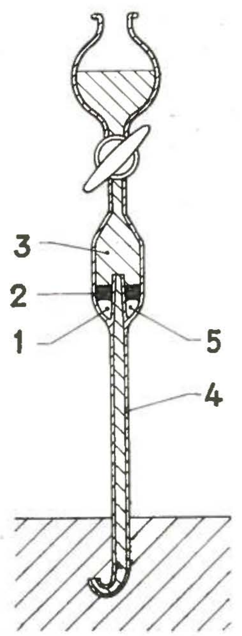


Fig. 5
Calomel electrode
1 mercury
2 calomel
3 potassium chloride solution
4 connecting tube
5 electrical connection

X 4499

For every substance with an oxidizing character there is a corresponding substance of reducing character, the latter substance being derived from the former by the addition of electrons (reduction). Two substances which in this way correspond to each other are said to form a *redox system* and are designated as the oxidized form *(oxform)* and the reduced form *(redform)* respectively of the system. A solution which contains both components of a redox system has the redox potential:

$$E' = E_0' + \frac{0.058}{n} \cdot {}_{10}\log \frac{a_{ox}}{a_{red}} \quad \ldots\ldots\ldots\ldots\ldots \quad (4)$$

where E_0' = the normal (or standard) potential of the redox system
n = the number of electrons required to reduce the oxform to the redform
a_{ox} = the activity (approximately concentration) of the oxform
a_{red} = the activity (approximately concentration) of the redform.

In Table II normal potentials and n-values of some redox systems are given.

Table II
Redox systems

redform	oxform	n	E_0, volt
Zn	Zn^{2+}	2	— 0.76
Cr^{2+}	Cr^{3+}	1	— 0.41
$H_2 + 2H_2O$	$2H_3O^+$	2	0.00
Sn^{2+}	Sn^{4+}	2	+ 0.15
Cu	Cu^{2+}	2	+ 0.34
Fe^{2+}	Fe^{3+}	1	+ 0.76
Ce^{2+}	Ce^{3+}	1	+ app. 1.40
$Mn^{2+} + 12H_2O$	$MnO_4^- + 8H_3O^+$	5	+ 1.52

It is seen from equ. (4) that the normal potential of a redox system is identical to the potential of a solution which contains the oxform and the redform in the same concentrations (or more exactly, the same activities).

Determination of Redox Potentials

The determination of a redox potential is carried out in the same way as a pH measurement, the only difference being that the pH sensitive electrode is replaced by a bright platinum electrode.

Potentiometric Titration

Measurements of redox potentials are chiefly used in connection with potentiometric titrations. At a potentiometric titration, the redox potential of a solution is determined as function of the added amounts of an oxidizing or reducing solution. Fig. 6 gives a curve obtained at a potentiometric titration. For certain amounts of the added reagent the curve shows rapid changes in the potential, these changes, as is known, indicating equivalence points. In the case shown in Fig. 6 two different substances have been determined in the same titration. By means of potentiometric titration it is often possible, especially in metal

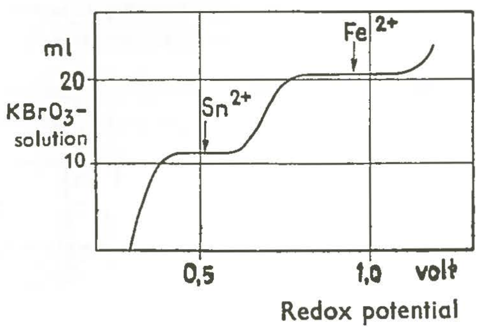


Fig. 6
Titration curve

X 6267

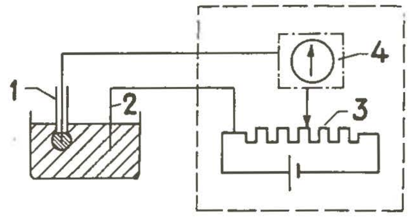


Fig. 7 X 4500

Principle of compensation apparatus

1 pH sensitive electrode
2 reference electrode
3 slide wire
4 zero indicator

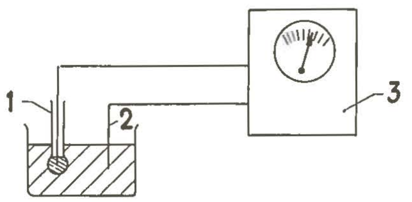


Fig. 8 X 4501

Principle of direct-reading apparatus

1 pH sensitive electrode
2 reference electrode
3 direct-reading apparatus

Fig. 9 X 6268

Direct-reading pH apparatus

1 pH sensitive electrode
2 reference electrode
3 electron tube
4, 5 input terminals
6 switch
7 rheostat
8 indicating instrument
9 resistance
10, 11, 12 batteries

analyses, to carry out determinations with the same accuracy as by gravimetric methods but with much higher speed.

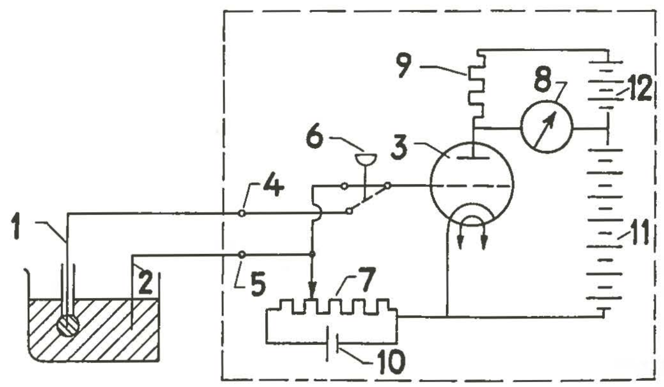
Compared with the general way to represent titration curves, at which the volume of the reagent is plotted along the horizontal axis and the redox potential along the vertical axis, the axis have been reversed in Fig. 6. Looking puzzling at first, this mode of representation has been found to possess some advantages, especially from a theoretical point of view, as it gives a more direct relation to the theoretical way of constructing the curves and, moreover, the so-called *buffer capacity* is obtained as the inclination of the curve.

If a pH sensitive electrode is used instead of the bright platinum electrode and an alkaline (or acid) solution is added, the potentiometric titration gives as result a determination of the amounts of acids (or bases) present in the solution. Even precipitation and complex forming reactions can be utilized for potentiometric titrations.

Various Kinds of Measuring Apparatus

Measuring apparatus for determination of pH and redox potentials may be divided into two main categories, compensation apparatus and direct-reading apparatus. With a *compensation apparatus,* Fig. 7, it is necessary at each measurement to adjust a contact on a slide wire until a zero indicator shows no deflection, in which case the EMF of the cell is equal to the voltage read on the slide wire. With a *direct-reading apparatus,* on the other hand, Fig. 8, the value of the EMF is read directly on an indicating instrument, whose dial is graduated in pH or redox potentials, without any manual adjustments being needed. Except for measurements demanding the utmost degree of accuracy, direct-reading apparatus are to be preferred to compensation apparatus chiefly because of the greater rapidity with which the measurements may be carried out. The continuous indication of the potential, moreover, enables the operator to observe immediately every variation in the EMF of the cell, which is of great importance in potentiometric titration work. The accuracy of a good direct-reading apparatus is sufficient for all practical purposes.

The principle of construction of a direct-reading pH apparatus is shown in Fig. 9. The apparatus is essentially a vacuum tube voltmeter. The galvanic cell is inserted between the grid and the cathode of an electron tube and the indicating instrument (e. g. a milliammeter) is located in the anode circuit of the valve. When the EMF of the cell changes, the grid voltage of the valve is altered and thereby the anode current. As the anode current is thus varying according to the cell's EMF and the latter in turn varies linearly with pH, the dial of the meter may be graduated in pH. The switch *6* enables the zero point to be checked. In its upper position the switch connects the grid of the tube to the contact on the rheostat *7*, disconnecting the galvanic cell from the tube and enabling the zero point to be adjusted by moving the contact on *7*. In the lower position the switch connects the cell to the grid, and in this position the measurements



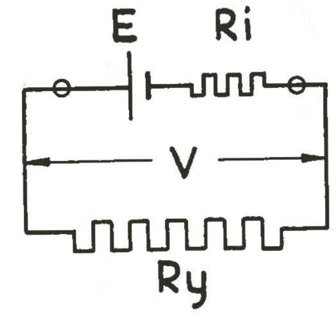


Fig. 10 X 4502

Dependence of terminal voltage on the external resistance

E the cell's EMF
Ri the cell's internal resistance
Ry external resistance
V the cell's terminal voltage

$$E - V = \frac{Ri}{Ri + Ry} \cdot E$$

are carried out. The resistance *9* and the battery 12 allow the current through the indicating instrument to be brought down to zero even though current is flowing through the electron tube.

It is hardly necessary to add that a modern direct-reading pH meter differs in many respects from the simple arrangement of Fig. 9. In fact, as the high resistance of the glass electrode renders every galvanometer insufficiently sensitive, for use as a zero indicator also a compensation apparatus has to contain an electron tube in about the same arrangement as in Fig. 9. The difference between a compensation and a direct-reading apparatus is, briefly stated, that in a compensation apparatus the rheostat *7* is a high-precision compensator, by the adjustment of which the compensating voltage is made equal to the EMF of the cell, the meter *8* serving as a zero indicator, whereas in a direct-reading apparatus the rheostat *7* is of simple design and is only used for the original adjustment of the zero point, the values of the EMF being read on the meter *8*. Consequently a direct-reading pH meter, in contrast to a compensation apparatus, has to contain arrangements, which provide a linear relation between the variations of the EMF and the deflections of the meter, independent of the durations from linearity which may occur in the relation between grid voltage and anode current. These arrangements, among others, are not shown in Fig. 9.

Special Requirements for Measurement with Glass Electrode

A pH apparatus should possess satisfactory accuracy, be easy to operate and capable to withstand the rather hard treatment, to which it may be exposed in chemical work. In addition to these properties, the apparatus must fulfil certain requirements which are due to the high resistance of the glass electrode.

In the first place, the input resistance of the apparatus, i. e. the resistance between terminals *4* and *5* in Fig. 9, has to be very high. If the resistance between these terminals is of the same order of magnitude as the internal resistance of the galvanic cell, the apparatus will not measure the EMF of the cell but its terminal voltage instead. From Fig. 10 is seen that, in order to make the error, which results from this deviation, less than 0.1 % of the cell's EMF, the input resistance of the measuring apparatus (i. e., *Ry* of Fig. 10) should be 1000 times greater than the resistance of the glass electrode. As the resistance of the latter, as stated above, amounts to 10^7—10^8 ohms, the input resistance should be 10^{10} to 10^{11} ohms. When using the apparatus care must also be taken that the input resistance does not fall below this value. Electrolytic or other solutions may not be dropped on the insulators of the input terminals, nor may the insulators be touched by wet or dirty fingers.

The second requirement concerns the grid current of the electron tube. With the arrangement shown in Fig. 9 the grid current of the electron tube flows through the galvanic cell and causes a voltage drop over the internal resistance of the cell, this voltage drop producing an error in the value of the EMF. Because of the high resistance of the glass electrode even a small current is sufficient to produce a considerable voltage drop. The electron tube must consequently have a very low grid current.

The above requirements are fulfilled by modern pH apparatus designed for measurements with glass electrodes.

Combined Selector and Loud-speaker Plant on the Stockholm—Roslagen Railway

G LINDBLOM, LM ERICSSONS TELESIGNALFABRIK, STOCKHOLM

U.D.C. 656.254.15

A loud-speaker plant intended for communications to passengers and train crews at unattended railway stations and halts has been installed by Telefonaktiebolaget L M Ericsson on the Stockholm—Roslagen Railway. The construction and operation of the plant is described in this article.

On the proposal of Engineer Kullenberg of the Stockholm—Roslagen Railway, Telefonaktiebolaget LM Ericsson has constructed a combined selector and loud-speaker plant, designed to make communications regarding changed times of trains and the like to passengers and train crews at unattended stations and halts along the lines Djursholms Ösby—Näsby Park and Djursholms Ösby—Eddavägen.

Construction

Central Equipment

The central equipment of the plant is located at Djursholms Ösby. It comprises telephone instrument with electrodynamic microphone, Fig. 1, line equipment, power supply unit, two selector sets, relay set with microphone amplifier, see Fig. 2.

Station Equipments

The station equipments, Fig. 3, are connected to the central equipment over a common two-wire line and are divided into two groups, one including the stations Parkvägen, Östberga, Altorp, Lahäll, Näsby Allé, Näsby Park and the other Bragevägen, Sveavägen, Restauranten, Germaniavägen, Framnäsviken, Vikingavägen, Eddavägen.

At each station or halt there are selector set, relay set, line transformer, amplifier, loud-speaker and control microphone.

Call Numbers

Each station has its individual call number. In addition there is for each group of stations a general call number for use when all amplifiers are to be connected or when announcements are to be issued that are common to all the stations in a group. To disconnect the amplifiers another general call number is dialled. The individual call numbers for the two station groups are *92, 93, 94, 95, 96, 97* and *01, 02, 03, 04, 05, 06* and *07* respectively. For connecting amplifiers and general call the numbers *99* and *09* respectively are used and for disconnection of the amplifiers No *90* and *00* respectively.

Fig. 1 X 4504
Telephone instrument
with built in signal lamps for connection to the amplifier, Fig. 2

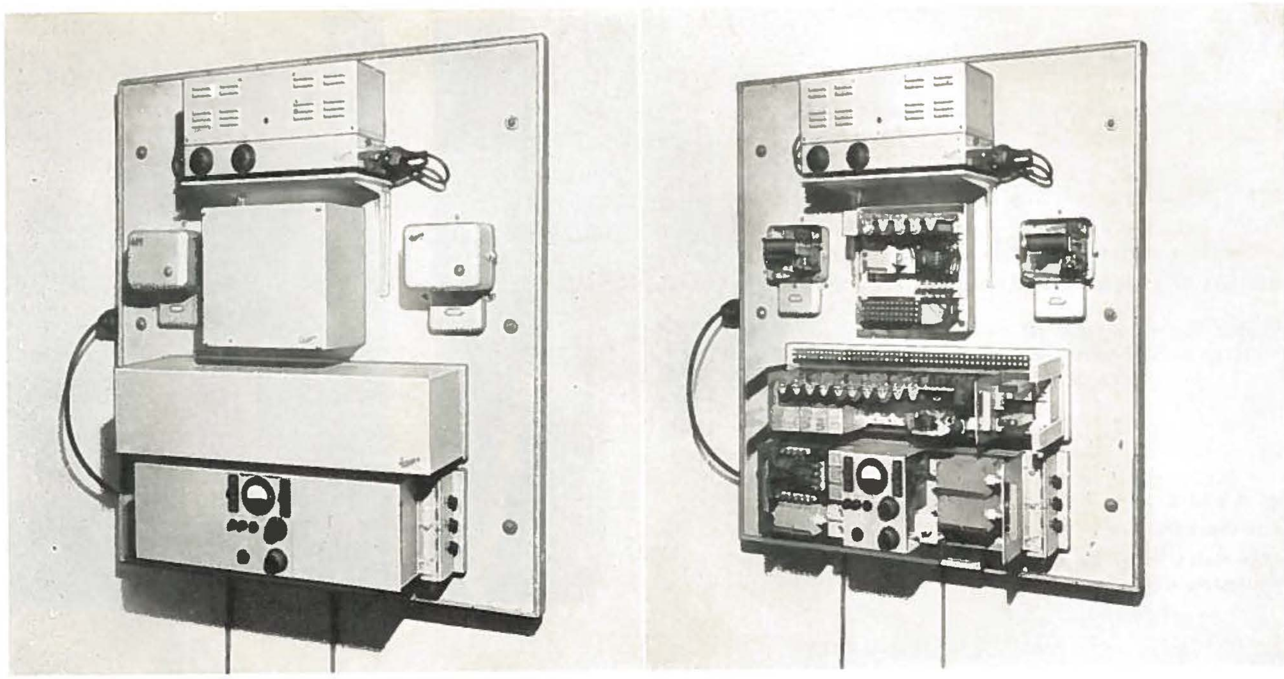


Fig. 2 X 7444
Central equipment
left with and right without protective covers; reading downwards: amplifier, relay set with selector set on both sides, line equipment, power supply unit

Amplifiers

The amplifiers in the plant have indirectly heated valves. To avoid a wait of nearly half a minute while the valves warm up after dialling a number, the amplifiers are coupled in stand-by connection, i. e., the anode tension to the valves is normally disconnected and is switched on only for the time the announcement is being sent out. The stand-by operating reduces the time of waiting to a couple of seconds besides increasing the life of the valves.

Operation

Each morning, before the plant is to be employed, the amplifiers are connected in on stand-by connection, which is done by dialling on the telephone instrument the numbers *99* and *09* respectively for the two groups of stations. To check that the amplifiers are connected in stand-by connection two lamps, one for each group of stations, light up on the front of the telephone instrument. When an announcement is to be sent out to a station the telephone handset is lifted, the button on the instrument is pressed and, after receipt of answering tone, the number for the station in question is dialled. At the station the amplifier is connected via the relay set, and a couple of seconds after the number has been dialled the announcement may be sent out on the loud-speaker, Fig. 4 and 5. To check that the announcement can be heard at the station a carbon granule microphone is mounted close to the loud-speaker and the sound is repeated in the receiver of the central equipment telephone instrument.

When a speaking circuit is connected to a station it is possible by means of the carbon granule microphone there to speak with the chief station and receive answer in the loud-speaker. At the close of the communication the station equipment handset is replaced after which the connecting devices return to home position. There is then heard in the telephone instrument a buzzer signal, which ceases when the amplifier in the station equipment has been switched down to stand-by connection.

If it is desired to send out a communication that is common for a whole group of stations, the general call number for that group is dialled, this connecting in all the amplifiers belonging to the group.

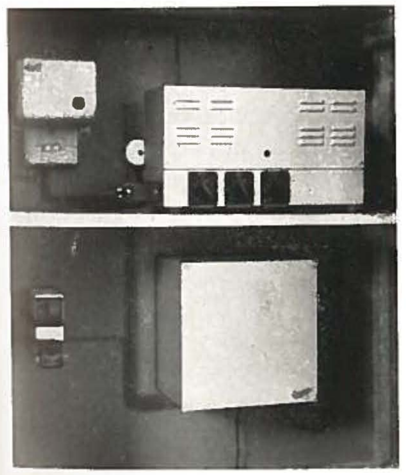


Fig. 3 X 4505
Station equipment
with protective covers removed; above, selector set and amplifier, with line transformer and relay set below

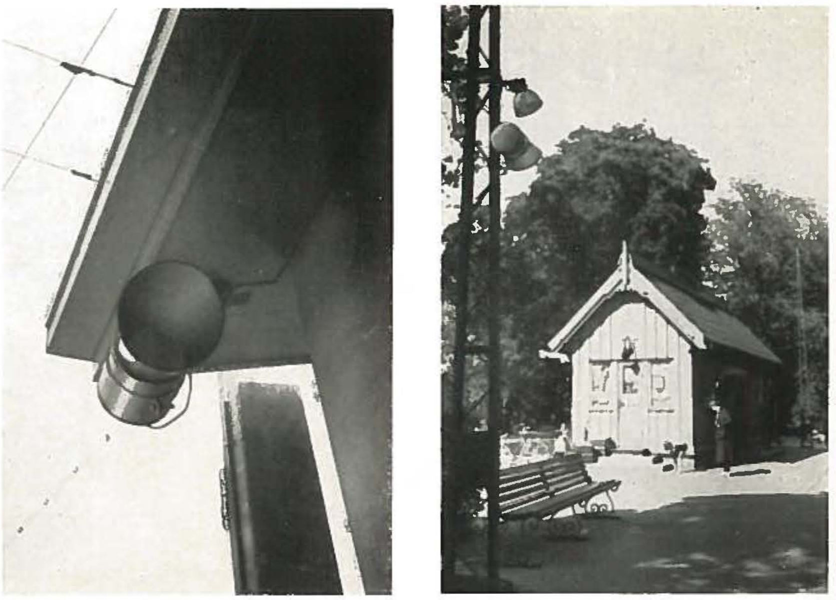


Fig. 4 and 5 X 4506 X 4503
Loud-speakers
left, mounted under the eaves of the station building; right, on a pole

When the plant is to be out of service for a lengthy period, e. g., during the night, the amplifiers are disconnected by dialling the numbers *90* and *00* respectively for the two groups of stations.

Current Sources

The current for the central equipment is furnished by a power supply unit which is mains connected and delivers 24 V D.C. tension for operation of the line equipment and charging of the buffer battery, and 200 V D.C. tension for impulsing on the selector sets. A transformer and rectifier built into the relay set gives 5 V tension for operation of the relays of the set. The microphone amplifier is mains connected.

The amplifiers and relay sets of the station equipments are mains connected. The operating relays receive 5 V D.C. tension from a transformer and rectifier built into the relay set.

Cable

As connecting cable between the central and station equipments there is used telephone cable type EPB 5 × 2 × 0.5 mm, laid as aerial line. One wire pair in this cable is employed for speech transmission and for connecting and disconnecting the amplifiers. The control microphone is connected to another wire pair when the amplifier is connected in. The other wire pairs comprised in the cable are intended for other purposes.

U.D.C. 656.254.15

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U.D.C. 621.315.67
621.395.741

SIDENMARK, N: *Distribution System in Local Telephone Networks with Through-Connected Basic Load.* Ericsson Rev. *24* (1947) No 2 pp. 26—35.

A brief account of LM Ericsson's network lay-out system and a description of *distribution system with through-connected basic load,* a system representing a development of the present distribution system.

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A general method for track circuit computation is described, applicable both to A.C. and D.C. track circuits and taking into account variations of both leakage and tension.

U.D.C. 621.317.39:545.371

BLOMGREN, E: *Measurement of pH and Redox Potentials.* Ericsson Rev. *24* (1947) No 2 pp. 47—53.

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