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The Stockholm "Förmedlings" Bureau.

The Telephone Commissions Office.

By *A. Lignell.*

As the use of the telephone has gradually extended from large houses and offices to the very smallest and is now found in almost every residence, efforts have been made to enlarge its scope, to make it a servant of the public not only for direct intercommunication but also for enabling the subscriber to benefit from his subscription in other ways also, e. g. during temporary absence.

For this purpose the Telephone Commissions Office, which for a small fee will accept various commissions from the subscribers, have been established in the larger towns of Sweden for many years.

Their usefulness to clients is best illustrated by a few examples.

A doctor is going away for a month's holiday. He informs the Commissions Office of the name, address, consulting hours, and telephone number of his locum tenens, his own postal address and perhaps telephone number, and the date of his return.

When the doctor's number is called, the Office will reply, and give the necessary information to the caller.

A midwife has her telephone connected to the Office, to which she gives full details of where she can be found at various times of the day. Should she go to a cinema, for instance, she would inform the Office of its name and the row and number of her seat.

When a business man with no office staff goes out for lunch, the Bureau can say when he expects to return and, if desired, inform him of the name and telephone number of any person ringing him up in his absence.

A subscriber leaves a message for a certain person, who will inquire for it by telephone. To avoid any unauthorized person receiving the message, a code word may be agreed on between the person who leaves the message and the recipient, without which it will not be given.

Certain local or trunk calls may be re-directed for any desired period to another number, and when his office is closed, for instance, a subscriber can have incoming calls distributed to various residential numbers.

Waking by telephone is also extensively used, both as a standing order and on odd occasions.

Some people get woken up every weekday—perhaps at different times each day according to their own time-table. Even a person who wishes to have an occasional nap can let the Office see that he does not oversleep.

If your watch has stopped or you wish to put it right, the Office will furnish the correct time.

Information is also supplied regarding what doctors are on duty at night or on Sundays and holidays in the various districts of the town.

As we see, the Commissions Office can be exceedingly useful to subscribers, and the most varied professions are increasingly availing themselves of its services.

Commissions.

The Office supervisor accepts orders for and cancellation of commissions. When ringing, the subscriber asks for "Förmedlingsbyrån" by name, and can then give his instructions by telephone. If a commission is for more than 7 days at a stretch, a written confirmation is required, experience having proved this necessary.

When receiving a commission, the supervisor notes the necessary information on an order card, which is put in a pocket in the switchboard, immediately above the subscriber's connecting jacks, easily accessible to the operator. The card is illustrated in fig. 1; on the back, all executed commissions are recorded.

The Stockholm Telephone Commissions Office.

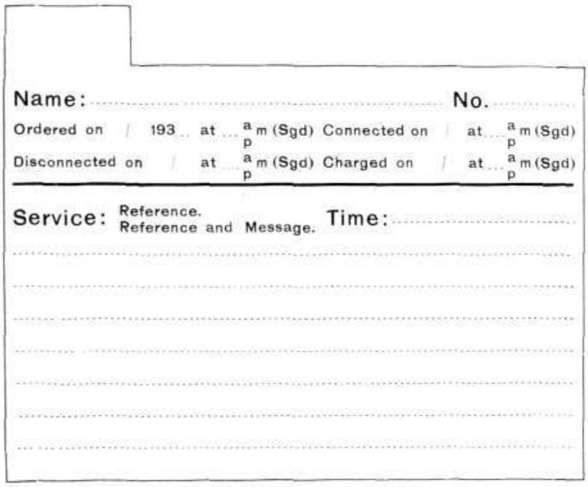
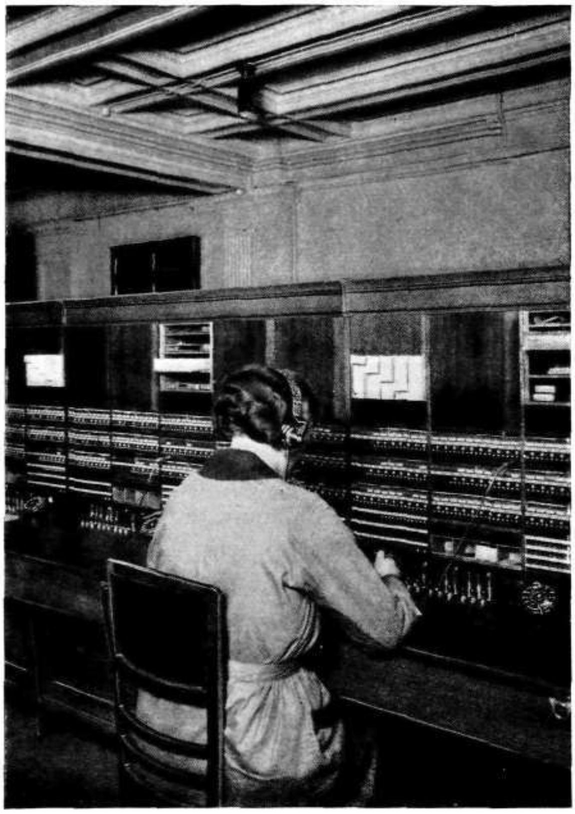

Name: .... No. ....
Ordered on / 193.. at ... a/p m (Sgd) Connected on / at ... a/p m (Sgd)
Disconnected on / at ... a/p m (Sgd) Charged on / at ... a/p m (Sgd)
Service: Reference. Reference and Message. Time: ....

Fig. 1.

Connexion of a Subscriber to the Bureau.

Having noted the subscriber's number and order on an order card, the supervisor instructs the exchange concerned to put his line through to the Bureau. Normally, this line is connected direct to the internal wire through the cutting-in switch, but in this case that connexion will be broken at the cutting-in switch, and each section of the subscriber's line will be connected to an extra calling-device in the "Commissions Office".

Operator's Positions. (See figs. 2 and 3.)



R 4048 Fig. 3.

Each subscriber's line has three jacks in the Office multiple field: one for the exchange line, one for the subscriber's line and one for connecting these two lines by a plug when required.

R 4077 Fig. 2.

The first two jacks have each a call lamp and the last one a supervisory lamp, which can be connected or disconnected as desired.

The multiple field is also provided with trunk-line jacks and order wire speaking-keys for the various exchanges, as well as jacks and call lamps for record operator's circuits.

The boards have 3 cord-groups per operator, each consisting of 3 cords, one for replying to calls from the exchange, one for replying to calls from the subscriber, and one for connexions to the various exchanges. For each cord there is a combined listening and speaking key, and each operator's position has also 3 ringing keys, one for each kind of cord.

The Office, open day and night, will undertake the following services.

Reference Service.

The subscriber's line is connected to the Bureau, which will request calling parties to ring another number, or inform them of the subscriber's absence, his address while away, time of return, etc. all without making any note of the calling party's number or business, for a fee of,

per day or part of a day .... kr. 1: —
for 10 *consecutive* days or more,
up to a month .... ,, 10: —

Reference and Message Service.

The subscriber's line is connected to the Bureau, and short messages are given or received on his behalf, for a fee of,

per day or part of a day .... kr. 1: 50
for 15 *consecutive* days or more,
up to a month .... ,, 20: —

The Office keeps any notes intended for the subscriber *until asked for,* or forwards them by post at his expense, but does *not undertake to ring him up specially to give him the messages.*

Message Service.

Short messages (not exceeding 20 words in length) are communicated by telephone from a subscriber to one or more stated subscribers.

The Office will either keep the message until it is asked for, or ring a specified number to deliver the message, either immediately or after a stated time. If there is no reply from the addressee number when first called, the Bureau will ring up again at 30-minute intervals for two hours. After that time no further call is made.

For a message kept until called for, a fee is charged irrespective of the number of inquiries, of .... kr. 0: 50
and for messages to be telephoned, a fee for each addressee of .... kr. 0: 50

Calling Service.

The Office can be made use of to connect the subscriber's instrument with another specified number (a person cannot be inquired for by name) either immediately or at a certain definite time, for a fee each time of .... kr. 0: 10

If there is no reply from the number called, the Office will on special request undertake to repeat the call, though not more than four times, either at certain specified times or at 30-minute intervals for the succeeding two hours. An extra fee is charged for this of .... kr. 0: 20

Waking.

The Bureau will wake a subscriber by calling his number at a certain time, for a fee each time of .... kr. 0: 20
(That the number given is correct is checked on receipt of the order.)

Time-giving.

The official time will be given, for a fee each time of .... kr. 0: 10
(That the number given is correct is checked on receipt of the order.)


Från

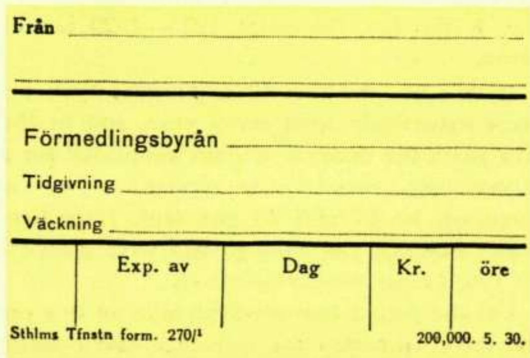
Hänvisning

Telefonvakt

	Förmedlingsbyrån Exp. av	Dag	Kr.	öre
		/		

Sthlms tfnstn form. 271/2. 30,000. 2. 31.

R 4050 Fig. 4.


Från

Förmedlingsbyrån

Tidgivning

Väckning

	Exp. av	Dag	Kr.	öre

Sthlms Tfnstn form. 270/1 200,000. 5. 30.

R 4049 Fig. 5.

The Stockholm Telephone Commissions Office.

The Telephone Commissions Bureau 1930.

Month	Reference Service			Reference and Message service			Message Service		Waking		Time giving		Total		
	days connected	debit cards	fees paid	days connected	debit cards	fees paid	debit cards	fees paid	debit cards	fees paid	debit cards	fees paid	days connected	debit cards	fees paid
Jan.	5 781	1 060	2 787: —	5 755	825	4 417: 90	8	3: 60	7 198	1 439: 60	7 369	736: 90	11 536	16 460	9 385: —
Feb.	4 444	897	2 074: 90	5 114	814	5 170: 10	8	3: 70	5 675	1 135: —	7 095	709: 50	9 588	14 489	9 093: 20
March ..	4 610	938	2 113: 10	5 784	918	4 513: 50	19	8: —	5 859	1 171: 80	7 451	745: 10	10 394	15 245	8 551: 50
April ..	5 435	1 220	2 674: —	6 150	1 051	4 953: 60	23	9: 60	5 159	1 031: 80	6 632	663: 20	11 585	14 085	9.332: 20
May	5 832	1 241	2 622: 20	6 505	1 105	5 050: 20	17	7: 90	6 459	1 291: 80	6 941	694: 10	12 341	15 763	9 666: 20
June	9 282	1 667	4 224: 70	9 746	1 417	7 387: —	13	4: 30	9 768	1 953: 60	6 504	650: 40	19 048	19 369	14 220: —
July	15 082	1 600	6 047: 30	13 606	1 783	10 218: —	10	4: 20	12 061	2 412: 20	6 226	622: 60	28 688	21 680	19 304: 30
Aug.	11 985	1 531	5 054: 50	12 434	1 572	9 552: 30	6	3: —	10 512	2 102: 40	6 704	670: 40	24 419	20 325	17 382: 60
Sept.	6 285	1 177	2 842: 30	7 568	1 110	5 869: —	14	5: 50	7 073	1 414: 60	6 948	694: 80	13 853	16 322	10 853: 20
Oct.	7 203	1 159	3 414: 70	6 917	1 007	5 288: 90	12	4: 40	6 120	1 224: —	7 103	710: 30	14 120	15 401	10 642: 30
Nov.	5 489	986	2 391: 90	6 075	800	4 570: 90	15	6: 70	6 709	1 341: 80	7 600	760: —	11 564	16 110	9 071: 30
Dec.	6 379	1 234	2 811: 50	6 269	908	4 668: 10	15	5: 90	9 410	1 882: —	8 392	839: 20	12 648	19 959	10 206: 70
Total	87 807	14 770	39 058: 10	91 957	13 310	71 686: 50	160	66: 80	92 008	18 400: 60	84 965	8 496: 60	179 764	205 208	137 708: 50
1929	82 458	12 981	38 933: 20	83 533	11 343	60 633: 10	86	43: —	79 035	15 767: 40	77 163	7 716: 30	165 991	180 608	123 093: —
1928	75 668	12 173	35 297: 60	78 295	10 709	59 066: 10	76	38: —	72 682	14 536: 40	73 723	7 372: 30	153 963	169 363	116 310: 40
1927	72 132	11 548	31 745: 55	77 935	10 252	50 220: 40	49	24: 50	66 417	13 283: 40	69 142	6 914: 20	150 067	157 408	111 188: 05
1926	66 762	10 754	29 520: 50	73 307	10 168	55 874: 20	—	—	62 157	12 431: 40	62 326	6 232: 60	140 060	145 395	104 058: 70
1925	69 209	10 329	29 344: 90	65 303	9 205	50 204: 25	—	—	54 714	10 967: 20	54 728	5 472: 90	134 599	129 026	95 989: 25

Fig. 6.

Debiting.

The supervisor debits the charge for the service when this is performed or, for a standing order, at the end of every month. Specification of the amount (debit card for reference, reference and message, and message services, and debit card for time-giving and waking, are illustrated in figs. 4 and 5) is sent to the subscriber with his ordinary telephone bill.

Extent of the Work.

Fig. 6 is a table giving the numbers of days *connected, debit cards, wakings, time-givings and* messages, and the fees debited for these during each month of the year 1930. In each column the totals for the years 1925—1929 are also given.

It will be seen that these services have been more extensively used every year, and in these five years the number of days connected for reference and reference and message services has increased by 27 and 40 per cent. respectively, while wakings and time-givings have grown by 68 and 44 per cent. respectively.

For the period January-September of this year, the days connected for reference and reference and message services have, in comparison with the same period of 1930, increased by 10 and 5 per cent. respectively, wakings by 6 per cent., and time-givings by 4 per cent.

Messages not combined with reference and messages are, on the other hand, but slightly used.

It may be of interest to see how the various commissions accepted by the Information Bureau are distributed on one day, and an investigation undertaken to ascertain this shows that on July 20th of this year these were:

Subscribers connected for extended periods of time:

Reference service 559
Reference and message service 450

Subscribers connected for one day or part of a day:

Reference service 23
Reference and message service .. 34
Total number of subscribers connected on 20/7/31 .... 1 066
on 20/7/31 .... 1 066
In addition there were .... 449 wakings
216 time-givings
and delivered .... 3 messages

All trades and professions were represented in the Office clientele. Some of the professions represented most numerously on that date are enumerated below:

Doctors	131
Business men	105
Dentists	94
Limited Companies	81
Engineers	60
Painters and Decorators	49
Directors and Managers	43
Wholesale Merchants	40
Architects	22
Lawyers	16
Professors	11
etc.	

The cost of the staff amounted to about 42 per cent. of the gross receipts.

R 1062 *Home of the Royal Swedish Telegraph Administration, Brunkebergstorg, Stockholm.*

The Stockholm Telephone Commissions Office.

Simplified methods of designing electric wave filters and a contribution to the theory of matching filter quadripoles.

Communication from the Research and Development Department.[1]

By *H. Sterky.*

Contents.

[1] Ms. received by the Editor Aug. 7th 1931.

Definitions.

f = arbitrary frequency.

f_1 = upper cut-off frequency, f_2 = lower cut-off frequency; $f_1 f_2 = f_{00}^2$.

$f_{00} = \sqrt{f_1 f_2}$ = geometric mean frequency.

f' = arbitrary frequency $> f_{00}$, f'' = „ „ $< f_{00}$; $f' f'' = f_{00}^2$

$\triangle = f_1 - f_2$ = absolute band width.

$x = \dfrac{f_1}{f_2}$ = relative band width.

$p = \dfrac{\triangle}{f_{00}}$ = percentual band width.

$\triangle' = f_1 - f_2$.

$y = \dfrac{f'}{f''}$.

$p' = \dfrac{\triangle'}{f_{00}}$.

Θ = quadripole propagation constant.

$\gamma = \beta + j\alpha$ = filter „ „ for one section.

β = attenuation constant for one section.

α = phase constant for one section.

b_D = effective attenuation.

a_1, a_2, b and c = quadripole quantities.

I_1 = open-circuit impedance at ′ end of quadripole.

I_2 = „ „ „ ″ end „ „

R_1 = short-circuit „ „ ′ end „ „

R_2 = „ „ „ ″ end „ „

A = quadripole impedance.

σ, σ' σ'' = position angles.

$\mathfrak{Z}'$ = image impedance at ′ end of quadripole.

$\mathfrak{Z}''$ = „ „ at ″ end „ „

R' = terminal load impedance at ′ end of quadripole.

R'' = „ „ „ at ″ end „ „

$\mathfrak{Z}'_B$ = impedance of loaded quadripole at ′ end.

$\mathfrak{Z}''_B$ = „ „ „ „ at ″ end.

ε = reflection coefficient.

z_1 = impedance of series arm.
z_2 = „ „ shunt arm.
$k = \sqrt{z_1 z_2}$ for "constant k" filter.
$U + jV = \frac{z_1}{4 z_2}$.
$U_k = \frac{z_1}{4 z_2}$ for "constant k" filter without losses.
$\mathfrak{Z}_T$ = midseries image impedance.
$\mathfrak{Z}_\pi$ = midshunt „ „
$\mathfrak{Z}_{T00}$ = value of $\mathfrak{Z}_T$ at f_{00}.
$\mathfrak{Z}_{\pi 00}$ = „ „ $\mathfrak{Z}_\pi$ „ „
R_T = load impedance at midseries termination.
R_π = „ „ „ midshunt „
$\mathfrak{Z}_{BT}$ = midseries impedance of loaded filter.
$\mathfrak{Z}_{B\pi}$ = midshunt impedance of loaded filter.
$a = \frac{R_\pi}{\mathfrak{Z}_{\pi 00}} = \frac{\mathfrak{Z}_{T00}}{R_T}$ = matching coefficient ($a > 1$).
m = m-derivation coefficient according to Zobel ($m < 1$).

1. Introductory Resumé.

The general equations determining the properties of a quadripole* have long been known from the theoretical works of among others Breisig, Campbell, Pleijel and Wagner. A special class of quadripoles, so called wave filters, are increasingly employed in telephony and wireless. A reference list of literature on the subject is given at the end of this article, for the benefit of readers who wish to study more closely the historical development and mathematical theories of filters. Wagner, Campbell and Zobel are the chief contributors to the practical computation methods for this kind of quadripoles, and have thus made a wider use of filters in electrotechnics possible.

The object of the present paper is to submit the results of a special investigation on the matching of filter image impedances, made by the author in designing apparatus for carrier current telephony and telegraphy. Zobel has published a method for matching filter image impedance and terminal load resistances, the method of "m-derivation", in which a number of elements—e. g. inductances or capacities or a combination of both—beyond the original number of the prototype filter must be introduced.

* Or four terminal network (U. S. A.).

According to the method described here, which has been designated a-matching, the filter image impedances and the terminal load resistances are more or less well matched without any increase of the number of elements in the filter prototype.

The importance of the results attained will hardly be made sufficiently evident by a mere account of the investigation. The first two chapters of this article will therefore be devoted to a resumé of the derivation of the fundamental equations on which all filter computations are based, although this will naturally involve a repetition of much that has been previously published.

In a following chapter, two fundamental filter conceptions, viz. load impedance and effective attenuation, are derived with the assistance of Kennelly's definitions of position angles; new formulæ are deduced for the computation of the effective attenuation of two different kinds of filters, which formulæ are characterized by the same simplicity and lucidity as those given by Kennelly for the relation of voltages and currents in recurrent networks. The new formulæ for effective attenuation are well adapted for practical use.

In a later chapter, the author has had an opportunity of deducing a simple formula for the computation of an auxiliary quantity in a certain type of band pass filter, the so-called "constant k" type, which is largely used by American, German and Swedish telephone concerns. This auxiliary quantity is of fundamental importance in the computation of attenuations, image impedances and load impedances in all-filters of this class. A mathematically simple and general method has thus been substituted for a previously tedious and troublesome calculation.

The later, and main part of the paper deals with a-matching, and formulæ are deduced for effective attenuation, load impedance and reflection coefficient in a-matched "constant k" filters. Finally, the advantages and drawbacks of a-matching are discussed, and suggestions made for further work on this subject.

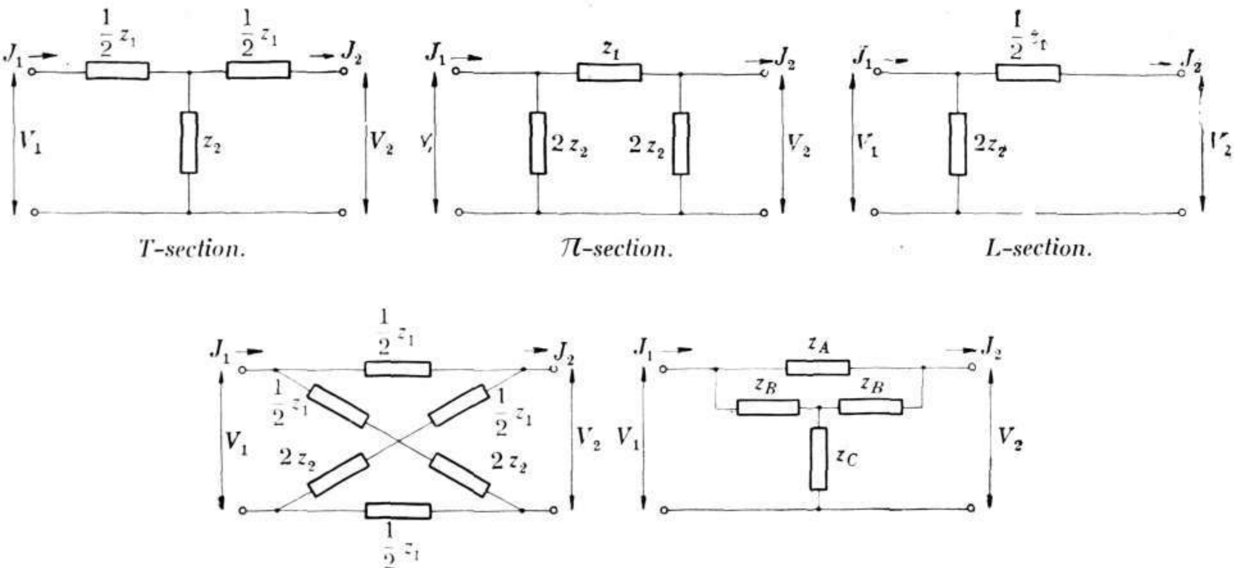
The grateful thanks of the author are due to Messrs. S. Herlitz and S. Rodhe, for their kind assistance in making certain numerical calculations.

2. Different forms of general equations for quadripoles.

All calculations regarding filters are based on the general quadripole equations. By a quadripole we mean an electrical network consisting of general impedances with or without E. M. F:s, and joined together at a number of points, of which four are accessible for measurements. The characteristic properties of a quadripole for two pairs of these points can be measured and computed if certain constants are known; these we will now determine.

From the beginning we will confine ourselves to a consideration of quadripoles of which no E. M. F:s or unidirectional impedances (thermionic valves) form part, but only ordinary impedances connected so as to form what is called *T*-, *Π*- or *L*-sections (see fig. 1), in which form electric wave-filters generally occur. This does ,not however, diminish the general validity of the deduction for other types of filter, for it is possible to show that other forms also, e. g. Lattice- and "Bridged-*T*"-sections, are equivalent to the *T*- and *Π*-sections[1] mentioned above. The *L*-section is to be regarded as half a *T*-or *Π*-section, and a knowledge of its characteristic properties will be useful for calculating those of an odd number of half *T*-or *Π*-sections.

[1] See Bibliography, 4.



T-section. *Π-section.* *L-section.*

Lattice-section *"Bridged-T"-section.*

Fig. 1.

A rectangle according to figure 2 is used as a general symbol for a filter quadripole. We

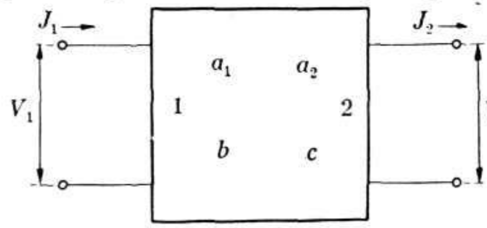


Fig. 2.

will now give a short summary of the German, Swedish, and Anglo-Saxon methods of designating the characteristic quantities of the quadripole and deducing its properties.

2 A. According to German praxis—Breisig and others.

Fig. 2 shows the quadripole with the four characteristic coefficients introduced by Breisig, a_1, a_2, b and c. If this quadripole is passive, i. e. contains no E. M. F:s or unidirectional impedances, the following three equations will give the relation between voltage and current in each of the two pairs of terminals 1 and 2.

$$\left.\begin{aligned} V_1 &= a_1 V_2 + b J_2 \\ J_1 &= a_2 J_2 + c V_2 \\ 1 &= a_1 a_2 - bc \end{aligned}\right\} \qquad (1)$$

Knowing the values of a_1, a_2 b, and c, and how the quadripole is connected, e. g. between an E. M. F. E with an internal impedance R' and a terminal load of impedance R'', we can obtain from (1) the voltages and currents V_1 and J_1 and V_2 and J_2 respectively. a_1, a_2, b, and c are calculated by Kirchoff's laws from the impedances forming the quadripole. As an example we will compute the impedance $\mathfrak{Z}_B'$ of the loaded quadripole, or the ratio of V_1 to J_1, when the quadripole is connected according to fig. 3. $\mathfrak{Z}_B'$ will in future be called the load impedance for short. We then have

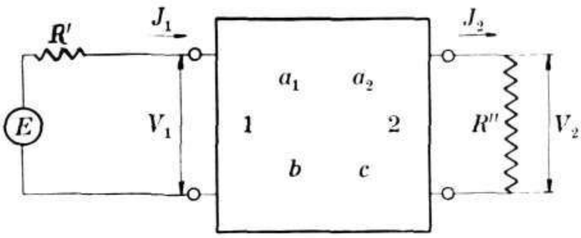


Fig. 3.

$$\left.\begin{aligned} V_1 &= a_1 V_2 + b J_2 \\ J_1 &= a_2 J_2 + c V_2 \\ E &= V_1 + R' J_1 \\ V_2 &= R'' J_2 \\ 1 &= a_1 a_2 - bc \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

From this we get

$$\mathfrak{Z}_B' = \frac{V_1}{J_1} = \frac{a_1 V_2 + b J_2}{a_2 J_2 + c V_2} = \frac{a_1 R'' + b}{a_2 + c R''} \quad \ldots\ldots\ldots (3)$$

The ratio of E to V_2—which is of great importance for calculating the so-called effective attenuation, of which more below—is also easily obtained from (2)

$$\frac{E}{V_2} = \frac{V_1 + R' J_1}{V_2} = \frac{a_1 V_2 + b J_2 + R' (a_2 J_2 + c V_2)}{V_2}$$

whence

$$\frac{E}{V_2} = a_1 + a_2 \frac{R'}{R''} + \frac{b}{R''} + c R_1 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

2 B. According to Swedish praxis—Pleijel.

According to (82) in Pleijel's "Telefonledningars elektriska egenskaper",[1] and with symbols as in fig. 4, the general equations for a passive asymmetrical quadripole will be as follows:

$$\left.\begin{aligned} V_1 &= I_1 J_1 - A J_2 \\ V_2 &= A J_1 - I_2 J_2 \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

[1] See Bibliography, 2.

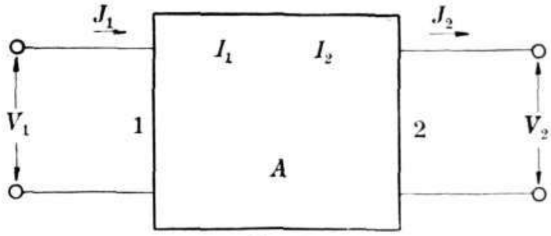


Fig. 4.

or, if V_1 and J_1 are solved from (5)

$$\left.\begin{aligned} V_1 &= \frac{I_1}{A} V_2 + \left(\frac{I_1 I_2}{A} - A\right) J_2 \\ J_1 &= \frac{I_2}{A} J_2 + \frac{1}{A} V_2 \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots (6)$$

In these equations I_1 and I_2 are the open circuit impedances of the quadripole measured from the input side 1 or output side 2. This can easily be verified by making $J_1 = 0$ or $J_2 = 0$, when equation 5 gives us

$$\left.\begin{aligned} \left(\frac{V_2}{-J_2}\right)_{J_1=0} &= I_2 \\ \left(\frac{V_1}{J_1}\right)_{J_2=0} &= I_1 \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

(5) and (6) are further simplified by introducing the short circuit impedances R_1 and R_2. These are obtained from (6) by making $V_1 = 0$ and $V_2 = 0$.

$$\left.\begin{aligned} \left(\frac{V_2}{-J_2}\right)_{V_1=0} &= R_2 = I_2 - \frac{A^2}{I_1} \\ \left(\frac{V_1}{J_1}\right)_{V_1=0} &= R_1 = I_1 - \frac{A^2}{I_2} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (8)$$

whence also the formula, important for asymmetrical quadripoles

$$\frac{I_1}{I_2} = \frac{R_1}{R_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (9)$$

Thus instead of (6) we get the following simplified pair of equations:

$$\left.\begin{aligned} V_1 &= \frac{I_1}{A} V_2 + \frac{I_1 R_2}{A} J_2 \\ J_1 &= \frac{I_2}{A} J_2 + \frac{1}{A} V_2 \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (10)$$

and are able to find the relation between a_1, a_2, b, and c in (1) and I_1, I_2, R_1, R_2 and A in (10).

We further introduce the propagation constant Θ of the quadripole and the two impedances $\mathfrak{Z}'$ and $\mathfrak{Z}''$ which we define as the image impedances of the quadripole at the input (′) and output (″) ends. According to p. 118 et seq. in "Telefonledningars elektriska egenskaper" we have:

$$\left.\begin{aligned} \mathfrak{Z}' &= \sqrt{R_1\, I_1} \\ \mathfrak{Z}'' &= \sqrt{R_2\, I_2} \\ \operatorname{tgh} \Theta &= \sqrt{\frac{R_1}{I_1}} = \sqrt{\frac{R_2}{I_2}} \end{aligned}\right\} \quad \cdots\cdots\cdots\cdots\cdots (11)$$

From (8), (9), and (11) we get:

$$\begin{aligned} A_2 &= I_1\,(I_2 - R_2) = \frac{\sqrt{R_2\, I_2}\,\sqrt{R_1\, I_1}}{\sqrt{R_2\, I_2\, R_1}}\,\sqrt{I_1}\,(I_2 - R_2) \\ &= \frac{\mathfrak{Z}'\,\mathfrak{Z}''}{\sqrt{R_1 R_2}}\,\sqrt{\frac{R_1}{R_2}}\,(I_2 - R_2) = \mathfrak{Z}'\,\mathfrak{Z}''\,\frac{I_2}{R_2}\left(1 - \frac{R_2}{I_2}\right) \\ &= \mathfrak{Z}'\,\mathfrak{Z}''\,\frac{1 - \operatorname{tgh}^2 \Theta}{\operatorname{tgh}^2 \Theta} \end{aligned}$$

or

$$A = \frac{\sqrt{\mathfrak{Z}'\,\mathfrak{Z}''}}{\sinh \Theta} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (12)$$

and

$$\left.\begin{aligned} \cosh \Theta &= \frac{\sqrt{I_1\, I_2}}{A} \\ \sinh \Theta &= \frac{\sqrt{I_1\, R_2}}{A} = \frac{\sqrt{I_2\, R_1}}{A} \end{aligned}\right\} \quad \cdots\cdots\cdots\cdots\cdots (13)$$

2 C. According to Anglo-Saxon praxis—Kennelly and others.

Using hyperbolic functions, the general equations for an asymmetrical passive quadripole can, according to Kennelly, be written as follows:

$$\left.\begin{aligned} V_1 &= \sqrt{\frac{\mathfrak{Z}'}{\mathfrak{Z}''}}\cosh \Theta\; V_2 + \sqrt{\mathfrak{Z}'\,\mathfrak{Z}''}\sinh \Theta\; J_2 \\ J_1 &= \sqrt{\frac{\mathfrak{Z}''}{\mathfrak{Z}'}}\cosh \Theta\; J_2 + \frac{1}{\sqrt{\mathfrak{Z}'\,\mathfrak{Z}''}}\sinh \Theta\; V_2 \end{aligned}\right\} \quad \ldots (14)$$

When a quadripole is connected between two impedances R' and R'' as fig. 5, the calculations are in certain cases simplified by introducing what are called position angles. The position angle

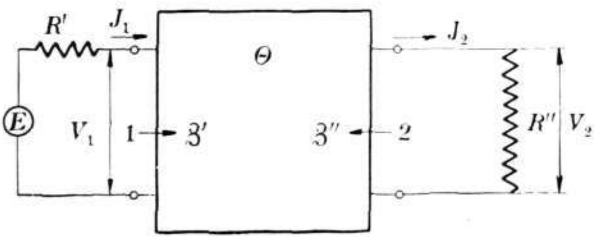


Fig. 5.

σ for the terminal load impedance R'', for instance, is defined by the equation.

$$\operatorname{tgh} \sigma = \frac{R''}{\mathfrak{Z}''} \quad \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots (15)$$

where $\mathfrak{Z}''$ is the image impedance of the quadripole at the ″-end.

If σ is introduced in (14), the following simple expression is obtained for voltages and currents:

$$\left.\begin{aligned} \frac{V_1}{V_2} &= \sqrt{\frac{\mathfrak{Z}'}{\mathfrak{Z}''}}\,\frac{\sinh(\Theta+\sigma)}{\sinh \sigma} \\ \frac{J_1}{J_1} &= \sqrt{\frac{\mathfrak{Z}''}{\mathfrak{Z}'}}\,\frac{\cosh(\Theta+\sigma)}{\cosh \sigma} \end{aligned}\right\} \quad \cdots\cdots\cdots\cdots\cdots\cdots (16)$$

2 D. Relation between quadripole quantities according to different methods.

The following table I has been drawn up to help in the study of the available literature on filters from different countries. In this the various quantities characterizing the quadripole according to German, Swedish, and Anglo-Saxon methods described above are given, with the relations existing between them.

3. Deduction of filter equations.

Fig. 6 represents a *T*-section and a *Π*-section, and the filter chains of infinite length that can be formed from them.

When the open circuit and short circuit impedances of the *T*- and *Π*-sections respectively are computed, in terms of the impedances z_1 of the series arms and z_2 of the shunt arms, it is also possible to obtain the value of the quantity A from (8). All the quantities in (10) are then known and can be put in. If these calculations are made, the general equations for the *T*- and *Π*-sections are obtained.

T-section.

$$\left.\begin{aligned} I &= I_1 = I_2 = \frac{z_1}{2} + z_2 \\ R &= R_1 = R_2 = \frac{z_1\, z_2\left(1 + \dfrac{z_1}{4 z_2}\right)}{\dfrac{z_1}{2} + z_2} \\ A &= z_2 \end{aligned}\right\} \quad \cdots\cdots\cdots (17)$$

TABLE I.

The relation between various quadripole quantities.

	German method	Swedish method	Anglo-Saxon method
German method	a_1	$\frac{I_1}{A}$	$\sqrt{\frac{\mathfrak{Z}'}{\mathfrak{Z}''}}\cosh\Theta$
	a_2	$\frac{I_2}{A}$	$\sqrt{\frac{\mathfrak{Z}''}{\mathfrak{Z}'}}\cosh\Theta$
	b	$\frac{I_1 R_2}{A}=\frac{I_2 R_1}{A}$	$\sqrt{\mathfrak{Z}'\mathfrak{Z}''}\sinh\Theta$
	c	$\frac{1}{A}$	$\frac{1}{\sqrt{\mathfrak{Z}'\mathfrak{Z}''}}\sinh\Theta$
	$a_1 a_2 - bc = 1$	$\begin{cases} I_1(I_2-R_2)=A^2 \\ I_2(I_1-R_1)=A^2 \end{cases}$	$\cosh^2\Theta-\sinh^2\Theta=1$
Swedish method	$\frac{a_1}{c}$	I_1	$\frac{\mathfrak{Z}'}{\operatorname{tgh}\Theta}$
	$\frac{a_2}{c}$	I_2	$\frac{\mathfrak{Z}''}{\operatorname{tgh}\Theta}$
	$\frac{b}{a_2}$	R_1	$\mathfrak{Z}'\operatorname{tgh}\Theta$
	$\frac{b}{a_1}$	R_2	$\mathfrak{Z}''\operatorname{tgh}\Theta$
	$\frac{1}{c}$	A	$\frac{\sqrt{\mathfrak{Z}'\mathfrak{Z}''}}{\sinh\Theta}$
Anglo-Saxon method	$\sqrt{\frac{a_1}{a_2}}\sqrt{\frac{b}{c}}$	$\sqrt{R_1 I_1}$	$\mathfrak{Z}'$
	$\sqrt{\frac{a_2}{a_1}}\sqrt{\frac{b}{c}}$	$\sqrt{R_2 I_2}$	$\mathfrak{Z}''$
	$\sqrt{bc}$	$\frac{\sqrt{I_1 R_2}}{A}=\frac{\sqrt{I_2 R_1}}{A}$	$\sinh\Theta$
	$\sqrt{a_1 a_2}$	$\frac{\sqrt{I_1 I_2}}{A}$	$\cosh\Theta$
	$\sqrt{\frac{bc}{a_1 a_2}}=\sqrt{1-\frac{1}{a_1 a_2}}$	$\sqrt{\frac{R_1}{I_1}}=\sqrt{\frac{R_2}{I_2}}$	$\operatorname{tgh}\Theta$

$$\left.\begin{aligned} V_1 &= \left(1+\frac{z_1}{2z_2}\right)V_2 + z_1\left(1+\frac{z_1}{4z_2}\right)J_2 \\ J_1 &= \left(1+\frac{z_1}{2z_2}\right)J_2 + \frac{1}{z_2}V_2 \end{aligned}\right\} \quad \ldots (18)$$

chain of similar T-sections, as in fig. 6. The load on such a link is $\mathfrak{Z}_T$ the mid-series image impedance of the infinite chain. The insertion of the filter link under consideration will not change

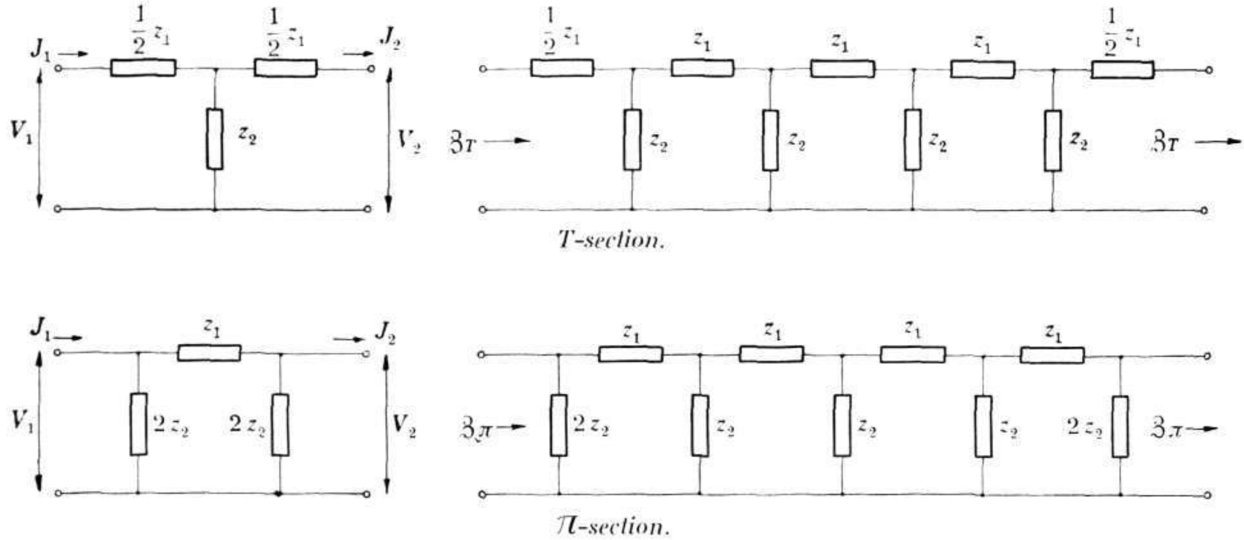


Fig. 6.

the mid-series image impedance of the chain, and hence we get

$$\mathfrak{Z}_T = \frac{z_1}{2} + \frac{\left(\frac{z_1}{2}+\mathfrak{Z}_T\right)z_2}{\frac{z_1}{2}+\mathfrak{Z}_T+z_2} \quad \ldots\ldots (21)$$

from which we solve

$$\mathfrak{Z}_T = \sqrt{z_1 z_2}\sqrt{1+\frac{z_1}{4z_2}} \quad \ldots\ldots (22)$$

For the π-section we get in the same way

$$\mathfrak{Z}_\pi = \frac{\sqrt{z_1 z_2}}{\sqrt{1+\frac{z_1}{4z_2}}} \quad \ldots\ldots (23)$$

The filter propagation constant γ for one section is defined as the natural logarithm of the square root of the ratio $\frac{P_1}{P_2}$, where P_1 is the power fed into, and P_2 the power taken out of, the filter section.

$$\therefore \gamma = \log_e \sqrt{\frac{P_1}{P_2}} \quad \ldots\ldots (24)$$

As $P_1 = \frac{V_1^2}{\mathfrak{Z}_T}$ and $P_2 = \frac{V_2^2}{\mathfrak{Z}_T}$ we get $e^\gamma = \frac{V_1}{V_2}$

The ratio $\frac{V_1}{V_2}$ is obtained directly by applying Kirchhoff's laws to the T-section in fig. 6.

π-section.

$$\left.\begin{aligned} I &= I_1 = I_2 = \frac{\frac{z_1}{2}+z_2}{1+\frac{z_1}{4z_2}} \\ R &= R_1 = R_2 = \frac{z_1 z_2}{\frac{z_1}{2}+z_2} \\ A &= \frac{z_2}{1+\frac{z_1}{4z_2}} \end{aligned}\right\} \quad \ldots\ldots (19)$$

$$\left.\begin{aligned} V_1 &= \left(1+\frac{z_1}{2z_2}\right)V_2 + z_1 J_2 \\ J_1 &= \left(1+\frac{z_1}{2z_2}\right)J_2 + \frac{1+\frac{z_1}{4z_2}}{z_2}V_2 \end{aligned}\right\} \quad \ldots\ldots (20)$$

With the help of the transformation formulæ in Table I, it is possible also to calculate, from (17) and (19), the mid-series and mid-shunt image impedances $\mathfrak{Z}_T$ and $\mathfrak{Z}_\pi$ respectively, of the T- and π-sections, and the filter propagation constant γ. There is however, a simpler and more direct way, which is given in detail by Zobel and others. In making this calculation for, say, the T-section, we assume this to form one link in an infinite

$$V_1 = V_2 + \frac{z_1}{2}\frac{V_2}{\mathfrak{Z}_T} + \frac{z_1}{2}\left[\frac{V_2}{\mathfrak{Z}_T} + \frac{V_2 + \frac{z_1}{2}\frac{V_2}{\mathfrak{Z}_T}}{z_2}\right]$$

and hence, using also (22)

$$e^{\gamma} = \frac{V_1}{V_2} = 1 + \frac{z_1}{2 z_2} + \sqrt{\frac{z_1}{z_2}}\sqrt{1 + \frac{z_1}{4 z_2}} \quad \ldots \; (25)$$

A simpler expression for γ is obtained with hyperbolic functions. We have

$$\cosh \gamma = \frac{e^{\gamma} + e^{-\gamma}}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \; (26)$$

By comparing equations (25) and (26) we get, after some intermediate calculations,

$$\cosh \gamma = 1 + \frac{z_1}{2 z_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \; (27)$$

The same expression is obtained in an analogous way for a Π-section.

We will now introduce some expressions which in certain cases may considerably simplify the calculations for filters; for this purpose we make

$$\frac{z_1}{4 z_2} = U + jV. \quad \ldots\ldots\ldots\ldots\ldots\ldots \; (28)$$

for in the general case the relation $\frac{z_1}{z_2}$ is complex, and we then obtain

$$\left.\begin{aligned} \mathfrak{Z}_T &= \sqrt{z_1 z_2}\sqrt{1 + U + jV} \\ \mathfrak{Z}_\pi &= \frac{\sqrt{z_1 z_2}}{\sqrt{1 + U + jV}} \\ \cosh \gamma &= 1 + 2\,(U + jV) \\ \sinh \gamma &= 2\sqrt{U + jV}\,\sqrt{1 + U + jV} \end{aligned}\right\} \ldots\ldots \; (29\,a)$$

In practice, when doing filter calculations, one generally assumes the impedances forming the series- and shunt-arms to be non-dissipative. On this assumption, z_1 and z_2 will be purely imaginary, and the ratio $\frac{z_1}{z_2}$ will then be real; and the formulæ (29 a) may consequently be simplified to

$$\left.\begin{aligned} \mathfrak{Z}_T &= \sqrt{z_1 z_2}\,\sqrt{1 + U} \\ \mathfrak{Z}_\pi &= \frac{\sqrt{z_1 z_2}}{\sqrt{1 + U}} \\ \cosh \gamma &= 1 + 2\,U \\ \sinh \gamma &= 2\sqrt{U} \cdot \sqrt{1 + U} \end{aligned}\right\} \ldots\ldots\ldots\ldots \; (29\,b)$$

Above (p. 8) we have pointed out that half T- or Π-sections are identical. The filter propagation constant for such a half section—what is called an L-section—can be shown to be $\frac{\gamma}{2}$, if γ be the corresponding constant for a whole T- or Π-section. For the L-section (fig. 7) the following equations are obtained

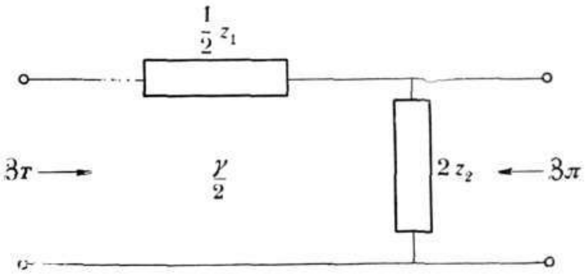


Fig. 7.

$$\left.\begin{aligned} \mathfrak{Z}_T &= \sqrt{z_1 z_2}\,\sqrt{1 + U} \\ \mathfrak{Z}_\pi &= \frac{\sqrt{z_1 z_2}}{\sqrt{1 + U}} \\ \cosh \frac{\gamma}{2} &= \sqrt{1 + U} \\ \sinh \frac{\gamma}{2} &= \sqrt{U} \end{aligned}\right\} \ldots\ldots\ldots\ldots \; (30)$$

As we have already mentioned (p. 7) there is a certain group of filters called the "constant k" group. In this, $\sqrt{z_1 z_2}$ is a constant (whence the name) independent of the frequency

$$\sqrt{z_1 z_2} = k \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (31)$$

If this value is substituted in (29 b) or (30), we find that the mid-series and mid-shunt image impedances, as well as the filter propagation constant, are determined exclusively by the value of U or U_k in this case. Later we will show that other properties, such as load impedances, effective attenuation, and others, may also be expressed as functions of U_k. The calculation of U or U_k as a function of the frequency is therefore of fundamental importance to calculations of filters.

4. Two fundamental filter conceptions.

4 A. Load impedance.

In chapter 2 A, we found a way of computing the load impedance of a quadripole. We will now examine a little more closely the calculation of the same quantity for a filter. When filters are used in practical electrotechnics, it often happens that their impedances have to be matched to one another or to a generator or load having a given impedance. The reflection coefficient

$$\varepsilon = \left| \frac{\mathfrak{Z}_B - \mathfrak{Z}}{\mathfrak{Z}_B + \mathfrak{Z}} \right| \quad \ldots\ldots\ldots\ldots\ldots \quad (32)$$

is a measure of the accuracy of this matching and in this equation $\mathfrak{Z}_B$ is the impedance of the loaded filter—the load impedance—and $\mathfrak{Z}$ the arbitrary impedance to be matched. To calculate this reflection coefficient it is therefore necessary to know $\mathfrak{Z}_B$, the load impedance of the filter.

In other instances also it is useful to have an expression for the load impedance, particularly in series or parallel connexion of filters passing different frequencies, when by judicious designing of the filters, they can be exellently matched with a line, i. e. the resultant impedance of the connected filters be made practically ohmic at all frequencies.

The load impedance of a filter is defined as the ratio of voltage to current at the input, or output, side of the filter, when its output, or input, side is loaded with a certain known impedance. With the aid of Breisig's formulæ (p. 9) we have already found an expression for the load impedance of a quadripole at the ′-end.

$$\mathfrak{Z}_B' = \frac{V_1}{J_1} = \frac{a_1 R'' + b}{a_2 + cR''} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

By exchanging input and output sides, we find instead the load impedance at the ″-end.

$$\mathfrak{Z}_B'' = \frac{V_2}{-J_2} = \frac{a_2 R' + b}{a_1 + cR'}, \text{ since } \frac{V_1}{-J_1} = R' \quad (33)$$

The values of the load impedances $\mathfrak{Z}_B'$, $\mathfrak{Z}_B''$ expressed by the Swedish and Anglo-Saxon methods respectively, may be obtained in an analogous way, or from Table I, and will be:

$$\left. \begin{aligned} \mathfrak{Z}_B' &= \frac{I_1 (R'' + R_2)}{I_2 + R''} \\ \mathfrak{Z}_B'' &= \frac{I_2 (R' + R_1)}{I_1 + R'} \end{aligned} \right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (34)$$

respectively

$$\left. \begin{aligned} \mathfrak{Z}_B' &= \mathfrak{Z}' \frac{R'' + \mathfrak{Z}'' \operatorname{tgh} \Theta}{\mathfrak{Z}'' + R'' \operatorname{tgh} \Theta} = \mathfrak{Z}' \operatorname{tgh} (\Theta + \sigma'') \\ \mathfrak{Z}_B'' &= \mathfrak{Z}'' \frac{R' + \mathfrak{Z}' \operatorname{tgh} \Theta}{R' \operatorname{tgh} \Theta + \mathfrak{Z}'} = \mathfrak{Z}'' \operatorname{tgh} (\Theta + \sigma') \end{aligned} \right\} (35)$$

in which - - - - - -

$$\left. \begin{aligned} \operatorname{tgh} \sigma' &= \frac{R'}{\mathfrak{Z}'} \\ \operatorname{tgh} \sigma'' &= \frac{R''}{\mathfrak{Z}''} \end{aligned} \right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (36)$$

according to the definitions introduced by Kennelly. (35) affords the most suitable means for calculating the load impedance of an arbitrary filter, as it will only be necessary to find the angles σ' and σ'' and the total angle Θ for the filter, to get the ratio of the desired load impedance $\mathfrak{Z}_B$ to the image impedance $\mathfrak{Z}$. As an example we will work out the load impedance of an *L*-section as in fig. 8, which we assume to be of the "con-

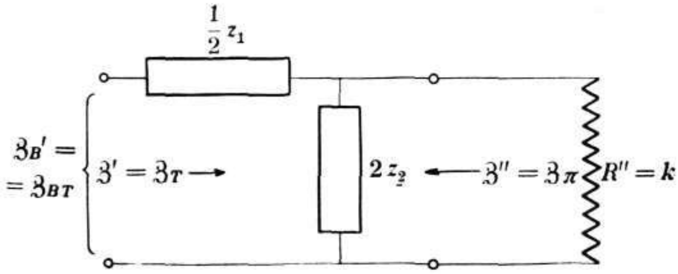


Fig. 8.

stant k" type—for which $k = \sqrt{z_1 z_2}$—and loaded with an ohmic resistance $R'' = k$. According to (30) we then have:

$$\mathfrak{Z}' = \mathfrak{Z}_T = k \sqrt{1 + U_k}$$

$$\mathfrak{Z}'' = \mathfrak{Z}_\pi = \frac{k}{\sqrt{1 + U_k}}$$

$$\operatorname{tgh} \frac{\gamma}{2} = \sqrt{\frac{U_k}{1 + U_k}}$$

whence:

$$\operatorname{tgh} \sigma'' = \frac{R''}{\mathfrak{Z}''} = \sqrt{1 + U_k}$$

$$\mathfrak{Z}_B' = \mathfrak{Z}_{BT} = \mathfrak{Z}_T \frac{\operatorname{tgh} \frac{\gamma}{2} + \operatorname{tgh} \sigma''}{1 + \operatorname{tgh} \frac{\gamma}{2} \operatorname{tgh} \sigma''}$$

and thus

$$\mathfrak{Z}_{BT} = k \sqrt{1 + U_k} \, \frac{\sqrt{\frac{U_k}{1 + U_k}} + \sqrt{1 + U_k}}{1 + \frac{\sqrt{U_k} \sqrt{1 + U_k}}{\sqrt{1 + U_k}}}$$

$$\mathfrak{Z}_{BT} = k\, \frac{1 + U_k + \sqrt{U_k}}{1 + \sqrt{U_k}} \quad \ldots\ldots \; (37)$$

In the same way we obtain the mid-shunt load impedance $\mathfrak{Z}_{B\pi}$.

$$\mathfrak{Z}_{B\pi} = k\, \frac{1 + \sqrt{U_k}}{1 + U_k + \sqrt{U_k}} \quad \ldots\ldots \; (38)$$

(37) and (38) show that the load impedances of the "constant k" class can also be expressed solely as functions of the variable U_k, which thus again proves to be of fundamental importance. We also see that $\mathfrak{Z}_{BT}$ and $\mathfrak{Z}_{B\pi}$ vary inversely when there is variation of the frequency or U_k, i. e. we have $\mathfrak{Z}_{BT} \cdot \mathfrak{Z}_{B\pi} = k^2$. This is a very important property of this group of filter and is just the reason for its having been so excessively used, for instance in two wire repeaters with differential transformer.[1]

4 B. Effective attenuation.

Above we have learnt how to define the propagation constant γ of a filter section. Knowing the value of this, it is possible to work out the ratio of the outgoing to the incoming voltage or current in a filter section, for

$$V_2 = V_1\, e^{-\gamma} \qquad J_2 = J_1\, e^{-\gamma} \quad \ldots\ldots\ldots\ldots\ldots\ldots \; (39)$$

These equations for the voltage and current are, however, only valid on the assumption that the filter section forms part of an infinite chain of identical sections or, in other words, for a single section, that this is connected between a generator impedance and a terminal load impedance each of which is at all frequencies equal to the image impedances of the section on its corresponding sides. Such an ideal condition never occurs in practice, as generally both the internal impedance of the generator and the terminal load impedance are constant ohmic resistances. In the general case, it will only be possible at one, or in certain cases two—of which more in Ch. 6—to design the filter section so that its image impedances will be identical with generator and terminal load impedances respectively. At all other frequencies the matching will not be ideal, and reflections will therefore occur. These will cause additional attenuations, which in certain cases impair, in others improve, the frequency-selective properties of the filter. In practice it is of great importance to have an unambiguous definition of the effective attenuation of the filter, taking just these reflections into account. For this effective attenuation we will henceforth use the symbol b_D.

The effective attenuation b_D of a given filter is defined as the natural logarithm of the ratio of the square root of the maximum power, P_{2fmax}, which a given E. M. F. E can supply to the terminal load impedance before the filter is connected in, to the root of the power, P_2, obtained in the terminal load impedance after the filter is connected in (see fig. 9).

$$b_D = \log_e \sqrt{\frac{P_{2f\max}}{P_2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \; (40)$$

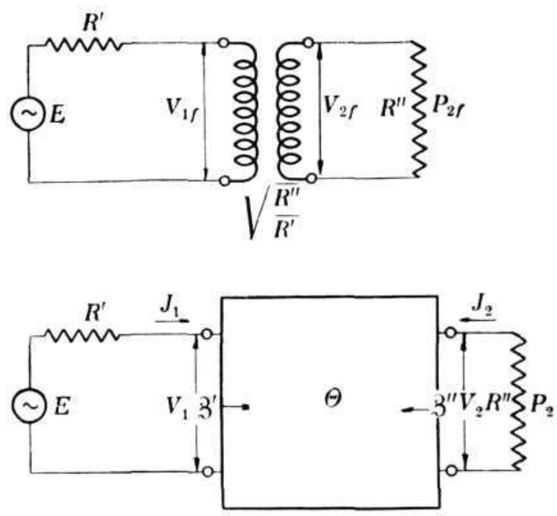


Fig. 9.

By expressing the effective attenuation like this in terms of the maximum power that a given terminal load impedance R'' can draw from a given generator of internal impedance R', we get a definition which can also be used for calculating the effective attenuation of a filter with transformation or for a filter connected in cascade to a transformer. In that case, the filter is assumed to consist of an ideal transformer, i. e. a transformer with no magnetic leakage, infinite induc-

[1] See Swedish patent applications by M. Vos and T. Laurent 5107/29, 1835/30, and M. Vos 4509/30.

tance, no losses and a ratio $\sqrt{\frac{R''}{R'}}$, and the right number of impedance elements to give the frequency-selective property of the filter. These elements may or may not form part of the ideal transformer. Defined in this way, the effective attenuation will exclusively determine the function of the filter as such, and is therefore independent of how the external impedances can be matched by transformation. This is of special importance in measurements, when the adjustment of and losses in the inductances and capacities of the filter elements have to be checked. Calculations too are helped by this definition, as in the general case they can easily be brought back to calculations of the effective attenuation of a filter without transformation.

The powers are calculated on the assumption that the impedances R' and R'' are ohmic, which is usually the case in actual practice (cf. Chap. 6). We get:

$$P_{2f} = \left(\frac{E}{R' + \frac{R'}{R''} R''} \right)^2 \frac{R'}{R''} R''.$$

and hence $P_{2f\max} = \frac{E^2}{4\,R'}$

In addition, $P_2 = \frac{V_2^2}{R''}$,

and hence

$$b_D = \log_e \left| \frac{E}{2\,V_2} \right| \sqrt{\frac{R''}{R'}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(41)}$$

According to (4):

$$\left| \frac{E}{V_2} \right| = \left| a_1 + a_2 \frac{R'}{R''} + \frac{b}{R''} + cR' \right|, \quad \ldots\ldots\ldots \text{(4)}$$

whence finally

$$b_D = \log_e \frac{1}{2} \left| \left[a_1 \sqrt{\frac{R''}{R'}} + a_2 \sqrt{\frac{R'}{R''}} + \frac{b}{\sqrt{R'\,R''}} + c\sqrt{R'\,R''} \right] \right| \ldots \text{(42)}$$

Using hyperbolic functions, the expression for the effective attenuation given in (42) can be written (cf. Chap. 2 D)

$$b_D = \log_e \frac{1}{2} \left| \left[\left(\sqrt{\frac{R''}{R'}} \sqrt{\frac{\mathfrak{Z}'}{\mathfrak{Z}''}} + \sqrt{\frac{R'}{R''}} \sqrt{\frac{\mathfrak{Z}''}{\mathfrak{Z}'}} \right) \cosh\Theta + \left(\frac{\sqrt{\mathfrak{Z}'\,\mathfrak{Z}''}}{\sqrt{R'\,R''}} + \frac{\sqrt{R'\,R''}}{\sqrt{\mathfrak{Z}'\,\mathfrak{Z}''}} \right) \sinh\Theta \right] \right| \quad \text{(43)}$$

On certain assumptions, this expression can be simplified still more.

We will discuss two cases, namely *symmetrical filters*, in which, when the frequency $\mathfrak{Z}'$ and $\mathfrak{Z}''$ varies proportionally, and *asymmetrical filters*, in which $\mathfrak{Z}'$ and $\mathfrak{Z}''$ vary inversely, i. e. their product is a constant real quantity k^2.

In the general case, when the filter includes *transformation*, the image impedances $\mathfrak{Z}'$ and $\mathfrak{Z}''$ may be of quite different orders of magnitude in both symmetrical and asymmetrical filters. If, for example, we represent the values of $\mathfrak{Z}'$ and $\mathfrak{Z}''$ at the frequency f_{oo} by $\mathfrak{Z}_{oo}'$ and $\mathfrak{Z}_{oo}''$, the transformation in the filter is given by the transformation coefficient $\mu^2 = \frac{\mathfrak{Z}_{oo}''}{\mathfrak{Z}_{oo}'}$.

4 Ba. Symmetrical filters.

In a symmetrical filter $\mathfrak{Z}'$ and $\mathfrak{Z}''$ vary proportionally when the frequency varies, and we may therefore put

$$\mathfrak{Z}' = n^2\,\mathfrak{Z}'' \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(44a)}$$

where n is a real number independent of the frequency.

The matching of the terminal load impedances R' and R'' at the generator side and loaded side with the image impedances $\mathfrak{Z}'$ and $\mathfrak{Z}''$ may be selected arbitrarily. Filters are however, usually designed by making R' and R'' equal to the values of $\mathfrak{Z}'$ and $\mathfrak{Z}''$ respectively at a given frequency, in most cases the geometric mean frequency f_{oo} in a band filter.

The problem of matching will be discussed in greater detail in a later chapter. Here we will only show that the general expression for the effective attenuation (43) can under certain circumstances be simplified. These circumstances involve the assumption of a constant ratio of the terminal load impedance R', on the generator side, to the input image impedance $\mathfrak{Z}'$ of the filter, and of the terminal load impedance R'' to the output image impedance $\mathfrak{Z}''$ of the filter i. e.

$$\frac{R'}{\mathfrak{Z}'} = \frac{R''}{\mathfrak{Z}''}, \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(45)}$$

or according to (44 a)

$$R' = n^2\,R'' \quad \ldots\ldots\ldots\ldots\ldots \text{(44b)}$$

If in addition, like Kennelly, we introduce as in (36) a position angle σ defined as follows

$$\text{tgh}\ \sigma = \frac{R''}{\mathfrak{Z}''},$$

we get, according to (45):

$$\text{tgh}\ \sigma = \frac{R''}{\mathfrak{Z}''} = \frac{R'}{\mathfrak{Z}'} \quad \text{.......................... (46)}$$

On substituting this in (43), we get

$$b_D = \log_e \frac{1}{2} \left| \left[2 \cosh \Theta + \left(\frac{1}{\text{tgh}\ \sigma} + \text{tgh}\ \sigma \right) \sinh \Theta \right] \right|$$

or

$$\boxed{b_D = \log_e \left| \frac{\sinh (\Theta + 2\sigma)}{\sinh 2\sigma} \right|} \quad \text{...... (47)}$$

4 Bb. Asymmetrical filters with $\mathfrak{Z}' \mathfrak{Z}'' = k^2$.

In certain asymmetrical filters the input image impedance $\mathfrak{Z}'$ varies inversely as the output image impedance $\mathfrak{Z}''$, i. e. the product of these impedances is a constant, real quantity, independent of the frequency, that is

$$\mathfrak{Z}' \mathfrak{Z}'' = k^2 \quad \text{.................................. (48a)}$$

This property is not uncommon in filters composed of a number of whole or half sections. For a certain group, viz. the "constant k" filters mentioned above, the two image impedances $\mathfrak{Z}'$ and $\mathfrak{Z}''$ vary inversely even in a half or L-section, as is indicated for instance by (30) and (31).

The general expression for the effective attenuation (43) can be simplified for asymmetrical filters satisfying condition (48 a), if we presume the generator impedance R' and the terminal load impedance R'' to be selected so that we also have

$$R' R'' = k^2 \quad \text{.................................. (48)}$$

We introduce the position angle σ here too, and with the help of (48 a) and (48 b) we get

$$\text{tgh}\ \sigma = \frac{R''}{\mathfrak{Z}''} = \frac{\mathfrak{Z}'}{R'} \quad \text{............................ (49)}$$

Finally, on substituting in (43) we get

$$\boxed{b_D = \log_e \left| \frac{\cosh (\Theta + 2\sigma)}{\sinh 2\sigma} \right|} \quad \text{...... (50)}$$

These two equations, (47) and (50), show that the definition chosen for the effective attenuation is particularly suitable, for even if the filters do have transformation, this will disappear from the formulæ for the effective attenuation. Only the complex angle Θ and an auxiliary angle σ, as defined in (46) or (49), will enter into the calculations. We shall see later how these calculations are worked out in practice.

The effective attenuation formulæ (47) and (50) are of the same general type as Kennelly used in calculations with position angles. *We have thus proved that position angles may with advantage be used for calculating effective attenuations also.*

Before going on to the calculation of certain much used filter types, we will make a little more detailed comparison between the various definitions of the effective attenuation b_D used in electrotechnics up to now.

In "Telefonledningarnas elektriska egenskaper", p. 53, Pleijel has given a definition of the effective attenuation slightly different from that given above. According to that author, the effective attenuation is the logarithm of the ratio in which the voltage or current in a given terminal load impedance is reduced by the insertion of an arbitrary quadripole, i. e., in this case, a filter in front of the terminal load impedance. Referring to fig. 10 the definition will thus be

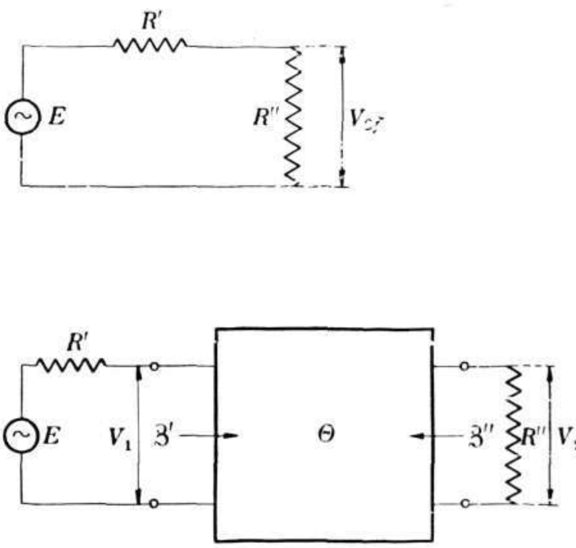


Fig. 10.

$$\bar{b}_D = \log_e \left| \frac{V_{2f}}{V_2} \right| \quad \text{............................ (51)}$$

V_{2f} is obtained direct from the figure:

$$V_{2f} = \frac{R''}{R' + R''} E \quad \text{............................ (52)}$$

and V_2 as before from (4):

$$\left|\frac{E}{V_2}\right| = \left|a_1 + a_2\frac{R'}{R''} + \frac{b}{R''} + cR'\right| \quad \ldots\ldots\ldots\ldots (4)$$

and hence

$$b_D = \log_e \left|\frac{a_1 R'' + a_2 R' + b + cR' R''}{R' + R''}\right|,$$

which can also, according to Table I, be written:

$$b_D = \log_e \left| \frac{1}{\sqrt{\frac{R'}{R''}} + \sqrt{\frac{R''}{R'}}} \cdot \left[\left(\sqrt{\frac{R''}{R'}}\sqrt{\frac{\mathfrak{Z}'}{\mathfrak{Z}''}} + \sqrt{\frac{R'}{R''}}\sqrt{\frac{\mathfrak{Z}''}{\mathfrak{Z}'}} \right) \cdot \cosh\Theta + \left(\frac{\sqrt{\mathfrak{Z}'\,\mathfrak{Z}''}}{\sqrt{R'\,R''}} + \frac{\sqrt{R'\,R''}}{\sqrt{\mathfrak{Z}'\,\mathfrak{Z}''}} \right) \sinh\Theta \right] \right| \quad (54)$$

This is identical with (43) except for the factor $\dfrac{2}{\sqrt{\frac{R'}{R''}} + \sqrt{\frac{R''}{R'}}}$, representing the transformation that can be introduced in the filter. The other factor within the brackets is, on the assumptions made for symmetrical or asymmetrical filters—see (46) or (49)—independent of the ratio R'/R''. Only when $R' = R''$ does the factor

$$\frac{2}{\sqrt{\frac{R'}{R''}} + \sqrt{\frac{R''}{R'}}} = 1,$$

and (54) becomes (43)

For all other values of R'/R'', this factor will be less than unity, and the effective attenuation therefore smaller than in the first case, in other words, an apparent gain has been introduced. The reason for this is that we have assumed that a certain transformation is included in the filter. On account of this transformation, the transmission of energy from the E. M. F. to R'' will be better when the filter is inserted than before this is done. This is equivalent to a lower effective attenuation.—To avoid any misunderstanding, we wish here to point out that the formula for the *effective attenuation given in* (54) is *generally* applicable, and that it will always give a correct value for b_D.

Besides Pleijel's definition of the effective attenuation given above, another definition is also used, by the CCI *among others, according to* which the effective attenuation of a quadripole is the logarithm of the ratio of the square root of the apparent power which a given generator can supply to an impedance equal to its internal impedance, to the root of the apparent power generated in a terminal load impedance connected behind the quadripole in question. This definition leads to exactly same formulæ as in (43).

The difference between, on the one hand, the definition given here or the CCI definition, and on the other, Pleijel's definition, is only that in the former the power output is compared with the maximum output from a given E. M. F., while in the latter no maximum output of power is required. In the former case it is often a great help in the calculations to introduce an ideal transformer of ratio $\sqrt{\frac{R''}{R'}}$, while in the latter case this is not needed (cf. figs. 9 and 10).

Which definition is to be preferred is to some extent a matter of taste, as long as due consideration is given to the factor $\dfrac{2}{\sqrt{\frac{R''}{R'}} + \sqrt{\frac{R'}{R''}}}$, when using the Pleijel definition. According to the definition here given and used, we obtain in the two cases examined—symmetrical filters satisfying the conditions of (46), and asymmetrical filters satisfying those of (49)—the same formulæ for and *value of the effective attenuation,* whatever the variation in the ratio of the external impedances R' and R''. This will not be the case according to Pleijel's definition.

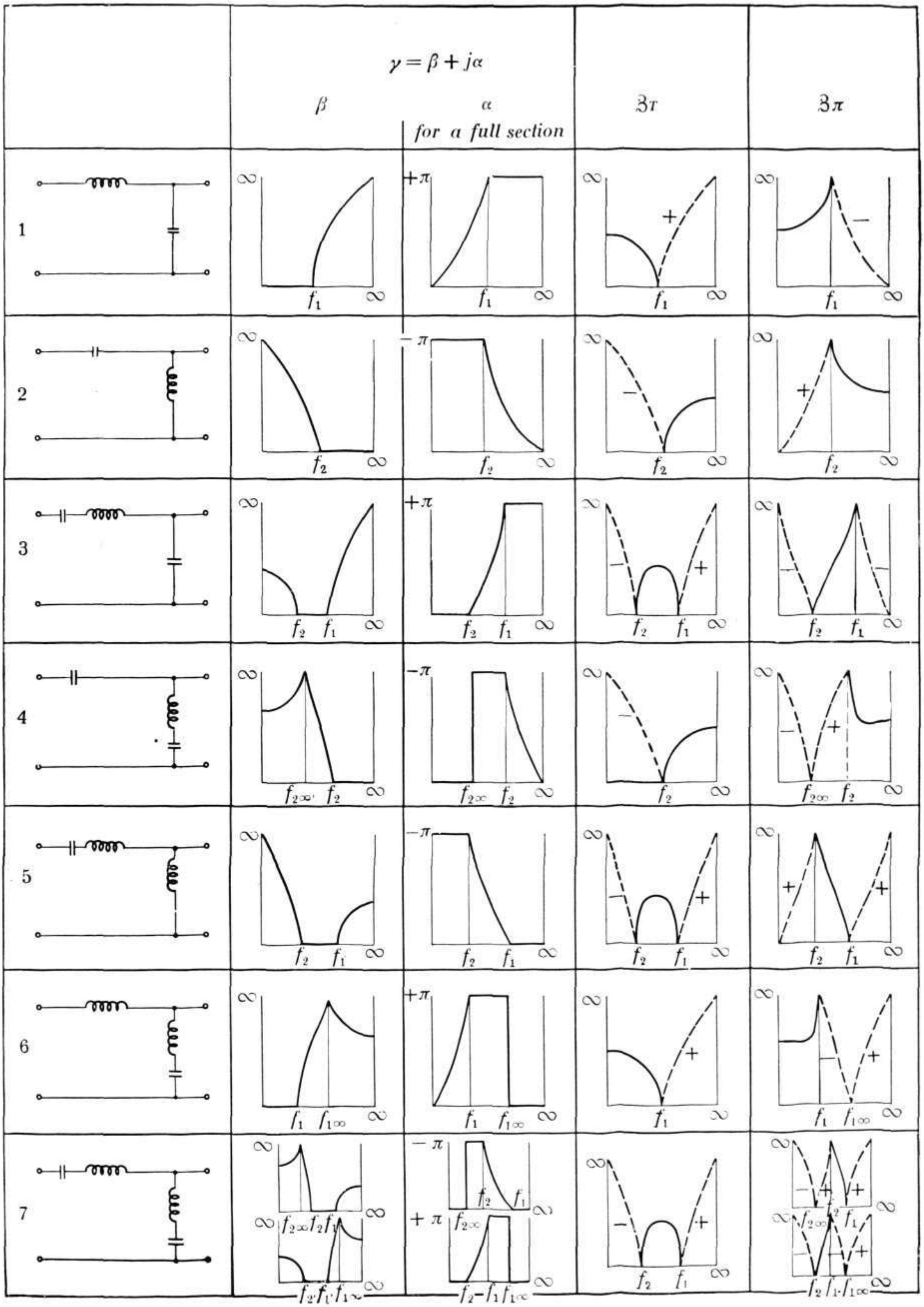
5. Various kinds of simple filter sections.

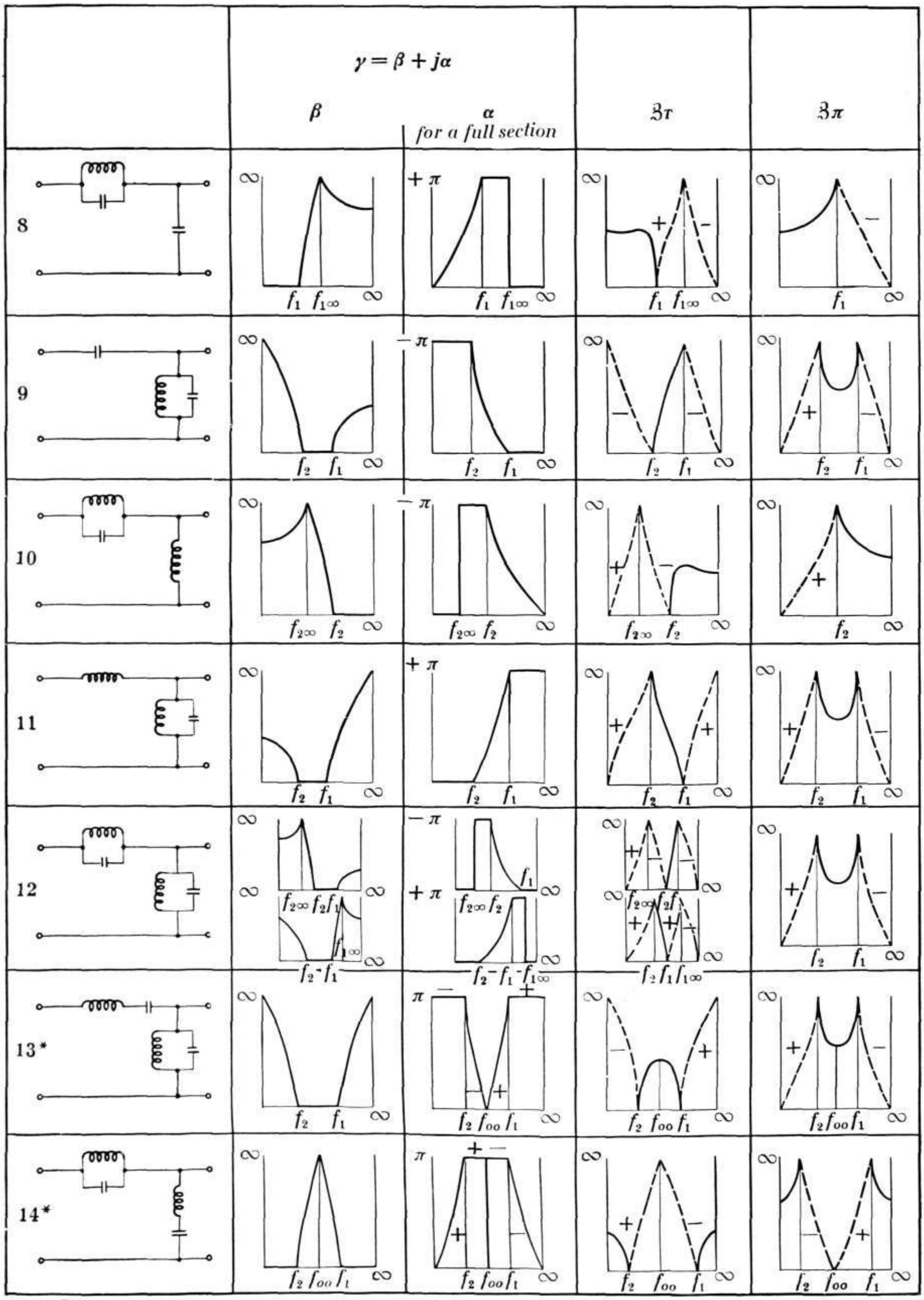
5 *A*. Diagrams and curves.

The filter propagation constant $\gamma = \beta + j\alpha$ and the two image impedances $\mathfrak{Z}'$ and $\mathfrak{Z}''$, or $\mathfrak{Z}_T$ or $\mathfrak{Z}_\pi$, are the quantities which characterize a certain type of filter. These quantities are determined exclusively by the composition of the impedances z_1 and z_2 forming the series and shunt arms respectively of the filter section.

As we have already mentioned, a filter is generally calculated on the simplifying assumption that there is no energy dissipation in either inductances or capacities, i. e. that no ohmic resistances enter into the filter arms. On this assumption, z_1 *and* z_2 *consist of pure inductances or capacities,* or else a series, a parallel or a series-parallel connexion of inductances and capacities. In Table II (p. 19 and 20) various different filter sections are plotted and the attenuation constant β, phase constant α, mid-series image impedance $\mathfrak{Z}_T$ and mid-shunt image impedance $\mathfrak{Z}_\pi$ are given.

TABLE II.

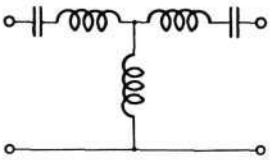
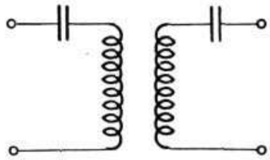
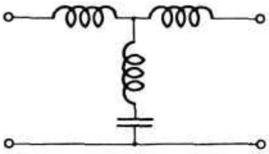
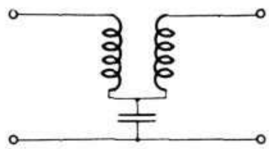
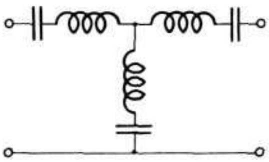
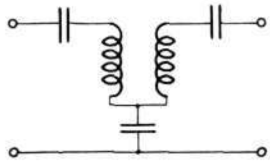
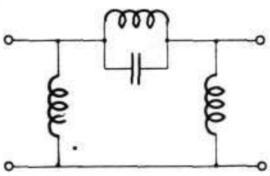
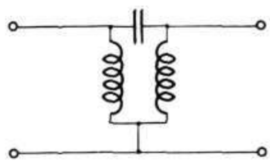
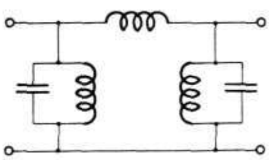
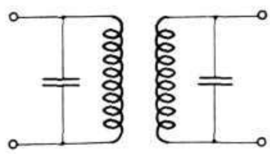
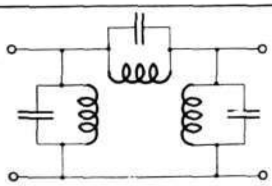
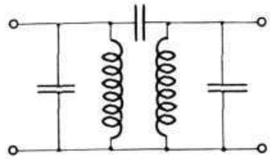
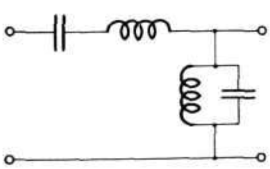
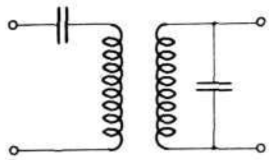

$\gamma = \beta + j\alpha$
β
α
for a full section
$\mathfrak{Z}_T$
$\mathfrak{Z}_\pi$
1
2
3
4
5
6
7
f_1
f_2
$f_{2\infty}$
$f_{1\infty}$
$+\pi$
$-\pi$
∞
+
−



Tabell II b

* These curves only apply if the series and parallel circuits are tuned to the same frequency f_{oo}. Otherwise these filters will act as double band pass and double band suppress filters respectively.

TABLE III.

No.	Fundamental type	No.	Filter type with mutual inductance	Remarks
5		5 a		*Band pass filter*
6		6 a		*Low pass filter*
7		7 a		*Band pass filter*
10		10 a		*High pass filter*
11		11 a		*Band pass filter*
12		12 a		*Band pass filter*
13		13 a		*Band pass filter*

Tabell III

The symbolic method used for plotting these quantities is given by Zobel. This involves a shortening of the abscissa axis for the frequency and the ordinate axis for the attenuation constant and image impedance respectively, so that infinity will be at a finite distance from the origin. Real values of the image impedances are represented by solid lines, and imaginary values by dotted lines, while the signs + and − indicate positive and negative reactances respectively.

The *L*-sections included in the table contain at most four elements. Obviously there is nothing to prevent the use of more, though in that case the filters will be more complicated and costly. Those who desire full information on the properties of these filters are referred to a paper by Johnson and Shea.[1]

If we examine the table, we see that nos. 1, 6, and 8 are low pass filters, i. e. filters which pass low, but cut off high frequencies. Nos. 2, 4, and 10 are high pass filters, with properties directly opposite to those of the low pass filters. The others, with the exception of no. 14, are band pass filters, passing a band of frequencies and cutting off all the rest. Finally, No. 14 is a so-called band-suppress filter, i. e. a filter suppressing a certain band of frequencies while allowing all others to pass.

Table II further shows that filters nos. 1, 2, 13, and 14 have mid-series and mid-shunt image impedances which always make the product of $\mathfrak{Z}_T$ and $\mathfrak{Z}_\pi$ constant and $= k^2$. The proof of this will be given in the next chapter. These are so-called "constant k" filters, and are as we have already mentioned particularly widely used in telephony and telegraphy; we will therefore now discuss their properties in detail. We will, however, first deal with certain modified forms which are equivalent to the filters given above, which provide possibilities both of circumventing in certain cases the difficulties of design, and of introducing an impedance transformation.

As we know, it is always possible to substitute for a certain *T*- or star-network of inductances or capacities a corresponding *Π*- or *Δ*-network, also of inductances or capacities. We know further that the equivalent diagram for a transformer is a *T*- or *Π*-combination of inductances, and that therefore, conversely, a *T*- or *Π*-combination of inductances is equivalent to a transformer.

When connecting some of the filters given in Table II to whole *T*- or *Π*-sections, we find that in some cases the capacities, in others the inductances, will form *T*- or *Π*-combinations, which can therefore, according to what has been said above, be converted. Here we will consider primarily the cases which lead to the introduction of a transformer in the filter. This case is of great practical importance, as the introduction of a transformer, beyond the advantage in respect of transformation, in most cases also means a saving in coils. The coils being usually the most expensive parts of a filter, it will be a greater saving to combine a number of coils into a transformer than to change a condenser *T* into a condenser *Π*, or vice versa. Table III gives in the third column a number of such transformer-filters and the fundamental types from which these filters are deduced.

The filter type 6 a is identical with Campbell's frequency meter, which from a theoretical point of view is based on the mutual inductance being adjusted so as to make the peak of the filter attenuation curve coincide with the measured frequency (cf. Table II 6). Types 5 a, 11 a and 13 a[2] are filters of great practical importance. They are equivalent to connecting in cascade a given filter of the fundamental type without transformation, with a transformer designed to match as desired. In this case, however, the desired matching is obtained in the filter itself, and the transformer in the filter therefore serves a double purpose: it makes transformation possible, and its inductances form part of the filter, which gives a frequency-selective effect. The costs of attaining the desired result will therefore be considerably reduced. In Sweden such filters with transformation have been widely used, but not much as yet in other countries.

5 B. Computation of U_k for "constant k" filters.

We will now pass on to the calculation of the parameter U_k for so-called "constant k" filters, or filters of types 1, 2, 13, and 14 in table II, and 13 a in table III. Among these, we will dwell

[1] See Bibliography 16.

[2] Swedish patent application (M. Vos and H. Sterky) no. 965/28.

mainly on types 13 and 13 a, as nos. 1, 2, 14 are special cases of this band filter.

In fig. 11 a half section of this band filter is drawn with the accepted symbols for inductances and capacities. To compute U_k, we will first find simple expressions for the impedances z_1 and z_2 of the series and shunt arms.

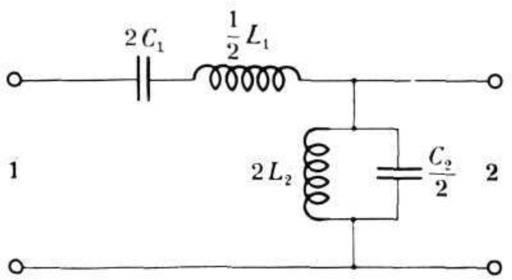


Fig. 11.

We get:

$$\left.\begin{aligned}\frac{1}{2}z_1 &= j\omega\frac{L_1}{2}+\frac{1}{j\omega\, 2\, C_1}\\ \frac{1}{2 z_2} &= \frac{1}{j\omega\, 2\, L_2}+j\omega\frac{C_2}{2}\end{aligned}\right\}$$

or

$$\left.\begin{aligned}z_1 &= j\omega L_1\left(1-\frac{1}{\omega^2 L_1 C_1}\right)\\ \frac{1}{z_2} &= j\omega C_2\left(1-\frac{1}{\omega^2 L_2 C_2}\right)\end{aligned}\right\} \quad \text{(55 a)}$$

To satisfy (31)

$$\sqrt{z_1 z_2}=k$$

we must obviously have

$$L_1 C_1 = L_2 C_2 = \frac{1}{\omega_{oo}^2}, \quad \text{(56)}$$

which, physically, means that the series resonance circuit of the series arm and the parallel resonance circuit of the shunt arm must be tuned to the same angular frequency ω_{oo}.

(55 a) will then become

$$\left.\begin{aligned}z_1 &= j\omega L_1\left[1-\left(\frac{\omega_{oo}}{\omega}\right)^2\right]\\ \frac{1}{z_2} &= j\omega C_2\left[1-\left(\frac{\omega_{oo}}{\omega}\right)^2\right]\end{aligned}\right\} \quad \text{(55 b)}$$

and we obtain

$$z_1 z_2 = \frac{L_1}{C_2} \quad \text{(57)}$$

According to (30) we get further

$$\mathfrak{Z}_T\,\mathfrak{Z}_\pi = z_1 z_2 \quad \text{(58)}$$

and the following properties of filters of the "constant k" group, can thus be given:

The product of the series and shunt arm impedances is equal to the product of the mid-series and mid-shunt image impedances of the filter and these products are constant and independent of the frequency, or

$$z_1 z_2 = \mathfrak{Z}_T\,\mathfrak{Z}_\pi = k^2 = \frac{L_1}{C_2} \quad \text{(59)}$$

We will now find the value of U_k from (28)

$$U_k = \frac{z_1}{4 z_2}, \quad \text{(28)}$$

whence, by substituting the values of z_1 and z_2 from (55 b)

$$U_k = -\frac{\omega^2 L_1 C_2}{4}\left[1-\left(\frac{\omega_{oo}}{\omega}\right)^2\right]^2 \quad \text{(60)}$$

To obtain U_k as a function of the angular frequency alone, we must obviously determine the product $L_1\, C_2$. This is done by determining the cut-off frequencies ω_1 and ω_2 from (29 b).

$$\cosh\gamma = \cosh(\beta + j\alpha) = 1 + 2\,U_k \quad \text{(29 b)}$$

The position of the filter band is obtained by determining the limits of U_k corresponding to purely imaginary values of the angle γ, for if γ is purely imaginary, β, or the attenuation constant, must be zero. These limits are obtained for

$\cosh\gamma = \pm 1$ corresponding to

$U_k = 0$ and $U_k = -1$ respectively.

According to (60) $U_k = 0$ will give us

$$\omega = \omega_{oo}$$

and $U_k = -1$

$$\omega = \frac{1}{\sqrt{L_1 C_2}}\left\{\mp 1 \pm \sqrt{1+\omega_{oo}^2 L_1 C_2}\right\}$$

As ω must be > 0, only two roots will be obtained, which will give us the two cut-off frequencies represented by ω_1 and ω_2 respectively,

We thus get:

$$\left.\begin{aligned}\omega_1 &= \frac{1}{\sqrt{L_1 C_2}}\left\{\sqrt{1+\omega_{oo}^2 L_1 C_2}+1\right\}\\ \omega_2 &= \frac{1}{\sqrt{L_1 C_2}}\left\{\sqrt{1+\omega_{oo}^2 L_1 C_2}-1\right\}\end{aligned}\right\} \quad \text{(61 a)}$$

If we now introduce what is called the relative band width x, as the ratio of the opper cut-off frequency to the lower

$$x = \frac{\omega_1}{\omega_2}, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (62)$$

we obtain from (61 a)

$$\frac{L_1 C_2}{4} = \frac{x}{(x-1)^2} \frac{1}{\omega_{oo}^2}, \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (61\,b)$$

which finally, on substitution in (60), gives

$$U_k = -\frac{x}{(x-1)^2}\left[\frac{\omega}{\omega_{oo}} - \frac{\omega_{oo}}{\omega}\right]^2 \ldots\ldots\ldots\ldots\ldots \quad (63)$$

Wi find further from (61 a) that the resonance frequency ω_{oo} is the geometric mean of the two cut-off frequencies ω_1 and ω_2.

$$\omega_1 \omega_2 = \omega_{oo}^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (64)$$

If frequencies are substituted for angular frequencies in (63), this equation can be given another form, which is found in, among others, Zobel's work quoted above:

$$U_k = \frac{f_1 f_2}{(f_1 - f_2)^2}\left[\frac{f^2}{f_1 f_2} + \frac{f_1 f_2}{f^2} - 2\right] \quad \ldots\ldots\ldots \quad (63\,a)$$

This form is not, however, the most suitable for calculating U_k in practice. We will now give an account of the simplifications that can be made in the above expression. It should be noted that no approximations at all have been made in the deduction of the following formulæ.

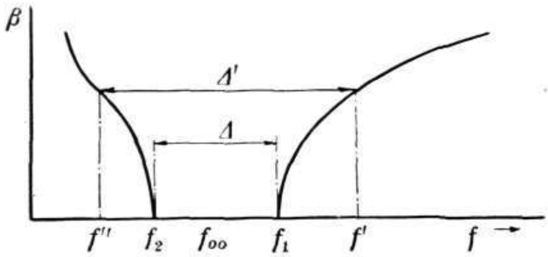


Fig. 12.

We introduce the symbols employed in fig. 12, where a curve has been plotted of the attenuation constant β against the frequency f. It should be pointed out that the following deduction of a simple formula for U_k would be equally valid if say, the effective attenuation, or the load impedance, or any other quantity depending on U_k, had been plotted as a function of the frequency. The following symbols are also introduced.

$$y = \frac{f'}{f''} \quad x = \frac{f_1}{f_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (65)$$

$$\triangle' = f' - f'' \quad \triangle = f_1 - f_2$$

The frequencies f' and f'' are so selected that

$$f' f'' = f_{oo}^2, \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (66)$$

but the position of f' or f'' is arbitrary. Also, according to (65) and (66),

$$\left.\begin{aligned} \frac{f'}{f_{oo}} = \frac{f_{oo}}{f''} = \sqrt{y} \text{ and } \frac{f_{oo}}{f'} = \frac{f''}{f_{oo}} = \frac{1}{\sqrt{y}} \\ \frac{f_1}{f_{oo}} = \frac{f_{oo}}{f_2} = \sqrt{x} \text{ and } \frac{f_{oo}}{f_1} = \frac{f_2}{f_{oo}} = \frac{1}{\sqrt{x}} \end{aligned}\right\}$$

Now the expression

$$U_k = -\frac{x}{(x-1)^2}\left[\frac{f}{f_{oo}} - \frac{f_{oo}}{f}\right]^2 \quad \ldots\ldots\ldots\ldots\ldots \quad (63)$$

is symmetrical with respect to f_{oo}, and according to it two frequencies, f' and f'', correspond to a given U_k. We can therefore write

$$U_k = -\frac{x}{y}\left(\frac{y-1}{x-1}\right)^2 = -\left(\frac{\sqrt{y} - \frac{1}{\sqrt{y}}}{\sqrt{x} - \frac{1}{\sqrt{x}}}\right)^2$$

or, multiplying top and bottom by f_{oo}^2 and with the help of (65),

$$\boxed{U_k = -\left(\frac{f' - f''}{f_1 - f_2}\right)^2 = -\left(\frac{\triangle'}{\triangle}\right)} \quad \ldots\ldots\ldots\ldots \quad (63\,b)$$

The relation between the absolute band width Δ' and the quantity $\sqrt{y}$ which determines the position of the unknown frequencies f' and f'', we obtain from (65):

$$\frac{\triangle'}{f_{oo}} = \sqrt{y} - \frac{1}{\sqrt{y}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (67)$$

If we replace $\frac{\triangle'}{f_{oo}}$ by p', we can solve $\sqrt{y}$ in the above equation and so get

$$\sqrt{y} = \frac{p'}{2} + \sqrt{1 + \frac{p'^2}{4}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (68)$$

(the minus sign is discarded, $\sqrt{y}$ being > 1).

As we have shown above (Ch. 4), all calculations for "onstant k" filters are reduced to a calculation of U_k. By means of (63 b), (67), and (68) this quantity in its turn can be very easily determined for any "constant k" filter for which the cut-off frequencies f_1 and f_2, and with them the absolute band width $\Delta = f_1 - f_2$, and their geometric mean $f_{oo} = \sqrt{f_1 f_2}$ are given. These calculations will be even simpler if (68) is plotted as a curve (see fig. 13). A couple of examples showing the calculation of U_k for given band filters will illustrate the simplicity of this method.

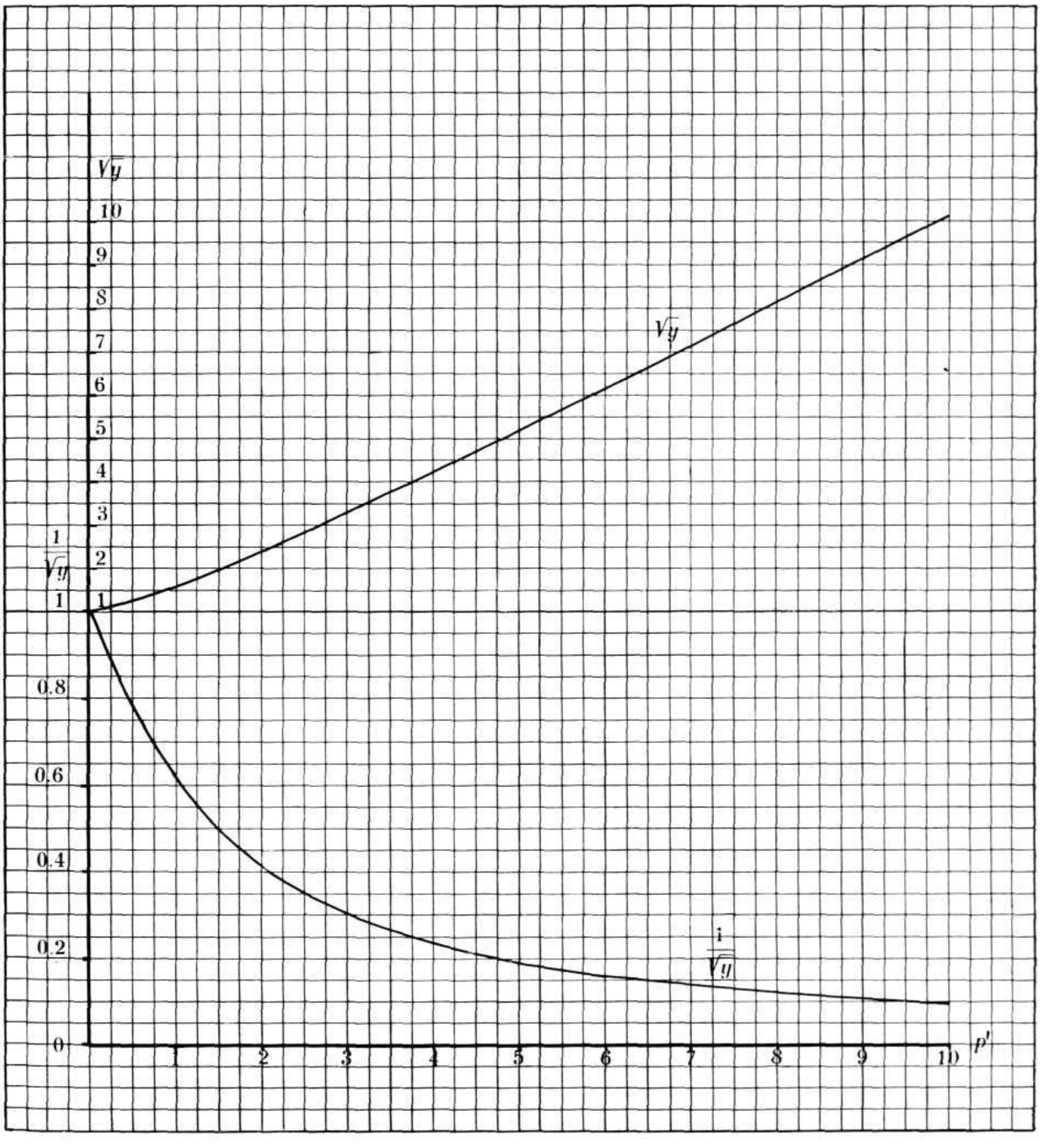


Fig. 13.

Example 1. *Given:* A band filter with the cut-off frequencies 12 750 and 9 750 cycles/sec.

Wanted: U_k for the frequencies 6 000, 11 500 and 15 000 cycles/sec. We first calculate $\Delta = f_1 - f_2 = 12\,750 - 9\,750 = 3\,000$ cycles/sec. and $f_{00} = \sqrt{f_1\, f_2} = \sqrt{12\,750 \cdot 9\,750} = 11\,150$ cycles/sec. after which the calculation follows the procedure given in Table IV below:

U_k is obtained not only for the frequencies given but also for the frequencies on the other side of their geometric mean f_{00} according to the formula $f'\, f'' = f_{00}^2$.

TABLE IV.

f'	f''	$f' = \frac{f_{oo}^2}{f''}$	$f'' = \frac{f_{oo}^2}{f'}$	$\triangle' = f' - f''$	$\frac{\triangle'}{\triangle}$	$U_k = -\left(\frac{\triangle'}{\triangle}\right)^2$
—	6000	20719	—	14719	4.906	— 24
11500	—	—	10810	690	0.230	— 0.0529
15000	—	—	8288	6712	2.237	— 5
Given.		Computed.				

Example 2. *Given:* A band filter of absolute width $\Delta = 200$ cycles/sec. and geometric mean frequency $f_{oo} = 4\,600$ cycles/sec.

Wanted: U_k for varying band width Δ'.

TABLE V.

$\triangle'$	$p' = \frac{\triangle'}{f_{oo}}$	$\sqrt{y}$	$\frac{1}{\sqrt{y}}$	$f' = f_{oo}\sqrt{y}$	$f'' = \frac{f_{oo}}{\sqrt{y}}$	$\frac{\triangle'}{\triangle}$	$U_k = -\left(\frac{\triangle'}{\triangle}\right)^2$
100	0.0217	1.0104	0.9897	4650	4550	0.50	— 0.25
300	0.0652	1.033	0.9681	4752	4452	1.5	— 2.25
1200	0.261	1.139	0.8780	5239	4039	6.0	— 36.0
Assumed.	Computed.	From curve fig. 13.		Computed.			

As we see, the procedure is very simple. The accuracy will also be sufficient for all practical purposes, especially if the curve $\sqrt{y} = f\,(p')$ in fig. 13 is plotted on a large scale on mm. paper. When the values of U_k have been found these can be used for calculating all the quantities characteristic of a "constant k" filter, e. g. the filter propagation constant, the mid-series and mid-shunt impedances of the loaded filter, the effective attenuation, etc., from formulæ of which some have already been given and some will be deduced in the next chapter.

The filter types nos. 1, 2, and 14 in Table II and nos. 13 a in Table III are also "constant k" filters. To calculate the value of U_k for these filters we can either proceed in the same way as with the type already discussed (fig. 11) or else find it mathematically from (63 b) by taking the limits. By either of these methods the following expression will then be obtained for calculating U_k. (Table VI.)

TABLE VI.

Filter type no.	of table	$U_k =$
1	II	$-\left(\frac{f'}{f_1}\right)^2$
2	II	$-\left(\frac{f_2}{f''}\right)^2$
13	II	$-\left(\frac{\triangle'}{\triangle}\right)^2$
13 a	III	$-\left(\frac{\triangle'}{\triangle}\right)^2$
14	II	$-\left(\frac{\triangle}{\triangle'}\right)^2$

6. Matching of filter image impedances.

In Ch. 4 A and B, "Load impedance and effective attenuation", the question of matching the *image impedance of the filter to external impedances* has been briefly touched upon. In this chapter it will be examined more closely and formulæ deduced for a new method called α-matching for matching filter image impedances with external impedances.

When matching image impedances, the general rule is that one ought to try to make the reflection losses as small as possible, as every reflection causes increased attenuation, and may besides give rise to disturbing subsidiary phenomena, e. g. increased crosstalk etc. When a number of filters of different types are to be connected in cascade, the rule is that only those can be connected together which have the same image impedances at the junctions. Thus, when connecting in cascade different types of filters from Table II or III, one must see that only such types are selected as have at least from one side an image impedance corresponding to the output image impedance of the previous section. The side having the right image impedance should then be connected to the previous filter. If there are several types with such image impedances, it will be the form of the attenuation curve and the consideration that it must be technically possible to manufacture the various inductances and capacities that will determine the choice of type.

The matching of image impedances of different types of filters when connecting them in cascade is thus a fairly simple matter. The problem of matching the image impedance of a particular type with the internal impedance of a generator or with a certain terminal load impedance is, however, considerably more difficult. If these impedances are complex, it is practically impossible to give any general rule for the matching. Fortunately, however, the filters used in telephony and wireless are generally connected between generators with purely ohmic internal impedances and loads consisting of ohmic resistances. Such, for instance, is the case of a filter connected between the anode circuit of an amplifying valve and a resistance in the grid circuit of the succeeding valve, as for example in fig. 14, which shows a band filter with the propagation constant Θ and image impedances $\mathfrak{Z}'$ and $\mathfrak{Z}''$ connected between a generator E of internal resistance R' and a load R''.

The two curves in fig. 14 shows how the image impedances $\mathfrak{Z}'$ and $\mathfrak{Z}''$ vary with the frequency for a "constant k" filter consisting of an odd number of half sections of type 13, Table II, according to the diagrammatic plan given for the same table. These curves indicate that the image im-

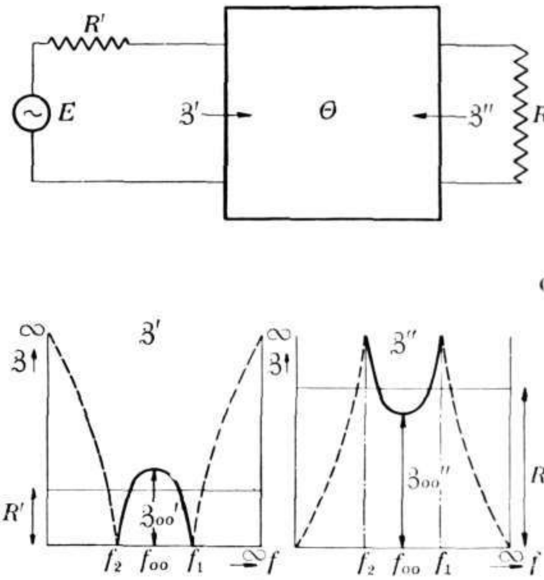
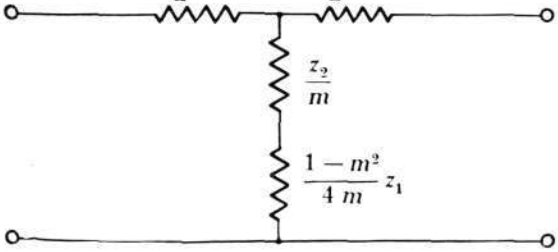
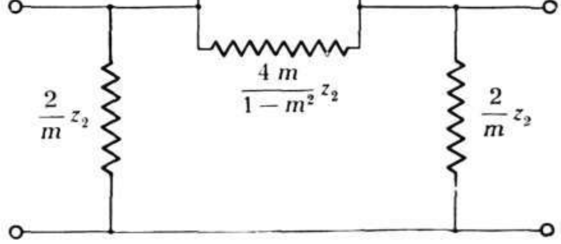


Fig. 14.

pedances within the band are real and thus of the same character as the external resistance. The image impedances within the band are, however, not constant resistances, but vary according to fig. 14 from infinity or zero at one of the cut-of frequencies to a constant value $\mathfrak{Z}_{oo}'$ or $\mathfrak{Z}_{oo}''$ at the geometric mean frequency and back to infinity or zero at the other cut-off frequency. Zobel gives a method of improving the matching within the band for "constant k" filters so that the reflection losses are reduced. This method, called "m-derivation", involves a change of the normal series and shunt arm impedances, z_1 and z_2 respectively, to values according to fig. 15. If the T- and Π-sections in fig. 15 are used as L-



T-section (m-type).



Π-section (m-type).

Fig. 15.

sections, the mid-shunt image impedance of the m-derived T-section and the mid-series image impedance of the m-derived Π-section will have favourable properties for matching to ohmic external resistances. The attenuation curves of filters m-derived in this way will in addition show high peaks for certain frequencies outside the filter bands—properties which are of great value, particularly, for instance, when certain frequencies have to be attenuated more thoroughly than other. To obtain these advantages, however, several new elements have to be introduced into the filters, e. g. in a band filter as in fig. 13, Table II, two inductances and two capacities. For more detailed information of the design and use of m-derived filters, the reader is referred to Zobel's works.

6 A. Effective Attenuation in a-Matching.

Another method will now be discussed for improving the matching in a filter band. As we have already mentioned (Ch. 4 Ba), filters are generally calculated so that $\mathfrak{Z}'$ and $\mathfrak{Z}''$ for *one* particular frequency—usually the geometric mean frecuency f_{oo}—coincide with the external resistances, or so that

$$\mathfrak{Z}_{oo}' = R' \text{ and } \mathfrak{Z}_{oo}'' = R''.$$

Formulæ for the effective attenuation with such matching have been given in ch. 4 B.

If now we look at fig. 14, we find that it would not be far-fetched to calculate the filters instead so that $\mathfrak{Z}'$ and $\mathfrak{Z}''$ for *two* frequencies coinside with the external resistances R' and R'', i. e. so that the straight lines R' and R'' resp. cut the curves of the filter's image impedances. At the geometric mean frecuency f_{oo} we then get

$$R' < \mathfrak{Z}_{oo}' \text{ and } R'' > \mathfrak{Z}_{oo}'',$$

if the filter is asymmetrical, which we assume, as being the most complicated case. We then put

$$\left.\begin{aligned} R' &= \frac{1}{a}\,\mathfrak{Z}_{oo}' \\ R'' &= a\,\mathfrak{Z}_{oo}'' \end{aligned}\right\} \quad (a > 1) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (69)$$

and have to determine the most favourable value of a in some typical cases. Such a-matching has been found to improve the form of the effective attenuation curve not only *inside* but also *outside* the band, while at the same time the reflection losses can be kept within reasonable limits. *We gain these advantages without having to introduce any new elements into the filters.*

In Ch. 4 B we have deduced the formula for the effective attenuation of an arbitrary filter having a propagation constant Θ

$$b_D = \log_e \frac{1}{2} \left| \left[\left(\sqrt{\frac{R''}{R'}} \sqrt{\frac{\mathfrak{Z}'}{\mathfrak{Z}''}} + \sqrt{\frac{R'}{R''}} \sqrt{\frac{\mathfrak{Z}''}{\mathfrak{Z}'}} \right) \cosh \Theta + \left(\frac{\sqrt{\mathfrak{Z}'\mathfrak{Z}''}}{\sqrt{R'R''}} + \frac{\sqrt{R'R''}}{\sqrt{\mathfrak{Z}'\mathfrak{Z}''}} \right) \sinh \Theta \right] \right| \quad (43)$$

This formula can be simplified for a "constant k"-filter, as according to (59)

$$\mathfrak{Z}' \cdot \mathfrak{Z}'' = k^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (59)$$

if we turn the filter so that $\mathfrak{Z}' = \mathfrak{Z}_T$ and $\mathfrak{Z}'' = \mathfrak{Z}_\pi$.

$\mathfrak{Z}_{oo}'$ and $\mathfrak{Z}_{oo}''$ being only particular values of $\mathfrak{Z}'$ and $\mathfrak{Z}''$ this must also be true for

$$\mathfrak{Z}_{oo}' \cdot \mathfrak{Z}_{oo}'' = k^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (70)$$

If we substitute in (43), (69) and (70) we get the effective attenuation for an *a-matched asymmetrical "constant k" filter:*

$$b_D = \log_e \frac{1}{2} \left| \left[\left(a \sqrt{\frac{\mathfrak{Z}_{oo}''}{\mathfrak{Z}_{oo}'}} \sqrt{\frac{\mathfrak{Z}'}{\mathfrak{Z}''}} + \frac{1}{a} \sqrt{\frac{\mathfrak{Z}_{oo}'}{\mathfrak{Z}_{oo}''}} \sqrt{\frac{\mathfrak{Z}''}{\mathfrak{Z}'}} \right) \cosh \Theta + 2 \sinh \Theta \right] \right|$$

or if we introduce T and Π image impedances:

$$\boxed{b_D = \log_e \frac{1}{2} \left| \left[\left(a \frac{\mathfrak{Z}_T}{\mathfrak{Z}_{Too}} + \frac{1}{a} \frac{\mathfrak{Z}_\pi}{\mathfrak{Z}_{oo\pi}} \right) \cosh \Theta + 2 \sinh \Theta \right] \right|} \quad (71)$$

6 Aa. Example of a "constant k" filter composed of three half-sections.

We will now continue the calculation of the effective attenuation for a special filter, and for that purpose will choose a "constant k" filter composed of three half sections, as in fig. 16.

If the propagation constant for a whole section "constant k" filter is γ, Θ will in this case be $\frac{3}{2}\gamma$, so that, leaving out some steps, we get, from (29 b) and (30)

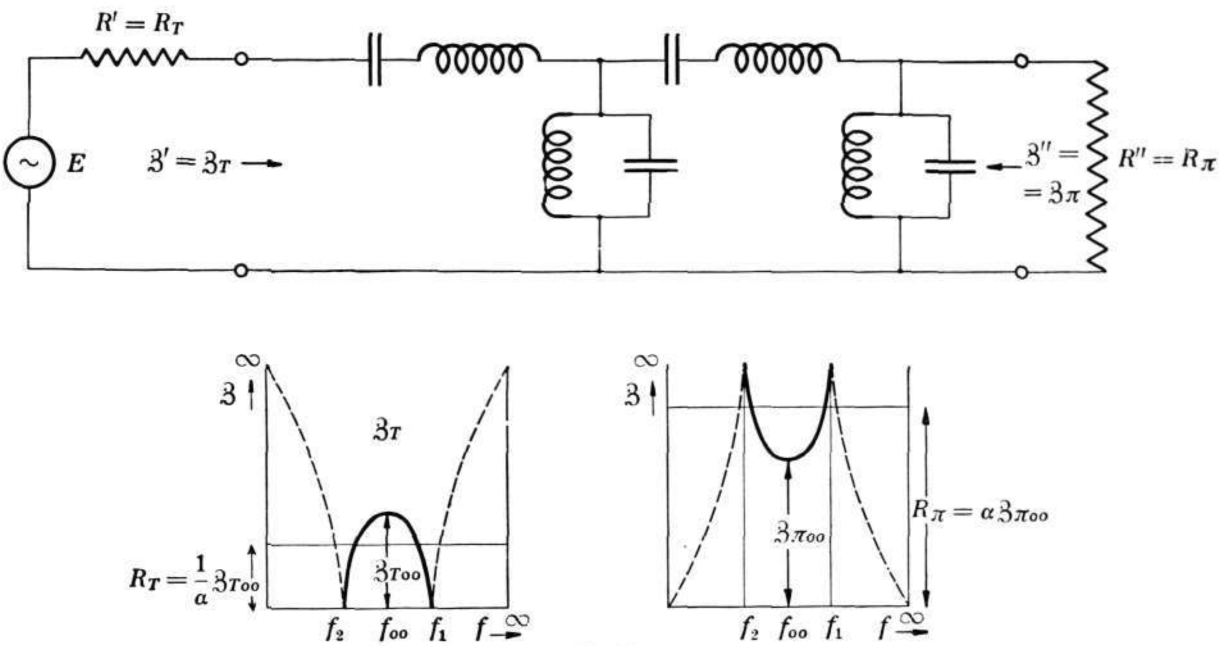


Fig. 16.

$$\left.\begin{aligned} \sinh\Theta &= \sinh\frac{3}{2}\gamma = (3+4U_k)\sqrt{U_k} \\ \cosh\Theta &= \cosh\frac{3}{2}\gamma = (1+4U_k)\sqrt{1+U_k} \\ \frac{\mathfrak{Z}_T}{\mathfrak{Z}_{Too}} &= \sqrt{1+U_k} \\ \frac{\mathfrak{Z}_\pi}{\mathfrak{Z}_{\pi oo}} &= \frac{1}{\sqrt{1+U_k}}, \end{aligned}\right\} \quad (72)$$

which if substituted in (71) gives us

$$b_D = \log_e \frac{1}{2}\left|\left[a(1+U_k)+\frac{1}{a}\right]\left[1+4U_k\right]+2\left[3+4U_k\right]\sqrt{U_k}\right| \quad \ldots\ldots (73\,a)$$

or if we want the absolute value, remembering that U_k is negative

$$b_D = \log_e \frac{1}{2}\sqrt{\left(a^2+2+\frac{1}{a^2}\right)+\left(10a^2-18+\frac{8}{a^2}\right)U_k+\left(33a^2-48+\frac{16}{a^2}\right)U_k^2+(40a^2-32)U_k^3+16a^2U_k^4} \quad (73\,b)$$

$$= \log_e \frac{1}{2}\sqrt{y}$$

When $a=1$ this becomes

$$b_D = \log_e \sqrt{1+\frac{U_k^2}{4}+2U_k^3+4U_k^4} \quad \ldots\ldots (74)$$

It will now be of interest to examine the value of the expression γ for various values of U_k and find the positions of any maxima and minima there may be. The calculations required for this take rather a long time and are not very interesting, so the results alone are given here (Table VII).

If we see whether there is any value at which all the maxima and minima coincide, we find there is one at $a=\frac{2}{\sqrt{3}}$. We also want a value of a, for which b_D and therefore also y will be the same for $U_k=0$ (f_{oo}) as for $U_k=-1$ (f_1 and f_2 respectively). This will occur when $a=2$. Table VIII below gives values of U_k and b_D for various values of a and for the more important points.

The results are given graphically in figs. 17 and 18, of which the former shows the effective attenuation curves mainly outside the cut-off frequencies ($U_k<-1$) and the latter shows on a large scale a small part of the same curve within the band ($-1<U_k<0$). For the correct interpretation of the curves it should here be pointed out that a fairly good idea of the form of the effective attenuation curve of an a-matched band fil-

TABLE VII.

U_k	y	Remarks
0	$\left(a+\frac{1}{a}\right)^2$	Geometric mean frequency f_{oo}
-1	$4+\frac{9}{a^2}$	Cut-off frequencies f_1 and f_2
$\frac{1}{a^2}-1$	4	Minima
$-\frac{1}{4}$	4	Absolute minima
$\frac{1}{2a^2}-\frac{5}{8}$	$\frac{37}{16}+\frac{81}{256}a^2+\frac{27}{8a^2}-\frac{3}{a^4}+\frac{1}{a^6}$	Maxima

TABLE VIII.

For special values of U_k (independent of a)

U_k	$b_D=\log_e \frac{1}{2}\sqrt{y}$ for $a=$ 1	$\frac{2}{\sqrt{3}}$	$\sqrt{2}$	2	$2\sqrt{2}$
0	0	0.010	0.060	0.223	0.46
$-\frac{1}{4}$	0	0	0	0	0
-1	0.589	0.492	0.378	0.223	0.132

For minima $U_k=\frac{1}{a^2}-1$

$a=$	1	$\frac{2}{\sqrt{3}}$	$\sqrt{2}$	2	$2\sqrt{2}$
U_k	0	$-\frac{1}{4}$	$-\frac{1}{2}$	$-\frac{3}{4}$	$-\frac{7}{8}$
$b_D=\log_e \frac{1}{2}\sqrt{y}$	0	0	0	0	0

For maxima $U_k=\frac{1}{2a^2}-\frac{5}{8}$

$a=$	1	$\frac{2}{\sqrt{3}}$	$\sqrt{2}$	2	$2\sqrt{2}$
U_k	$-\frac{1}{8}$	$-\frac{1}{4}$	$-\frac{3}{8}$	$-\frac{1}{2}$	$-\frac{9}{16}$
$b_D=\log_e \frac{1}{2}\sqrt{y}$	0.0005	0	0.001	0.03	0.108

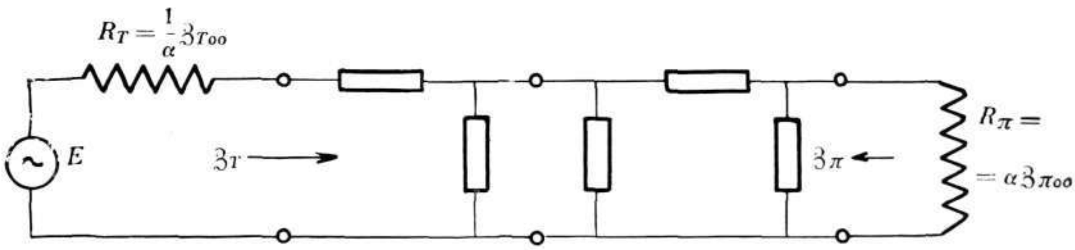
ter can be obtained by imagining the curves in figs. 17 and 18 extended to the right by their images. The cut off frequencies f_2 and f_1 will then be to the left and right of $U_k=0$ at the points where $U_k=-1$. The abscissa axis must then be conceived as having a frequency scale related to the U_k scale according to (68) or fig. 13. Also the curves for the effective attenuation are only applicable on the assumption that the filters have no losses.

From fig. 17 we first find that below a certain value of U_k all a-matched filters ($a>1$) will be better from the point of view of the attenuation than the normal filter where $a=1$. *The effective attenuation of an a-matched filter ($a>1$) slightly outside the cut-off frequencies is thus greater than in the corresponding normally matched filter ($a=1$).* The reason for this is that the reflections due to the a-matching will cause an increase in the effective attenuation: the greater a, the greater the reflections.

Within the band, for $-1<U_k<0$ the effective attenuation depends very much on the value of a. Fig. 18 shows that the effective attenuation in a filter where $a=1$ is relatively large at the edges of the band. *The greater a is, the lower will be the effective attenuation at the cut-off frequencies, at the same time increasing at the geometric mean frequency.* This fact gives us a chance of obtaining a more rectangular effective attenuation curve for a filter of this kind.

How large then should a be made? To answer this we will consider fig. 19 which gives the effective attenuation curves for a three-half-sections "constant k"-filter with $a=1$ (curve 1) and $a>1$ (curve 2), in both cases without losses, and for $a=1$ with losses (curve 3).

If allowance is made for the losses in coils and condensers the theoretically effective attenuation curve 1 for $a=1$ will become curve 3. As we see, the losses cause an increase of attenuation within the band, but are less important outside. Both curves 1 and 3 show that, on account of the reflections for which we have just allowed in calculating the effective attenuation, the band will be narrower than that determined by the cut-off frequencies f_1 and f_2. If a is made greater than


$R_T = \frac{1}{\alpha} \mathfrak{Z}_{T\infty}$
E
$\mathfrak{Z}_T$
$\mathfrak{Z}_\pi$
$R_\pi =$
$= \alpha \mathfrak{Z}_{\pi\infty}$

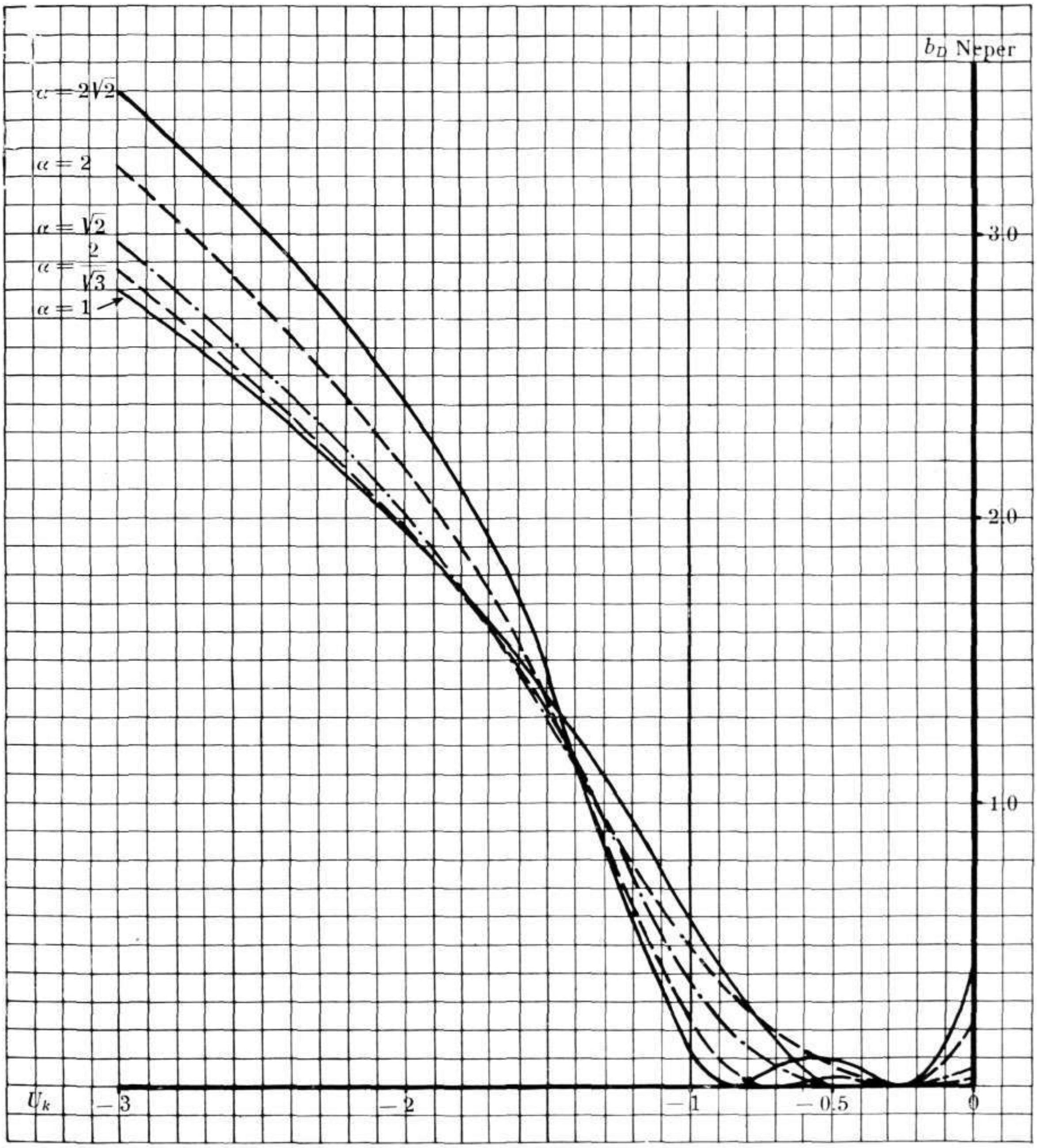

b_D Neper
$\alpha = 2\sqrt{2}$
$\alpha = 2$
$\alpha = \sqrt{2}$
$\alpha = \frac{2}{\sqrt{3}}$
$\alpha = 1$
3.0
2.0
1.0
U_k
— 3
— 2
— 1
— 0.5
0

Fig. 17.

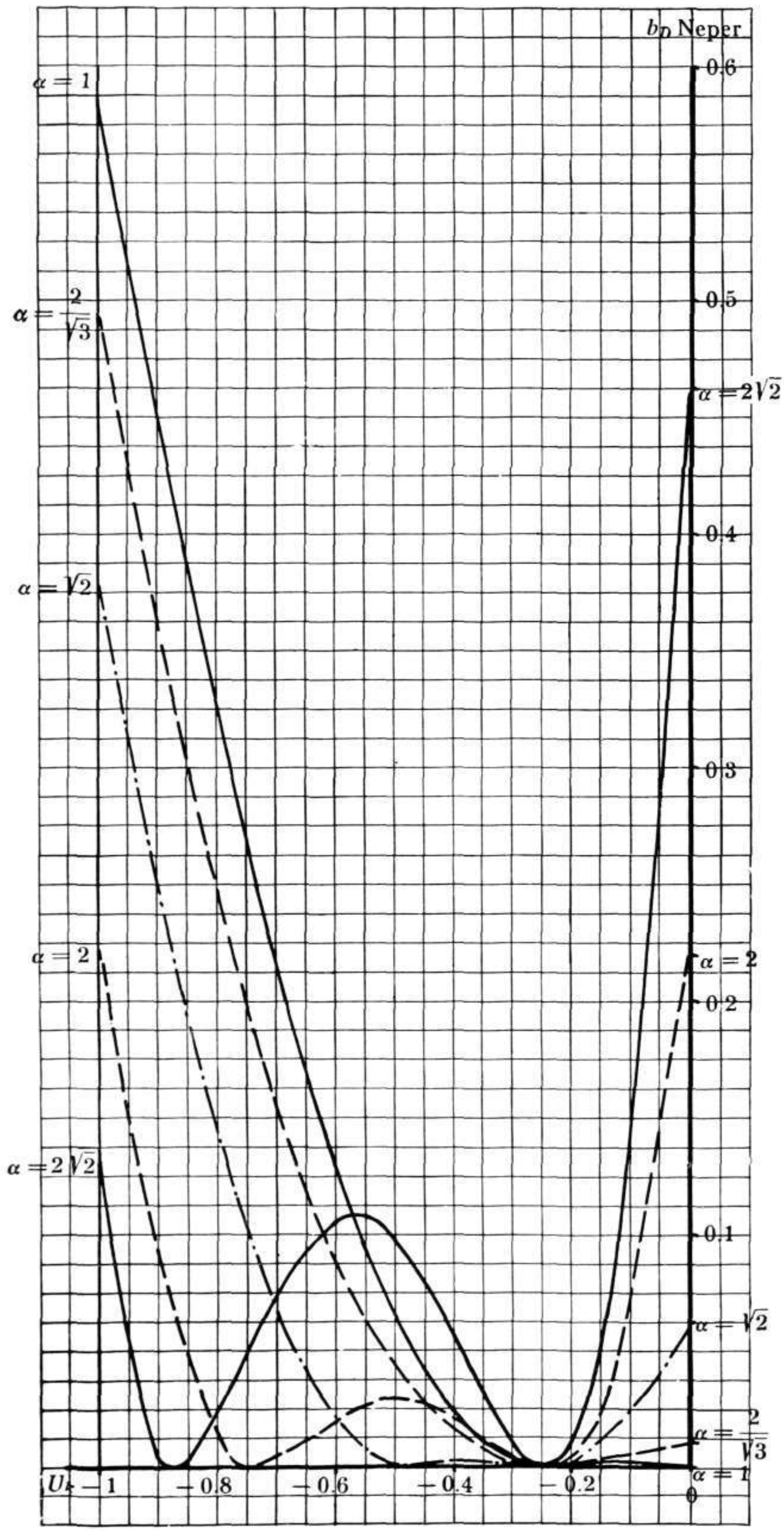


Fig. 18.

1, the band will be widened, as can be seen by comparing curves 1 and 2. If allowance is made for the losses in a filter where $\alpha > 1$ also, an effective attenuation will be obtained as in curve 4, fig. 19. This shows an apparently increased band width, owing to the attenuation being reduced at the cut-off frequencies and increased in the middle.

The ideal shape for the effective attenuation curve is a rectangle open at the top. To obtain a curve approaching this, α should be determined for the filter *with losses,* so that b_D will be the same for f_1, f_{oo} and f_2. Such a calculation will, however, be very complicated, and before that is done the following procedure will serve the purpose with sufficient accuracy. α is determined for the filter *without losses* so that the effective attenuation at f_{oo} ($U_k = 0$) will be equal to that at the cut-off frequencies ($U_k = -1$). For the filter in question this calculation will give us $\alpha = 2$. Measurements of calculated and manufactured filters also show this value of α to be suitable. If there is any reason for suspecting that reflections *within* the band will cause disturbances, a smaller value of α should, however, be chosen. (cf. ch. 6 C). For $\alpha > 1$ an improvement of the effective attenuation is always obtained in the direction of the ideal rectangular shape.

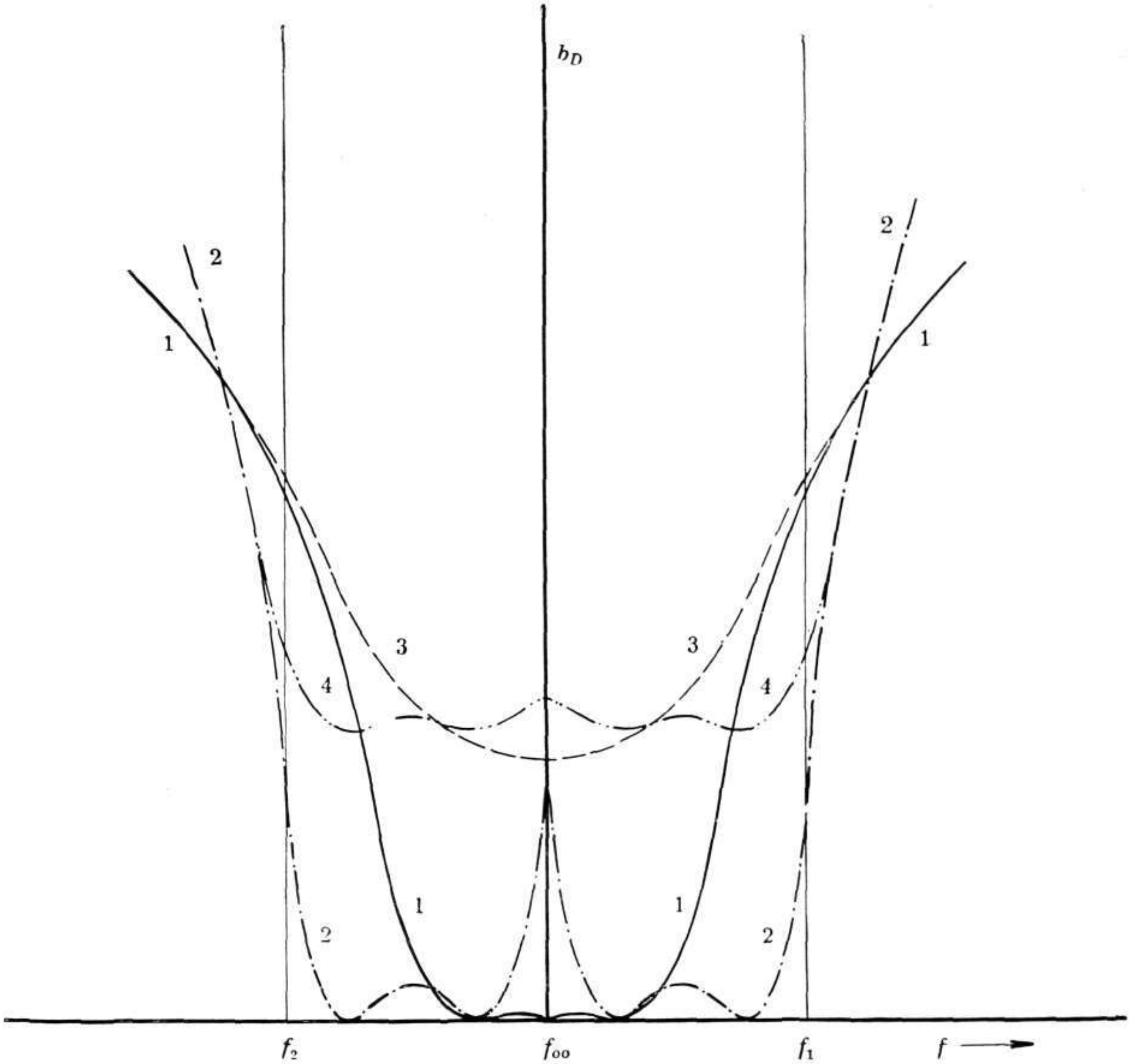


Fig. 19.

6 Ab. Effective attenuation in α-matched symmetrical or asymmetrical "constant k" filters.

In the preceding chapter we have deduced a general formula for the effective attenuation in an asymmetrical α-matched "constant k" filter. We will now deduce the corresponding formula for a symmetrical filter of the same kind (fig. 20).

We assume both $\mathfrak{Z}'$ and $\mathfrak{Z}''$ to be of W-type, but that they are differentiated by a constant factor n^2 (cf. 44)

$$\mathfrak{Z}' = n^2 \mathfrak{Z}'' \quad \dots\dots (44)$$

In addition we introduce an α-matching

$$\left.\begin{aligned} R' &= \frac{1}{a} \mathfrak{Z}_{oo}' \\ R'' &= \frac{1}{a} \mathfrak{Z}_{oo}'' \end{aligned}\right\} \quad \dots\dots (75)$$

According to (44 a) we also have

$$\mathfrak{Z}_{oo}' = n^2 \mathfrak{Z}_{oo}''$$

and from this we get:

$$\left.\begin{aligned} \frac{R'}{\mathfrak{Z}'} &= \frac{R''}{\mathfrak{Z}''} \\ R' R'' &= \frac{1}{a^2} \mathfrak{Z}' \mathfrak{Z}'' \left(\frac{\mathfrak{Z}_{oo}'}{\mathfrak{Z}'}\right)^2 \end{aligned}\right\} \quad \dots\dots (76)$$

Substituting (76) in the general expression for the effective attenuation b_D according to (43)

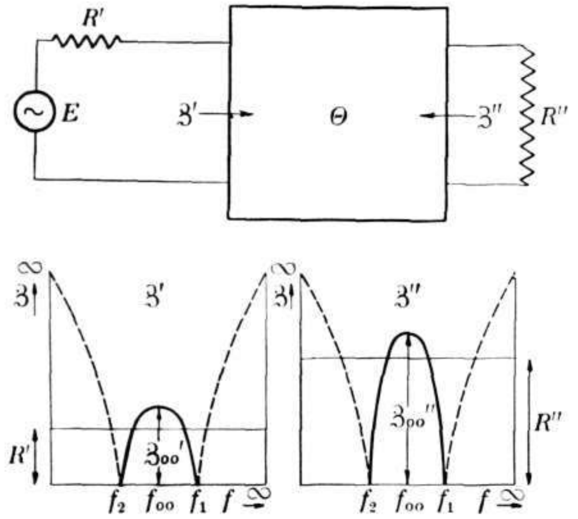


Fig. 20.

gives us

$$b_D = \log_e \frac{1}{2}\left[2\cosh\Theta + \left(a\frac{\mathfrak{Z}'}{\mathfrak{Z}_{oo}'} + \frac{1}{a}\frac{\mathfrak{Z}_{oo}'}{\mathfrak{Z}'}\right)\sinh\Theta\right], \quad (77)$$

or, if we introduce the mid-series impedance $\mathfrak{Z}_T$ instead of $\mathfrak{Z}'$

$$b_D = \log_e \frac{1}{2}\left[2\cosh\Theta + \left(a\frac{\mathfrak{Z}_T}{\mathfrak{Z}_{Too}} + \frac{1}{2}\frac{\mathfrak{Z}_{Too}}{\mathfrak{Z}_T}\right)\sinh\Theta\right] \quad (78)$$

which is the general expression for the effective attenuation in an *a-matched symmetrical "constant k" filter.*

It will be appropriate to point out here that *both (71) and (78) apply even if we exchange the mid-series image impedances for the mid-shunt image impedances,* which can easily be verified if we remember that in a "constant k" filter we have

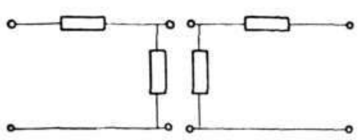
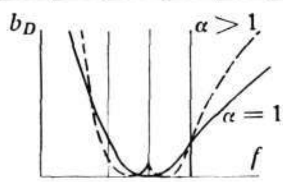
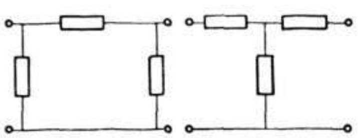
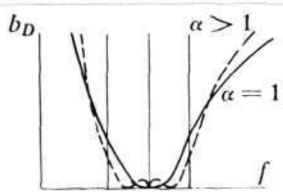
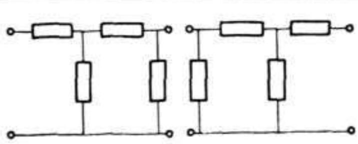
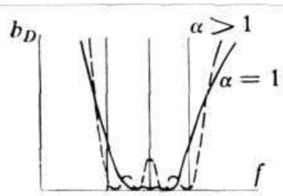
$$\frac{\mathfrak{Z}_T}{\mathfrak{Z}_{Too}} = \frac{\mathfrak{Z}_{\pi oo}}{\mathfrak{Z}_\pi} \quad \ldots\ldots\ldots\ldots \quad (79)$$

and that, when exchanging image impedances, a must be replaced by $\frac{1}{a}$.

The two formulæ (71) and (78) can be used for calculating the effective attenuation of any a-matched "constant k" filter consisting of an arbitrary number of half sections. In the following table IX are given the results obtained by applying these formulæ to "constant k" band pass filters of one, two, and three half-sections.

The formulæ for calculating the effective attenuation indicate that the degree of the function $y = f(U_k)$ under the root sign rises by one for each half section added. For each degree of $y = f(U_k)$ we find a maximum or minimum in

TABLE IX.

No. of ½ sections in the filter	*Formula for computing the effective attenuation b_D nepers*	*Effective attenuation curve*
 ½-section.	$b_D = \log_e \frac{1}{2}\sqrt{\left(a+\frac{1}{a}\right)^2 + 2\,(a^2-1)\,U_k + a^2 U_k^2}$	
 ²/₂-sections.	$b_D = \log_e \sqrt{1 - \left(a-\frac{1}{a}\right)^2 U_k + 2\,(1-a^2)\,U_k^2 - a^2 U_k^3}$	
 ³/₂-sections.	$b_D = \log_e \frac{1}{2}\sqrt{\left(a+\frac{1}{a}\right)^2 + \left(10\,a^2 - 18 + \frac{8}{a^2}\right)U_k + \left(33\,a^2 - 48 + \frac{16}{a^2}\right)U_k^2 + (40\,a^2 - 32)\,U_k^3 + 16a^2 U_k^4}$	

the effective attenuation curve on either side of the geometric mean frequency.

The formulæ are also applicable to high pass, low pass, and band-suppress filters as long as values for U_k are introduced as in Table VI.

6 B. Load impedance of α-matched filters.

The formulæ deduced in the preceding section have provided us with a basis for calculating the effective attenuation of any α-matched "constant k" filter. The load impedance of such a filter must, however, often be known before one is able to determine how practical and suitable it is. We will therefore find, on the basis of the general formulæ given in Ch. 4 A, general expressions for the load impedance of α-matched "constant k"-filters and work out an example of a half section of such a filter.

According to (35) and (36) we have

$$\left.\begin{aligned}\mathfrak{Z}_B' &= \mathfrak{Z}' \operatorname{tgh}(\Theta + \sigma'') \\ \mathfrak{Z}_B'' &= \mathfrak{Z}'' \operatorname{tgh}(\Theta + \sigma')\end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (35)$$

where

$$\left.\begin{aligned}\operatorname{tgh}\sigma' &= \frac{R'}{\mathfrak{Z}'} \\ \operatorname{tgh}\sigma'' &= \frac{R''}{\mathfrak{Z}''}\end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (36)$$

As in the foregoing chapters we identify $\mathfrak{Z}'$ with $\mathfrak{Z}_T$ and $\mathfrak{Z}''$ with $\mathfrak{Z}_\pi$ and further introduce according to (69)

$$\left.\begin{aligned}R' &= \frac{1}{\alpha}\mathfrak{Z}'_{oo} = \frac{1}{\alpha}\mathfrak{Z}_{Too} \\ R'' &= \alpha\,\mathfrak{Z}_{oo}'' = \alpha\,\mathfrak{Z}_{\pi oo}\end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (69)$$

We then get

$$\left.\begin{aligned}\operatorname{tgh}\sigma' &= \frac{1}{\alpha}\frac{\mathfrak{Z}_{Too}}{\mathfrak{Z}_T} \\ \operatorname{tgh}\sigma'' &= \alpha\frac{\mathfrak{Z}_{\pi oo}}{\mathfrak{Z}_\pi}\end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots (80)$$

and, from (35),

$$\left.\begin{aligned}\mathfrak{Z}_{BT} &= \mathfrak{Z}_T\frac{\operatorname{tgh}\Theta + \alpha\dfrac{\mathfrak{Z}_{\pi oo}}{\mathfrak{Z}_\pi}}{1 + \alpha\dfrac{\mathfrak{Z}_{\pi oo}}{\mathfrak{Z}_\pi}\operatorname{tgh}\Theta} \\ \mathfrak{Z}_{B\pi} &= \mathfrak{Z}_\pi\frac{\operatorname{tgh}\Theta + \dfrac{1}{\alpha}\dfrac{\mathfrak{Z}_{Too}}{\mathfrak{Z}_T}}{1 + \dfrac{1}{\alpha}\dfrac{\mathfrak{Z}_{Too}}{\mathfrak{Z}_T}\operatorname{tgh}\Theta}\end{aligned}\right\} \quad \ldots\ldots\ldots\ldots (81\text{ a})$$

and finally, with the aid of (72), the load impedance of an α-matched "constant k"-filter.

$$\left.\begin{aligned}\mathfrak{Z}_{BT} &= \mathfrak{Z}_T\frac{\operatorname{tgh}\Theta + \alpha\sqrt{1+U_k}}{1 + \alpha\sqrt{1+U_k}\operatorname{tgh}\Theta} \\ \mathfrak{Z}_{B\pi} &= \mathfrak{Z}_\pi\frac{\operatorname{tgh}\Theta + \dfrac{1}{\alpha\sqrt{1+U_k}}}{1 + \dfrac{1}{\alpha\sqrt{1+U_k}}\operatorname{tgh}\Theta}\end{aligned}\right\} \quad \ldots\ldots\ldots (81\text{ b})$$

In the above equations tgh Θ can be expressed in terms of U_k if the number of sections forming the filter in question is known. This generally simplifies the expression considerably.

As an example we will apply (81 b) to filter section 13 a, Table III, connected as in fig. 21.

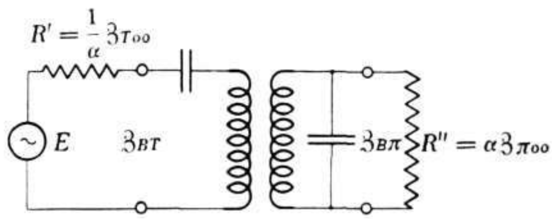


Fig. 21.

This filter section is equivalent to a half section "constant k" filter and according to (30) (cf. also (72)) we thus have

$$\left.\begin{aligned}\mathfrak{Z}_T &= \mathfrak{Z}_{Too}\sqrt{1+U_k} \\ \mathfrak{Z}_\pi &= \frac{\mathfrak{Z}_{\pi oo}}{\sqrt{1+U_k}} \\ \sinh\Theta &= \sinh\frac{\gamma}{2} = \sqrt{U_k} \\ \cosh\Theta &= \cosh\frac{\gamma}{2} = \sqrt{1+U_k}\end{aligned}\right\} \quad \ldots\ldots\ldots (82)$$

from which $\operatorname{tgh}\Theta = \operatorname{tgh}\frac{\gamma}{2}$ can be calculated. The value thus obtained is substituted in (81 b), which when reduced to its simplest terms becomes

$$\left.\begin{aligned}\mathfrak{Z}_{BT} &= \mathfrak{Z}_{Too}\frac{\alpha(1+U_k) + \sqrt{U_k}}{1 + \alpha\sqrt{U_k}} \\ \mathfrak{Z}_{B\pi} &= \mathfrak{Z}_{\pi oo}\frac{1 + \alpha\sqrt{U_k}}{\alpha(1+U_k) + \sqrt{U_k}}\end{aligned}\right\} \quad \ldots\ldots\ldots (83)$$

Here also we find what we expected, namely, that the product of the two load impedances $\mathfrak{Z}_{BT}$ and $\mathfrak{Z}_{B\pi}$ is constant, or that

$$\mathfrak{Z}_{BT} \cdot \mathfrak{Z}_{B\pi} = \mathfrak{Z}_{Too} \cdot \mathfrak{Z}_{\pi oo} = k^2 \quad \ldots\ldots\ldots\ldots\ldots \ (84)$$

which is always the case in "constant k"-filters.

In (83) U_k is always negative, and hence the load impedance will be complex. We therefore put

$$\frac{\alpha\,(1+U_k)+\sqrt{U_k}}{1+\alpha\sqrt{U_k}} = a + jb \quad \ldots\ldots\ldots\ldots\ldots \ (85)$$

and solve a and b, which become:

$$\left.\begin{aligned} a &= \frac{\alpha}{1-\alpha^2\,U_k} \\ b &= \pm\sqrt{-U_k}\,\frac{1-\alpha^2\,(1+U_k)}{1-\alpha^2\,U_k} \end{aligned}\right\} \quad \ldots\ldots\ldots \ (86\,\text{a})$$

which when $\alpha = 1$, become

$$\left.\begin{aligned} a &= \frac{1}{1-U_k} \\ b &= \pm\frac{-U_k\sqrt{-U_k}}{1-U_k} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots \ (86\,\text{b})$$

The signs + and − for b mean that the imaginary component may be a positive or negative reactance on different sides of the geometric mean frequency, as will be seen from Tables II and III.

From this we can then calculate the impedance for $\mathfrak{Z}_{BT}$ and the admittance $Y_{B\pi}$ for $\mathfrak{Z}_{B\pi}$ according to the following formulæ:

$$\left.\begin{aligned} \mathfrak{Z}_{BT} &= \mathfrak{Z}_{Too}\,(a+jb) \\ \mathfrak{Z}_{B\pi} &= \mathfrak{Z}_{\pi oo}\,\frac{1}{(a+jb)} \\ Y_{B\pi} &= Y_{\pi oo}\,(a+jb) \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (87)$$

An examination of (86) with regard to maxima and minima and the limit values when $U_k = 0$ and $U_k = -1$ respectively gives the following results (Table X).

The results are given graphically in fig. 22, where a and b are plotted as functions of $-U_k$ for $\alpha = 1$, $\sqrt{2}$, and 2 respectively. The real component a is always positive, while the imaginary component b, as we have already mentioned, can be either positive or negative, which means that the reactance can be either positive or negative. If, for instance, $\mathfrak{Z}_{BT}$ is plotted as a function of the frequency instead of U_k in a band filter, we find that a varies symmetrically about the geometric mean frequency f_{oo}, while b passes through zero at this frequency and at the two frequencies (fig. 23), determined by the α-matching.

Figs. 22 and 23 show that at normal matching $(\alpha = 1)$ the mid-series load impedance $\mathfrak{Z}_{BT}$ is equal to the external resistance, e. g. the internal impedance $\mathfrak{Z}_{Too}$ of the generator where $U_k = 0\,(f_{oo})$, and that its real component is continuously approaching zero while its imaginary component is approaching infinity for a falling or rising frequency. When $\alpha > 1$ the load impedance at $U_k = 0\ (f_{oo})$ is also real and equal to $\alpha\,\mathfrak{Z}_{Too}$, which is thus larger than in the preceding case. For frequencies lower or higher than f_{oo}, the real part of this load impedance will rapidly diminish, while its imaginary component first rises and becomes positive (or negative), then passes through zero, and subsequently grows continuously, reaching very high negative (or positive) values. The real part becomes $\frac{1}{\alpha} \cdot \mathfrak{Z}_{Too}$, *i. e.* equal to the external

TABLE X.

U_k	a	b	Remarks
0	α	0	Geometric mean frequency f_{oo}
1	$\frac{\alpha}{1+\alpha^2}$	$\frac{1}{1+\alpha^2}$	Cut-off frequency f_1 and f_2
$\frac{1}{\alpha^2} - 1$	$\frac{1}{\alpha}$	0	zero value of b
$\sqrt{\frac{2}{\alpha^2}+\frac{1}{4}} - \left(\frac{1}{\alpha^2}+\frac{1}{2}\right)$	$\frac{1}{2}\sqrt{2+\frac{\alpha^2}{4}+\frac{\alpha}{4}}$	$\frac{\alpha^2}{2}\sqrt{\sqrt{\frac{2}{\alpha^2}+\frac{1}{4}} - \left(\frac{1}{\alpha^2}+\frac{1}{2}\right)} \times \left(\frac{2}{\alpha^2} - \frac{1}{2} - \sqrt{\frac{2}{\alpha^2}+\frac{1}{4}}\right)$	minimum value of b

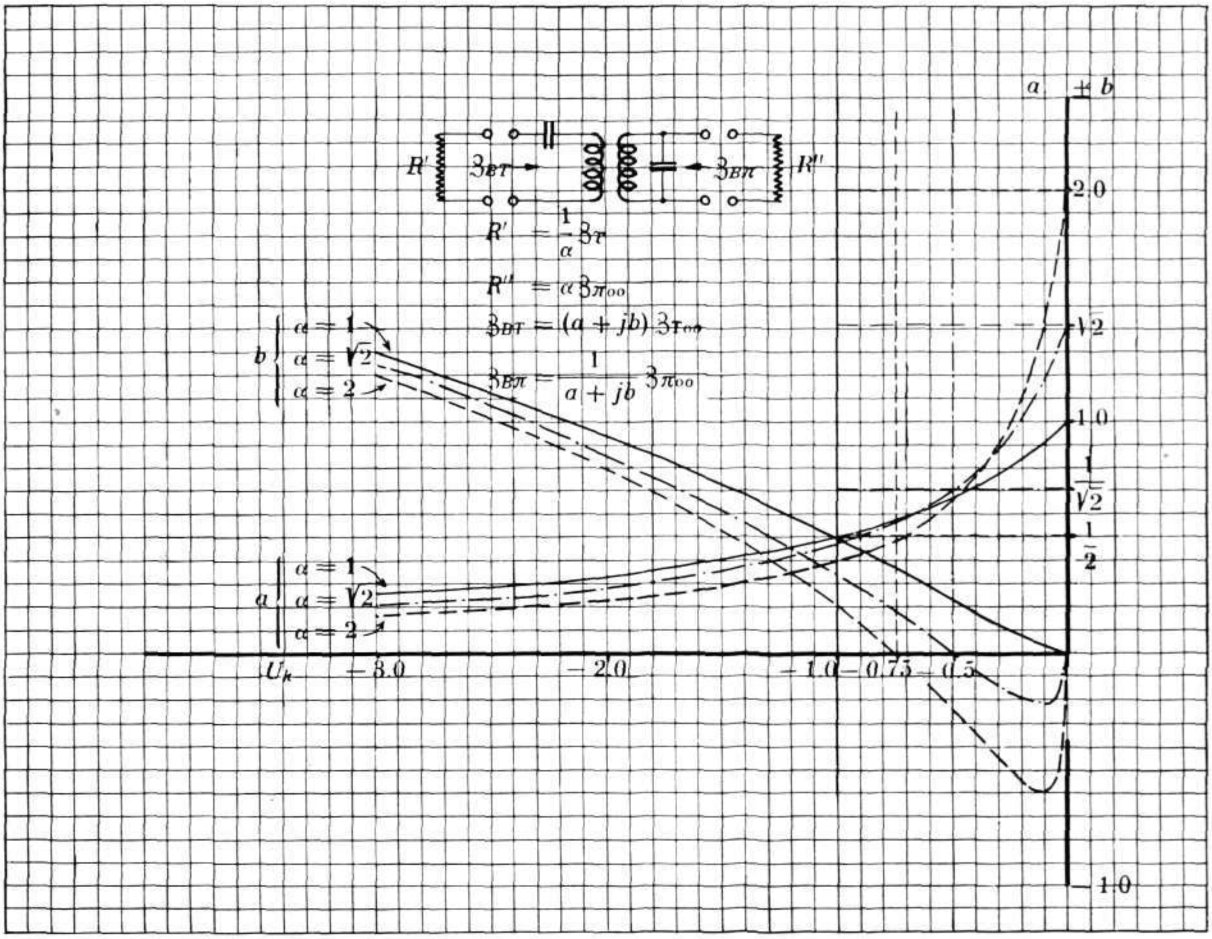


Fig. 22.

resistance, at the same time as the imaginary part becomes zero. Here, then the filter is matched with the external resistance, the reflections disappear and the effective attenuation becomes zero, as can be seen by comparison with Table XI.

It should be observed that the curves in fig. 23 for the load impedance are continuous. In Tables II and III this does not seem to be the case for the filter image impedances, but this is only apparent and due to the symbolic method of plotting (cf. p. 22).

The load impedance of a-matched filters may be calculated from (35) or (81) for various numbers of half sections. In each case we then get curves corresponding to those of fig. 23. A common characteristic of these curves is that the real component of the load impedance is equal to the external resistance for those values of U_k which make the imaginary component zero. Thus here the matching is ideal and the effective attenuation zero.

6 C. Reflections in a-matched filters.

The formulæ deduced in the last chapter for the load impedance may be used for finding the reflection coefficient ε. According to the definition in ch. 4 A.

$$\varepsilon' = \frac{\mathfrak{Z}_B' - R'}{\mathfrak{Z}_B' + R'} \quad \text{or} \quad \varepsilon'' = \frac{\mathfrak{Z}_B'' - R''}{\mathfrak{Z}_B'' + R''}$$

We have now, in the same way as in the foregoing chapter,

$$\left.\begin{aligned} \mathfrak{Z}_{BT} &= \mathfrak{Z}_B' = \mathfrak{Z}_T \operatorname{tgh}(\Theta + \sigma'') \\ \mathfrak{Z}_{B\pi} &= \mathfrak{Z}_B'' = \mathfrak{Z}_\pi \operatorname{tgh}(\Theta + \sigma') \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots (35)$$

and

$$\left.\begin{aligned} R' &= \frac{1}{a}\,\mathfrak{Z}_{Too} \\ R'' &= a\,\mathfrak{Z}_{\pi oo} \end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (69)$$

from which we obtain the reflection coefficients ε_T and ε_π respectively

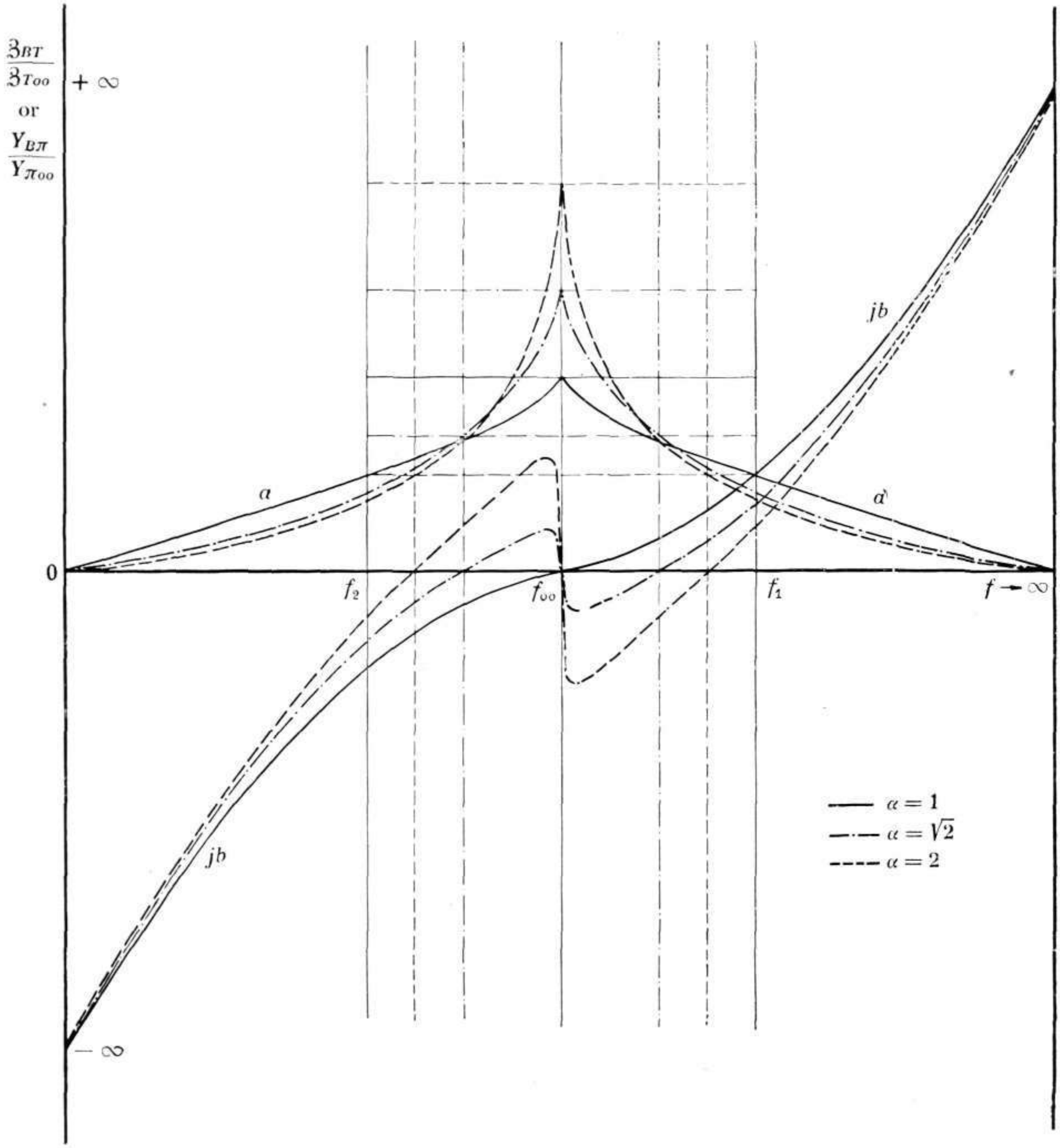


Fig. 23.

$$\left.\begin{aligned}
\varepsilon_T &= \frac{\operatorname{tgh}(\Theta + \sigma'') - \frac{1}{a}\frac{\mathfrak{Z}_{Too}}{\mathfrak{Z}_T}}{\operatorname{tgh}(\Theta + \sigma'') + \frac{1}{a}\frac{\mathfrak{Z}_{Too}}{\mathfrak{Z}_T}} \\
\varepsilon_\pi &= \frac{\operatorname{tgh}(\Theta + \sigma') - a\frac{\mathfrak{Z}_{\pi oo}}{\mathfrak{Z}_\pi}}{\operatorname{tgh}(\Theta + \sigma') + a\frac{\mathfrak{Z}_{\pi oo}}{\mathfrak{Z}_\pi}}
\end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots \quad (88)$$

where

$$\left.\begin{aligned}
\operatorname{tgh}\sigma' &= \frac{1}{a}\frac{\mathfrak{Z}_{Too}}{\mathfrak{Z}_T} \\
\operatorname{tgh}\sigma'' &= a\frac{\mathfrak{Z}_{\pi oo}}{\mathfrak{Z}_\pi} \\
&\text{and according to (79)} \\
\operatorname{tgh}\sigma' \operatorname{tgh}\sigma'' &= 1
\end{aligned}\right\} \quad \ldots\ldots\ldots\ldots\ldots \quad (89)$$

By reducing (88) and (89) to their simplest terms we finally obtain the reflection coefficients

$$\left.\begin{aligned}\varepsilon_T &= \frac{\operatorname{tgh}\sigma'' - \operatorname{tgh}\sigma'}{2\operatorname{tgh}\Theta + \operatorname{tgh}\sigma' + \operatorname{tgh}\sigma''}\\ \varepsilon_\pi &= \frac{\operatorname{tgh}\sigma' - \operatorname{tgh}\sigma''}{2\operatorname{tgh}\Theta + \operatorname{tgh}\sigma' + \operatorname{tgh}\sigma''}\end{aligned}\right\}\ldots\ldots\ldots\ldots (90)$$

which are thereby shown to be identical at the mid-series and mid-shunt terminations except for the sign. Normally, it is the absolute value of the reflection coefficient that is of interest, and we then have in the general case

$$\varepsilon = \varepsilon_T = \varepsilon_\pi = \left|\frac{\operatorname{tgh}\sigma'' - \operatorname{tgh}\sigma'}{2\operatorname{tgh}\Theta + \operatorname{tgh}\sigma' + \operatorname{tgh}\sigma''}\right| \quad (91)$$

As an example of the calculation of reflections in a filter we will work out ε for the same filter as in the foregoing chapter, namely, a half section "constant k" filter (fig. 21). For this filter we have according to the above

$$\operatorname{tgh}\Theta = \operatorname{tgh}\frac{\gamma}{2} = \frac{\sinh\frac{\gamma}{2}}{\cosh\frac{\gamma}{2}} = \frac{\sqrt{U_k}}{\sqrt{1+U_k}}$$

$$\operatorname{tgh}\sigma' = \frac{1}{a}\frac{\mathfrak{Z}_{T\infty}}{\mathfrak{Z}_T} = \frac{1}{a\sqrt{1+U_k}}$$

$$\operatorname{tgh}\sigma'' = a\frac{\mathfrak{Z}_{\pi\infty}}{\mathfrak{Z}_\pi} = a\sqrt{1+U_k}$$

By substituting in (91) we get

$$\varepsilon = \left|\frac{a^2(1+U_k)-1}{2a\sqrt{U_k} + a^2(1+U_k)+1}\right| \ldots\ldots\ldots (92\text{ a})$$

or

$$\varepsilon = \frac{|a^2(1\ U_k)-1|}{\sqrt{[a^2(1+U_k)+1]^2 - 4a^2U_k}} \ldots\ldots (92\text{ b})$$

The reflection coefficient ε for this half section is plotted graphically in fig. 24 for various values of a viz. 1, $\sqrt{2}$, and 2. It will be zero when

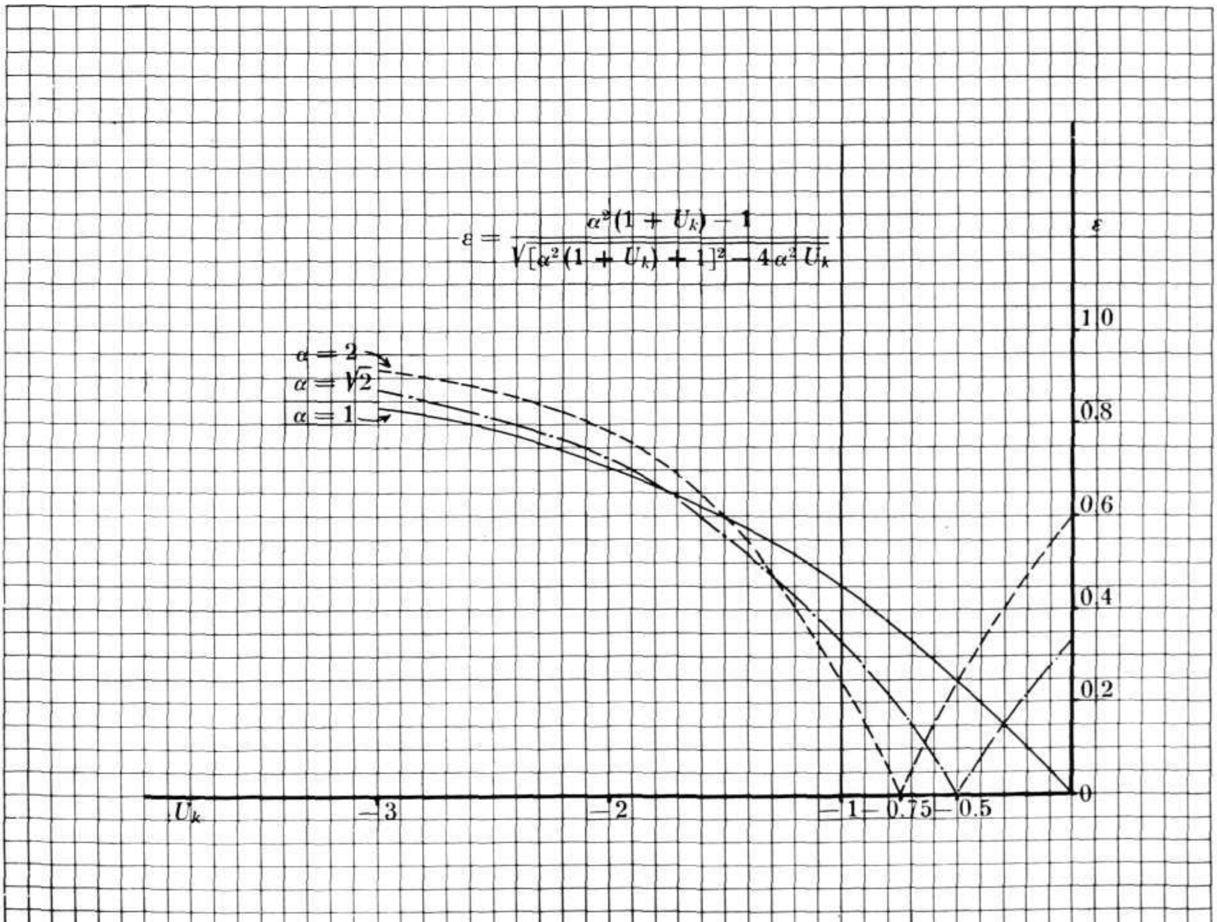


Fig. 24.

$$U_k = \frac{1}{a^2} - 1, \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (93)$$

which agrees with the statements in Table X, where it was shown that the imaginary part of the load impedance became zero and the real part exactly equal to the external resistance at this value of U_k.

(92 b) can be simplified still further if instead of the variable U_k—reckoned from the origin along the negative abscissa axis—we introduce the variable u_k, which is reckoned positive or negative from the value of U_k given above in (93) at which ε becomes zero—in other words we move the coordinates. The expression for the reflection coefficient ε then takes the form

$$\varepsilon = \frac{1}{\sqrt{1 + \left(\frac{2}{au_k}\right)^2}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (94)$$

and the actual value of U_k is determined by

$$U_k = \frac{1}{a^2} - 1 \pm u_k \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (95)$$

The curve for the reflection coefficient ε is symmetrical about an axis determined by $U_k = \frac{1}{a^2} - 1$.

Fig. 24 shows that the reflections are least in the middle of the filter band ($U_k = 0$) in a filter where $a = 1$, while they rise to 45 per cent. at the cut-off frequency ($U_k = -1$) for the same value of a. In a filter where $a = \sqrt{2}$ — which has for other reasons been found a suitable value — the reflection coefficient at the centre of the band and at the cut-off frequencies will be 33.3 per cent, and will be reduced to zero between these points at $U_k = -0.5$. The reflections are thus considerable, even in a-matched filters, but a-matching does make it possible to shift the ranges of minimum reflections to frequencies which are on either side of the centre of the band. As we have already mentioned, not only the effective attenuation but also the reflections must be considered when selecting the value of a. The points of view given above will then form a good guide.

6 D. Discussion of advantages and drawbacks in a-matching.

Proceeding from general formulæ for effective attenuation, load impedance and reflection coefficient, we have above deduced special formulæ for a-matched "constant k" filters. These special formulæ have become relatively simple and suitable for algebraic treatment on account of the favourable properties of these filters. Again, in "constant k" filters it is very simple to make the conversion from expressions having U_k as parameter to other forms with the frequency as parameter, as has been shown in Ch. 5. The universal applicability already attained by this class of filter will have been even further extended by this work. In conclusion we give below a summary of the advantages of a-matching in the calculation of filters.

1. The effective attenuation curve approaches the ideal, a rectangle open at the top. This property is specially marked in narrow band filters of the kind used for carrier-current telegraphy.

2. By choosing a suitable value of a the point on the effective attenuation curve where the effective attenuation is a minimum may be fixed at a frequency which has to be transmitted with particularly low attenuation, e. g. the carrier frequency in carrier current telephony plants working with one of the side bands suppressed. Another example of such a shifting of the minimum on the effective attenuation curve is the case in which it is desired to transmit a certain frequency, e. g. 800 cycles/sec., or certain frequencies within a band of voice frequencies, with the least possible attenuation.

3. In a-matching of filters ($a > 1$) greater effective attenuation is always obtained far outside the filter band than in the normal case where $a = 1$.

Certain drawbacks naturally accompany the use of a-matched filters. The most important of these has already been pointed out above, viz. increased reflections for certain frequencies in the filter band. But these reflections are the very cause of the favourable appearance of the effective attenuation curve, and the drawback of reflections is often balanced by improved attenuation.

In the cases of asymmetrical "constant k" filters discussed above, we have assumed that the filters are to be a-matched both ways, so that the external impedances have been made smaller (or greater) than the image impedances at mid-series (or mid-shunt) terminations. This is of course not essential. One can also sometimes with advantage a-match the filter on one side only, or select different values of a for the two sides.

Zobel's method, called the "m-derivation" of "constant k" filters, which gives a level image impedance within the filter band, can in certain cases be used in conjunction with α-matching, e. g. by making the filter on the one side of m-type while it is α-matched on the other side. A filter of m-type in itself shows good matching with an external resistance within the filter band, and, by a suitable choice of magnitude for the parameter m, this matching can so be done that the image impedance becomes equal to the external resistance at *three* frequencies.

By α-matching such a m-type filter also, the image impedance can be made to coincide with the external resistance for *four* frequencies, of which two will be very close to the cut-off frequencies. It has not yet been investigated which values should in such a case be given to m and which to α, but what has been proved in this paper makes it possible to say that further improvements in matching are possible by this means.

It has already been pointed out that calculations for the choice of the best value of α to obtain the most rectangular effective attenuation curve possible, ought really to have been performed with due allowance for energy dissipation in coils and condensers. This calculation is, however, very complicated, though it might be done in some special cases. A new general method for calculating the attenuation in filters with energy dissipation, which has just been published by Pleijel,[1] is very promising in this respect.

It now only remains to be pointed out that α-matching can naturally be used not only in "constant k" filters but also in other types of filters, e. g. as in Tables II and III. In these cases, however, the calculations can not be so easily surveyed and will take more time, for in them the product $z_1\ z_2$ is not independent of the frequency. Their image impedances and load impedances can therefore not be expressed as functions only of the parameter U. At the same time it seems very likely that in these cases too α-matching will have advantages, especially with regard to effective attenuation.

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Method of Installation of Subscriber's Automatic Telephones when Changing over from LB to the Automatic System.

Communication from the Concession Department.

By *Hugo Blomberg.*

When a telephone plant is automatized it is often found possible to retain the same lines in the automatic system—although perhaps a few alterations and repairs may be necessary. The new automatic exchange is connected by transfer joints to the primary cables coming from the old manual exchange, and at a fixed moment all the subscribers, or in large exchanges a group of subscribers, are switched over to the automatic exchange. If the manual exchange is designed on the CB system, the subscribers' stations have been fitted with dials or exchanged for automatic telephones before the switch-over, so that they do not complicate that process.

But if the manual exchange is arranged on the LB-system, the old subscribers' LB telephones obviously cannot be exchanged for an automatic one before the switch-over; instead it must be left, and the new automatic telephone installed as well. The LB telephones have therefore to be used right up to the actual time of switch-over, and not until then can the automatic ones be used.

The usual plan for this has been to connect the subscriber's incoming line to a special switch with which the subscriber can turn his line over from one set to the other at a definite time. In this case, however, it has been found necessary to put in, besides the switch, a condenser in series with the LB telephone, as otherwise every telephone having its bell connected direct to the subscriber line would, when the switch-over is done (usually at night), make call at the exchange until the subscriber had thrown over the switch and so changed the line to the automatic set.

Apart from considerations of cost, this arrangement is not very convenient, for the subscriber's incoming line cannot be fixed finally to the line terminals of the automatic telephone before the switch-over is done, because the switch, condenser and LB telephone have to be removed afterwards.

In order to avoid this, the following method has been worked out, and recently used in practice with good results.

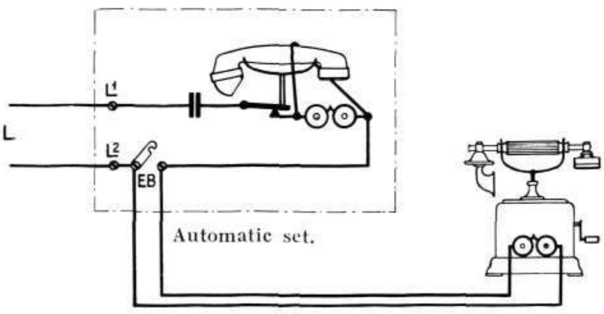


Fig. 1.

Fig. 1 shows how the connexions are made when the automatic telephone is installed before the switch-over. The incoming subscriber's line *L* is connected to the two line terminals, L_1 and L_2, of the automatic telephone, which is therefore connected at once in its permanent position. The latter's terminal strip always has two terminals *EB*, for connecting an extra bell, these being normally joined by a metal strip. To these the line terminals of the LB telephone are connected, the metal strip being folded to one side. When, therefore, the hook of the automatic telephone is depressed, i. e. when it is in the signalling position, the LB telephone will be connected to the line in series with the bell and condenser of the automatic telephone. The bell impedance is, however, far too high for speech currents and

R 4068 Fig. 2.

R 4067 Fig. 3.

cannot therefore be connected while the LB telephone is being used. It is therefore short circuited by an ordinary connecting wire arranged at the telephone and connected to the bell terminals on the strip of the telephone, taken out through the hole for the cord in the casing,, and laid round the receiver hook or over the microtelephone and dial in such a way as to keep the hook depressed, as in figs. 2 and 3. This connecting wire has two functions, the electrical one of short-circuiting the ringing bell, and the mechanical one of preventing the hook from being moved. By means of it (it might suitably be enamelled and spun over in some colour) the automatic set is sealed in the ringing position and at the same time shows the subscriber that *it is not to be used*. The LB telephone is connected to the subscriber's line in series with the condenser, and conversation can thus be carried on undisturbed.

The subscriber is instructed to cut this connecting wire at a stated time—subsequent to the switch-over having been completed—thus breaking the mechanical sealing, after which the automatic telephone will be used. By cutting the wire the short circuit across the bell is broken and the automatic telephone is put into normal working order, while the LB telephone remains connected as an extra bell. Incoming signals will thus ring the bells of both sets. After some time a fitter will arrive and remove the LB telephone and the connecting wire, the latter being left hanging till then. He will also connect the two terminals E and B by the metal strip. No change whatever need be made then in the incoming line.

By this method the new automatic telephone can be installed very simply without either an extra switch or a condenser being necessary, while at the same time the old LB telephone is left in use. Obviously, the method can be used for switching over from a local battery system just as well to a manual as to an automatic CB-system.

Possibilities and Tendencies of Power Transmission.

By Professor *Sten Velander.*

The need of power transmission.

Today, man and his goods are carried at over a hundred miles an hour, and his messages go round the world with the speed of light. A century or two ago, the speed was a few miles an hour and limited to what man and beast could do by muscular effort. Earlier still, speed and transport facilities had remained practically unchanged during the thousands of years of man's existence. Progress has been similar in many spheres of material culture—slow and snail-like at first, then suddenly almost explosive.

The turning point came when humanity began to harness the forces of nature, when the muscles of man and beast were relieved, first by steam power, and later even more by electric power. The internal combustion engine has played a very important part too, particularly in the development of transport during the last decades.

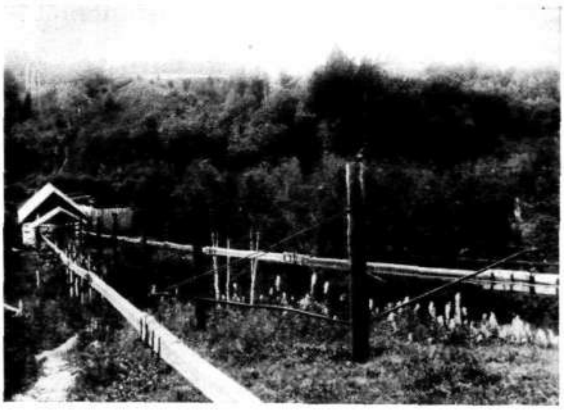
It meant a great deal to progress when man began to fetch raw materials from other countries, from the far corners of the earth. That was done already in ancient times however, though the quantity transported in those days did not go far and consisted mostly of luxuries for the rich, as operations on a large scale were impossible for lack of power. We depend of course on other countries and continents for the raw materials of, say, motor cars, but more than that is required for car manufacture. Even if man had been able to collect these several raw materials, all his efforts to put the modern automobile within the reach of everybody would have been vain if he had not forced the energy contained in coal and water into his service and made it do 99 per cent. of the mechanical work.

For two thousand years man has been very near to subjugating the wild and intractable forces of nature. Suggestions and proposals have been made, but never carried through. The first steam engine was made before the beginning of our era, likewise the first water wheel. The art of making the never-failing energy of running water do one's work was known, but little used. The significance of being able to increase human strength tenfold or a hundredfold was not appreciated and — there was no means of transmitting the power.

Power transmission in ancient times.

Attempts with rods or shafts actually succeeded in transporting the power a few miles. Kristoffer Polhem, our great engineering genius, improved this method considerably, and especially increased its efficiency. These transmissions were greatly admired, and would carry the power of the huge water wheel a whole mile and a half across forest and mountain to the pumps of the mine. At that time wonder and admiration were felt for this transmission of a few horse power, stretching, noisily grating, through the forest. To many it seemed witchcraft, and the legend of a Polhem transmission having frightened ravaging Russian hordes may be true. All things considered, these rod transmissions did good service in their day and odd examples of them have even survived till now, so that the Technical Museum has been able to acquire several. Fig. 1 shows a mechanical power transmission of the 18th century, side by side with an electrical power line of the 20th.

During the 19th century, direct-driving water power, and direct-driving steam power even more, became the dominant source of energy in industry. Our iron works, our textile and paper industries, were lined up along the falls and rapids of the rivers. In the plains the industrial communities were marked by their chimneys. In agriculture, the horse-gear was relieved by the portable engine barely a generation ago. But the small factory, the craftsman, and the home,



R 4022 Fig. 1. Mechanical power transmission by Polhem's rods; in the background an electrical overhead line.

still lacked the untiring helper which large scale industry had procured for the rough work.

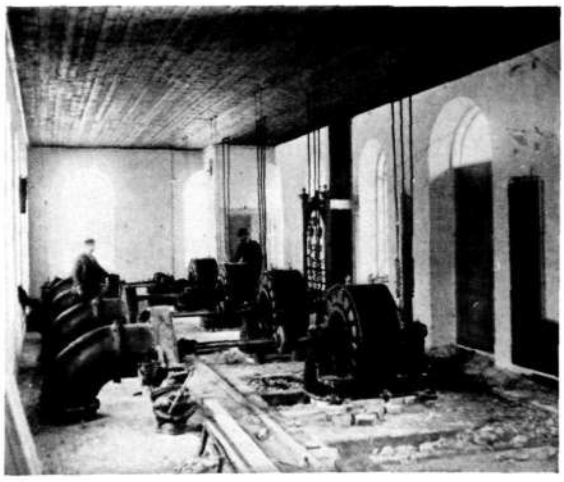
Beginning of electric transmission.

Then, 50 years ago, electrical energy, the new force of nature, began to be heard of. It could be transmitted in any quantity for miles by thin metal wires. It could be used for lighting, for mechanical work, for heating, for chemical processes. It was pure magic.

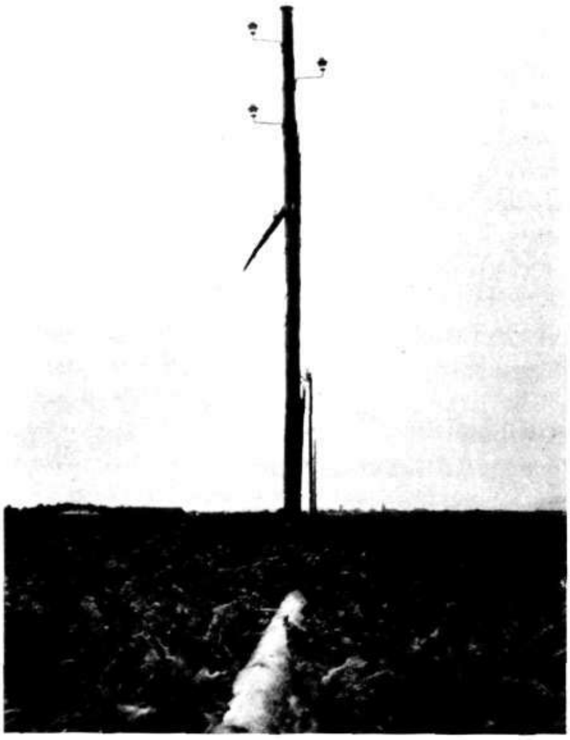
The first steps in electric power transmission were taken about 1880. Electrical energy was then distributed in towns over short distances for lighting and to some extent for power. The first municipal electricity works were built in the eighties. Even some small Swedish towns built electricity works. The larger towns already possessing gas works as a rule came later. The first municipal electricity works of Stockholm was established in 1892, in Malmö in 1901, and in Norrköping in 1904. Electric power transmission did not seriously begin until the beginning of the nineties, when the 3-phase electric motor was invented. Easily transformable A. C. could then be used for both large and small power requirements in industry. Our iron works were the first to make use of electrical power transmission. The Hellsjön—Grängesberg line, carrying 500 HP at 10 000 volts and completed in 1893, was probably among the first, if not the very first, industrial power line in the world. Its simply equipped power station (fig. 2) is vastly different from modern power stations, and would scarcely suit the increased demands of our days.

These early plants, however, showed that the natural power of the water falls could be successfully transformed into electrical energy, easily carried, and used at incredible distances from the water falls. It was also found that by means of electrical energy power could with great advantage be transmitted and distributed even at as short distances as within a factory. Power was therefore distributed electrically even when the electrical energy was produced by steam power in or in the immediate neighbourhood of the factories. When, at the beginning of this century, the turbine became the dominant type of steam engine and the power requirements at the same time grew to many thousands of horse power, the employment of ropes, countershafts and belting became out of the question. Practically all power transmission and distribution then became electrical, whether the power was produced by water or fuel.

With the close of last century, when technical designs had settled down and become reliable, confidence in electricity grew and its value, particularly as a means of utilizing water power, was exaggerated. The ever-flowing masses of water, producing day after day immense amounts of power, fascinated and dazzled. It was overlooked that the dams, canals, turbines, and generators necessary for harnessing the forces of nature to the engines of industry, cost millions of money. It was forgotten that the power lines had to be carried mile after mile. Even though they were relatively cheap compared to rod or



R 4021 Fig. 2. The old Hellsjön power station, from which the first electric power line was built.



R 4028 Fig. 3. 40 kV line with wooden poles, one shattered by lightning.

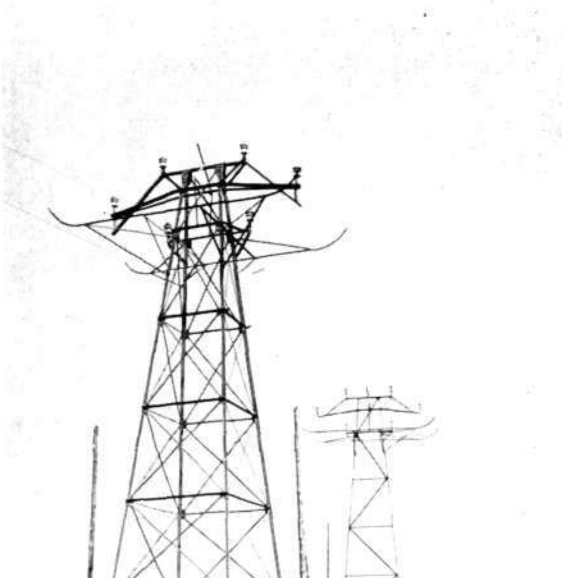
rope transmissions, the large distances made a few poles and a bit of wire swell into thousands of long, heavy poles and tons of valuable copper.

It was found that lines as simply and cheaply built as telephone lines could no longer transmit the increasing power. Their reliability had to be raised. Storm and bad weather must not interfere with the work, lightning must not damage the wires, shatter the poles, or cause any other injury (fig. 3). About 1908—1910 the demand for steel towers (fig. 4) for all more important lines was raised. This further increased the costs. The capital cost of power transmission rose. Even if cheaper maintenance and greater length of life resulted from this, it was nevertheless an additional financial burden. To the economic and financial difficulties which at this time had to be met by the power companies were added political claims for the right of the State to the water, for an extra tax on the power undertakings in the form of concession payments, etc., which all helped to make the money market uncertain and dubious of power plants, even though most of these threats came to nothing.

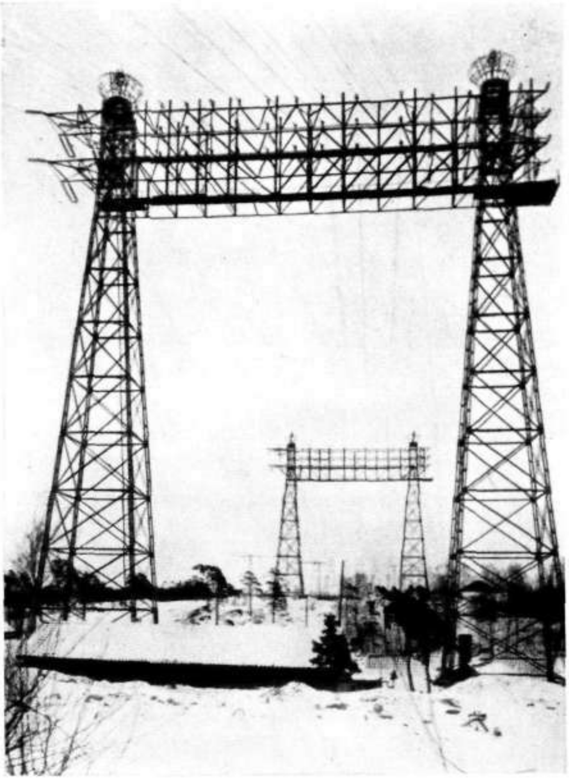
Creation of large power transmission companies.

The beginning was thus none too easy; yet, in spite of everything, the majority of our large power companies were founded at this time. The State built the Trollhättan Power Works, and from this a radial system of power lines was soon built, feeding the towns, villages, and industries all round. On crowned towers, 130 ft. high (fig. 5), an enormous bundle of copper conductors was carried across the canal, to put 100 000 HP at the disposal of every branch of industry. North and south of Trollhättan stretched the lines of the Gullspång and Yngeredsfors Companies. The South Swedish Power Company built a number of magnificent power stations on the Lagan, with the Knäred Works as their centre, whence a heavy bundle of wires ran down the West coast, branching off to the industrial towns there, with Malmö as the natural terminus and centre of a power system which distributed at first 20 000 and later 40 000 HP over the province (fig. 6).

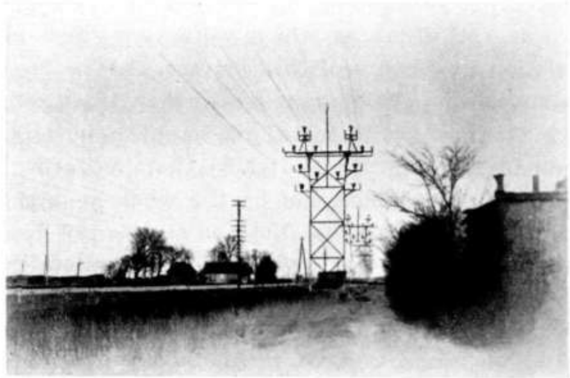
Further East, where prospects of consumption



R 4031 Fig. 4. 50 kV towers with guard brackets at a road crossing.



R 4033 Fig. 5. The 130 ft. towers carrying the Trollhättan lines across the Trollhätte Canal.

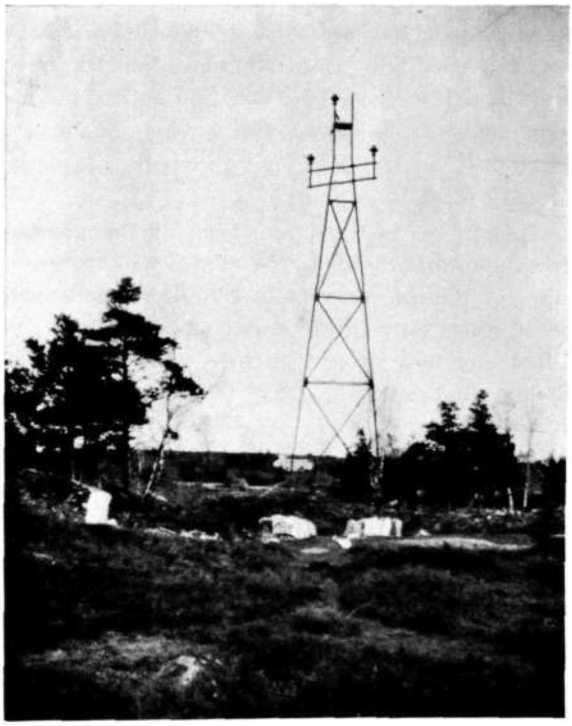


R 4025 Fig. 6. The Sydsvenska Kraftaktiebolaget main line entering Malmö. Old type of tower.

were much more modest, the Hemsjö Power Company built a number of small power stations, with lines crossing Blekinge and North-East Scania (fig. 7). In Östergötland the electrification was also carried out from small power stations in the West by the Motala Ström Power Company, one of the oldest power distributing firms in the country. The urban power supplies of Norrköping, used by the local industries, were in 1910 supplemented from Öjebro. This power was transmitted at the then high voltage of 40 kV in a double line carried on steel towers.

In the Bergslags district of central Sweden also, a few power-distributing companies were formed at an early date, e. g. Örebro Elektriska A.-B., but the transmissions were generally more or less local. As a rule the iron works transmitted power for their own requirements from water falls in the neighbourhood. In Norrland the conditions were similar, though the distances were generally longer and consequently the voltages higher than in Bergslagen. Power distribution systems for serving the public in these districts were as a rule established 5 to 10 years later than in Southern Sweden, whether built by the State or private interests.

At the time, about the end of the first decade of this century, when the majority of public service power distributing concerns were started both in this and other countries, supporting insulators were the only kind available. These restricted the tension used to 50 000 volt or slightly more, which meant a very inconvenient limitation of the possibilities of transmission,



R 4029 Fig. 7. Steel tower on the Hemsjö-Karlshamn line.

noticeable at anything beyond 60 miles, in other words, at distances which were very small in relation to the size of this country.

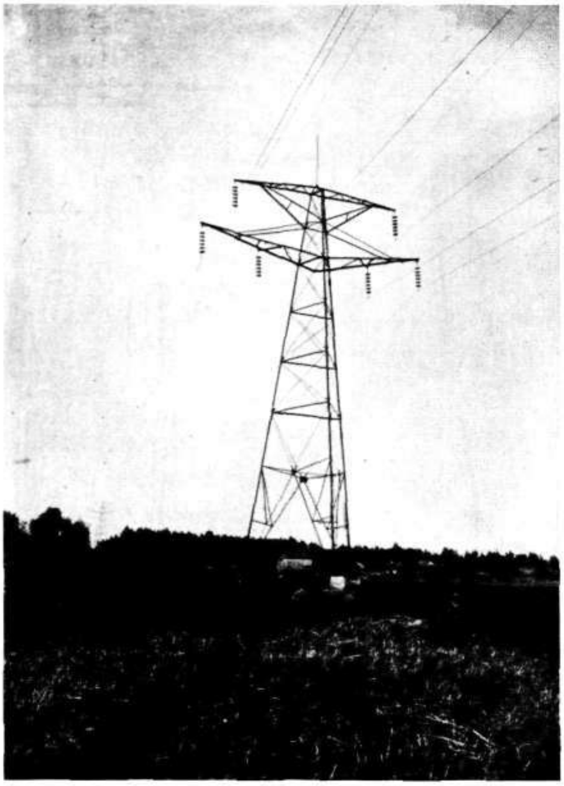
Suspension insulators were then invented, which theoretically solved the problem of unlimited operating voltages (fig. 8). Certain practical difficulties remained, but on the whole it might be said that from that time on it was not this sort of difficulty, but high costs, that limited the distance at which electric power could be transmitted with advantage.

At the same time as the main cross-country lines spread over large parts of the more densely populated areas of the country, underground cables began to be used for the distribution in towns and villages. At first, technical reasons limited the voltages to 6 to 10 kV, but this was of no great importance, considering the short distances and the moderate amounts of power at first distributed in towns.

The increased power consumption, and its significance to transmission methods.

The consumption, however, grew year by year. This universal increase has resulted in the annual output for the whole Sweden, which a little more than 20 years ago stopped at 500 million kWh, having today become 5 000 million kWh, i. e. it has increased tenfold in little more than 20 years. Part of this increase of 200 to 300 million kWh a year comes from new power systems, but a very large part is accounted for by increased loads on already existing systems.

This increased load has been of the greatest economic importance to the methods of transmission. A line to carry 500—1 000 kW a distance of 50 miles is hardly cheaper than one built for 2 000 or 3 000 kW. A further increase to, say, double that amount, i. e. 5 000 kW, raises the cost of the line not by 100 % but only by about 30 %. And it is practically the same for shorter transmission distances and proportionately smaller amounts of power. The total cost of the line, and hence also the total transmission cost, will therefore only rise slightly with increased power. This means that as the power grows the small increase in the total cost can be divided amongst a much increased number of kilowatts. The transmission cost per kW will thus fall as the consumption rises. This applies not only to the



R 4030 Fig. 8. 70 kV tower with suspension insulators. Royal Board power station, Älvkarleby.

large cross-country lines, but even more to the systems in towns, villages, etc., and is the principal reason for the selling price of electric power remaining at the same level in spite of rising wages, cost of materials, etc. It has even been possible to reduce the price of power distributed in towns considerably, while at the same time increasing, both absolutely and relatively, the profit to the towns from this source.

Improving the strength and reliability of the lines.

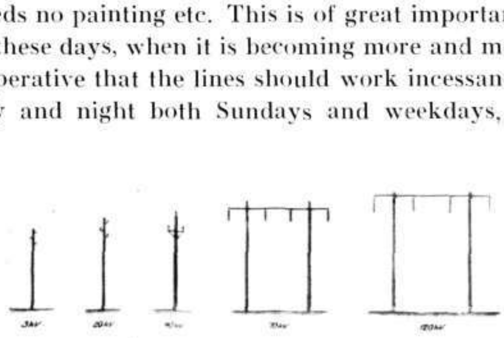
This favourable economic improvement has also had an effect on the purely technical side of power transmission. It was no longer necessary to keep building costs down to a bare minimum to make both ends meet. A fair amount of money could be spent on increasing the strength and reliability in working. What was economically impossible in a line which carried only 500 kW, became an obvious and paying proposition in one of 5 000 kW. As electrical energy gradually became a necessity for an increasing number of purposes, the demands of consumers for greater reliability were also increased, and improvement in quality, i. e. greater freedom from disturbances, was more and more appreciated.

The past 20 years have therefore been marked by incessant efforts to produce better, stronger, and more reliable transmission plants.

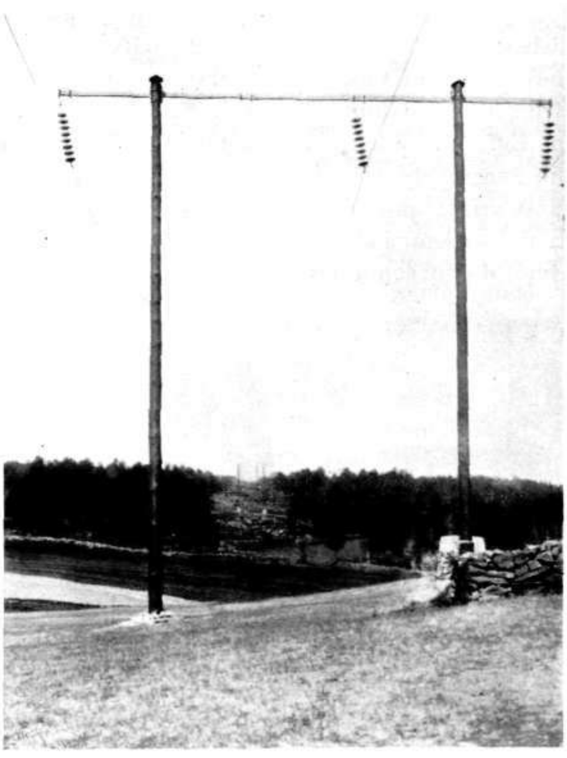
Mechanically, the lines have been improved mainly in the following directions. Experience gained in older systems was collected and analysed. In this way more extensive and certain knowledge was obtained of the strains and stresses to which lines may be exposed in bad weather conditions. Special attention is now given to the stresses to which wires covered by ice may be subjected in a wind or when there is hoar-frost. In the standard specifications for power-lines, which have been in force for some years, values for these extra loads are included. Since, as mentioned above, a line transmitting much power with good economy can, and should, be constructed with greater strength and reliability than one for less power, the reliability requirements of these Swedish specifications are graded according to the importance of the line from a power transmitting point of view — an innovation which is gradually being adopted in other countries. Attempts are also made to allow for the varying weather conditions in different parts of the country.

During the efforts to obtain the strongest and most reliable lines possible, wooden poles have come to the fore in a way undreamt of 20 years ago (figs. 9 and 10). Creosote-impregnated wood has proved as durable as iron. Further, wood needs no painting etc. This is of great importance in these days, when it is becoming more and more imperative that the lines should work incessantly, day and night both Sundays and weekdays, so that there is hardly ever time to switch off the power for inspection and repairs.

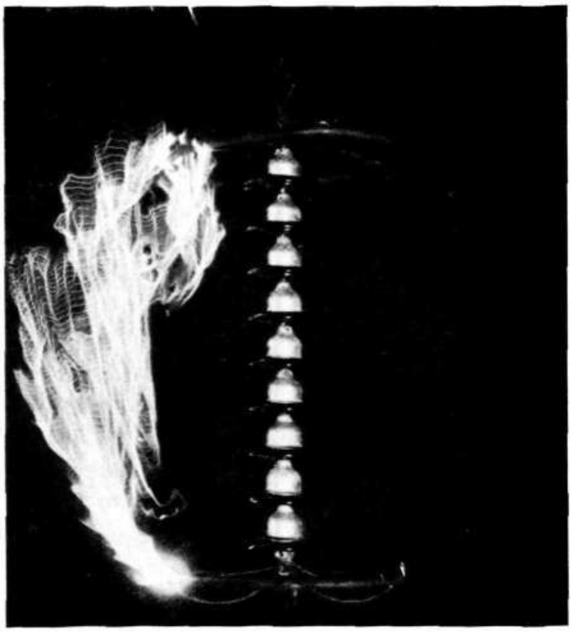
About as important as the mechanical strength of towers and cables is the reliability of the insulators. In past times, the insulators have on occassion left much to be desired in operating reliability. Many expedients have been suggested and tried, and have frequently failed, but the last decade has brought about considerable improvements. It has been realized that insulator faults must be ascribed to mechanical and thermal stresses, and that much can be gained by using a strong, tough porcelain. Extra margin has also been allowed in the size of the insulators. In a suspension insulator, for instance, a couple of extra units may be put in, to give sufficient insulation even when one or two of them are broken, for even the best insulator may be damaged by shots or other causes. The same principle is also applied with good results to pintype insulators, which are made so large that flash-overs will not occur even if one of the shells has been broken clean off. Considerable progress has also been made in pro-



R 4019 Fig. 9. Wooden poles of the types used by the Royal Board of Waterfalls.



R 4034 Fig. 10. 70 kV wooden pole in the Trollhättan—Alingsås line.



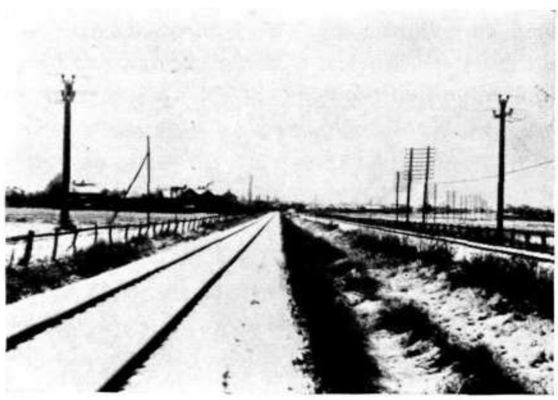
R 4018 Fig. 11. Flash-over on a string of insulators with protective rings.

tecting the strings of insulators from damage by possible flash-overs. The investigations carried out by Sydsvenska Kraftaktiebolaget (South Swedish Power Company) have contributed much to the solution of this problem and have led to the string of insulators with protective rings shown in fig. 11. Such high insulation also makes the lines fairly safe from over-voltages, not only those arising internally from switching operations in the system, but also external ones caused by atmospheric conditions. There are examples of solidly built lines with heavy copper conductors and ample insulation which have worked for years without a single mechanical or electrical disturbance interrupting the service. The time therefore does not seem to be far distant when we will have power transmissions able to work practically 24 hours a day year after year with no interruptions at all.

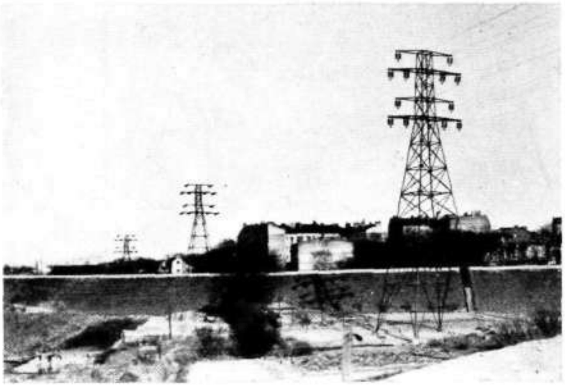
Crossings of power lines and other communication routes.

The strength and reliability attained by modern power lines have made it possible to do away with the protection formerly considered necessary when one of them crossed a railway, a telephone line, or a main road. Not so long ago, at the beginning of the century, it was considered that a power line should be carried across a railway on a viaduct nearly as solid as a road bridge (fig. 12). A sound view, which is rapidly gaining ground, is that it is better to spend more on making the line itself safe against breakages, than to make the line weak and fragile and then put up expensive devices to support and carry the lines when these are once broken and out of action. Stout poles, heavy conductors, and strong insulators — frequently double — will, when properly used, make a line strong enough to allow its crossing railways, telephone lines, etc. in one free span (figs. 13, 14). Such crossings are now beginning to be used regularly in large power transmission systems both in our country and in most others. For minor, weak lines the old guard brackets etc. may possibly be retained.

R 4023 Fig. 12. Old fashioned railway-crossing, with a viaduct for the power line.



R 4020 Fig. 13. Modern fracture-proof crossing, with double insulators and extra stout poles.



R 4024 Fig. 14. The line entering Malmö. Fracture-proof railway crossing.

Underground cables for power transmission.

As mentioned above, underground cables began to be used fairly soon for this purpose, though chiefly in towns and densely populated rural districts, or where it was difficult to find room for overhead lines. Obviously it would often be desirable and convenient to pass directly from a high tension overhead line to an underground cable when bringing the line into a town, crossing some wide water, or the like. In past times the maximum voltages for cables were comparatively low, but the researches and experiments of the last decade have advanced manufacturing methods so far that it is only for the very highest voltages, i. e. above 132 kV, that cables have not yet been designed and used. Underground cables can nowadays be used for all voltages employed in Sweden, and submarine cables for 50 kV have been laid across both the Sound and Kalmar Sound. At the same time voltages in the urban cable systems have risen from 5 or 6 to 30 kV; the latter is now used in, for instance, Stockholm. Cables are already used for taking the overhead line pressure of 40 or 50 kV straight to the centre of the town.

Sieverts Cable Works have contributed in many ways to the development of cable designs for very high voltages. The oil-filled cable boxes, probably the best for this particular purpose, are only one of the valuable contributions of this firm to the design of cable lines.

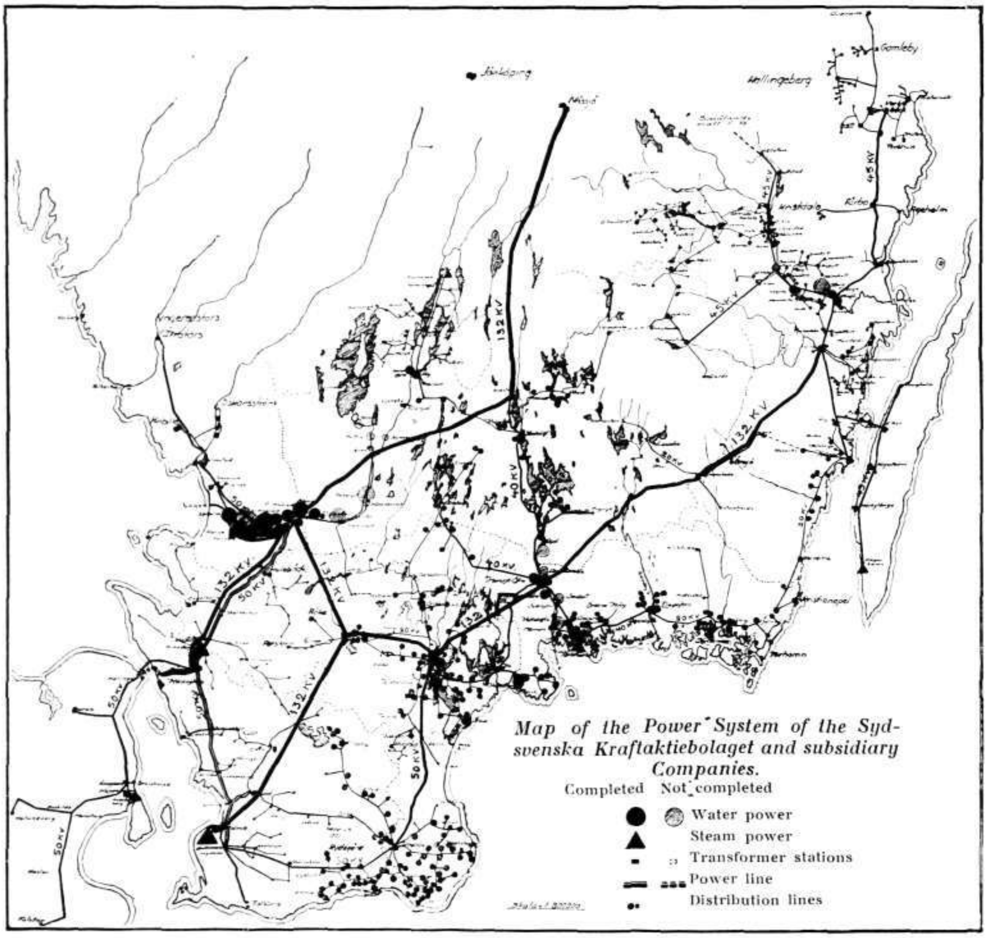
Underground cables, however, are more expensive than overhead lines and are therefore, in spite of their advantages, not used as often as they might be. It is generally the cost of laying which makes the cable so expensive. Attempts have lately been made in Germany to dig the cable trenches by machinery, which, it is hoped, will lead to a more extensive use of cables, for they possess great advantages. An absolutely safe and reliable transmission is often more easily obtained with an underground cable than with an overhead line. The modern cables with rationally designed cable-boxes have proved particularly insensitive to anything in the way of over-voltages. A section of cable before a machine, a transformer, or a switching station, will furnish very effective protection against lightning. It should further be emphasized that even if the initial cost of cables is somewhat higher than of overhead lines, their maintenance costs are considerably less. The annual cost of a cable transmission will therefore frequently be less than that of an air transmission, especially if allowance is made for the above-mentioned technical advantages of the cable. A careful consideration of cables as an alternative to overhead lines is therefore strongly recommended.

Phase compensation in power transmission.

Most electrical machines and appliances used in industry, agriculture etc. unfortunately not only consume electric current in proportion to the work done, but also a certain amount for magnetizing the necessary iron framework. We have the active load and energy which does useful work. We have a frequently equally large reactive load and energy, which is consumed in magnetizing.

This is the much-discussed power factor, the mystic $\cos \varphi$ which is so puzzling to the layman.

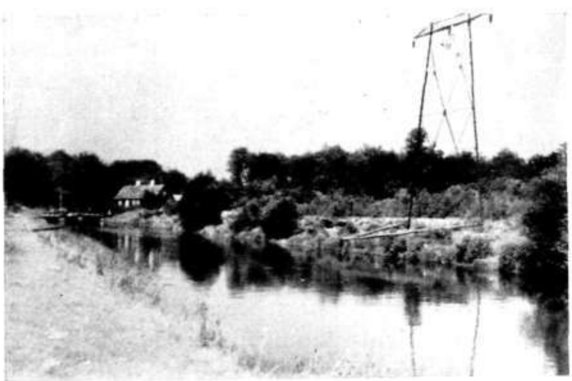
As the electrical transmission plants have been enlarged and come to serve an increasing number of purposes, it has proved more and more unsuitable to produce the magnetizing current, the reactive load, in the power stations and transmit it by the lines. It is generally better to produce it mainly at or near the place of consumption. This is an absolute necessity in long high voltage lines, where it is generally supplied by synchronous light-running machines, so-called synchronous condensers. A very large condenser — of no less than 12 000 kVA — is, for instance, installed at Malmö.



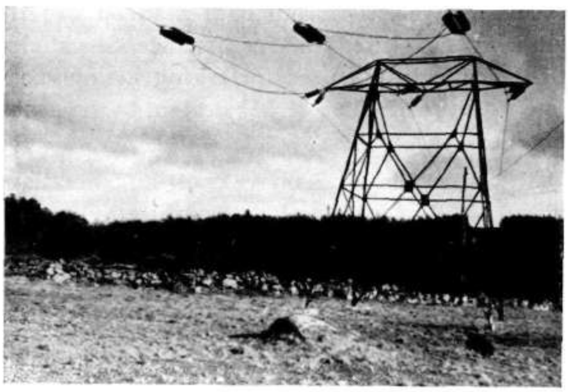
R 4037

Fig. 15. Map of the Sydsvenska Kraftaktiebolaget system.

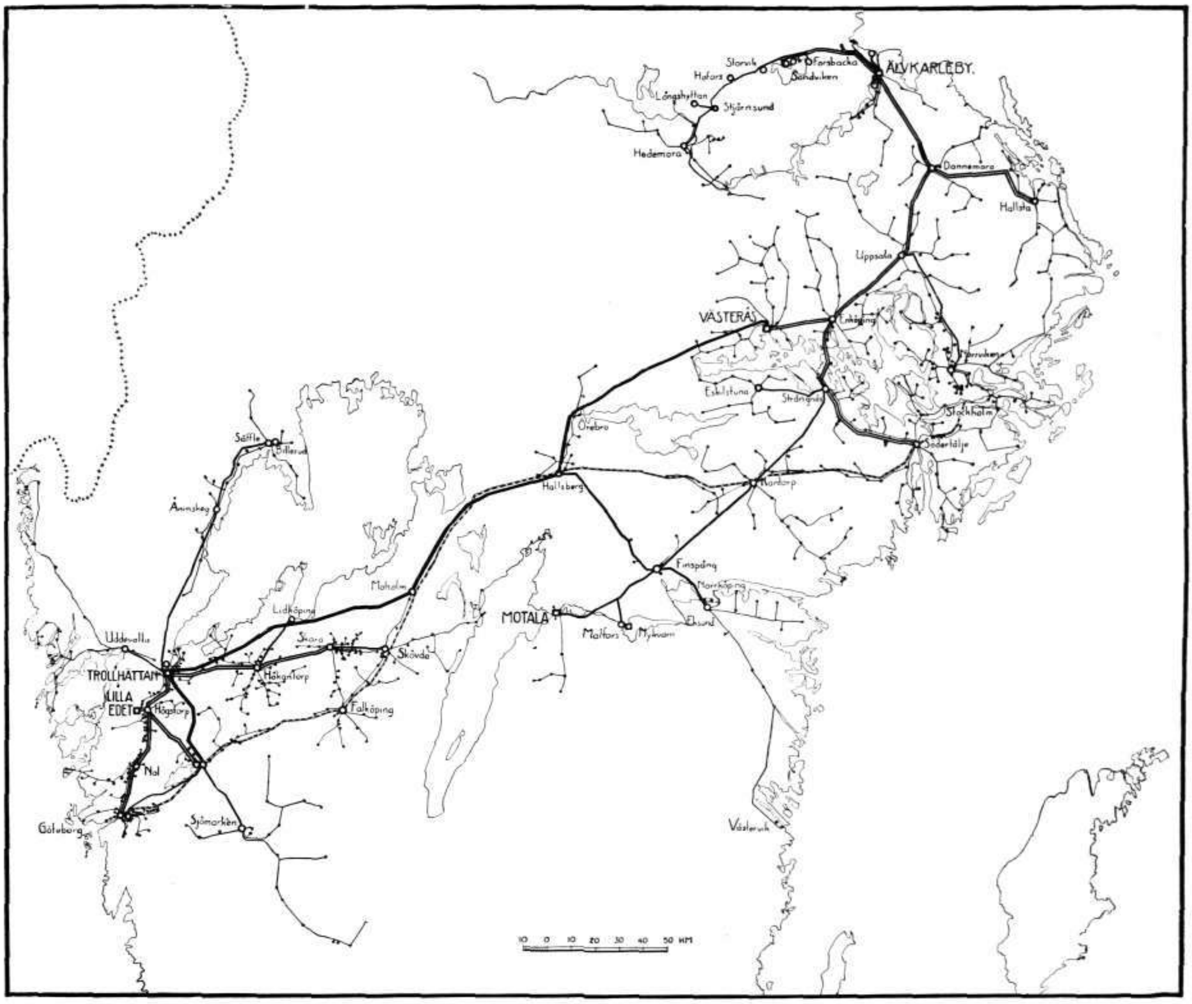
In many other cases, and especially when it is a question of producing a small amount of reactive power close to the place of consumption, static condensers are most practical. Sieverts Cable Works have improved these condensers enormously, and have made them a rational adjunct of electricity-consuming plants. Here we will only emphasize the extremely small losses



R 4026 Fig. 16. Tower built for 132 kV, present voltage 55 kV.



R 4027 Fig. 17. Tower for 132 kV, present voltage 55 kV. Device for giving the line 1/3 of a turn this side of the tower.



R 4054

Fig. 18. Map of the State Central Block system.

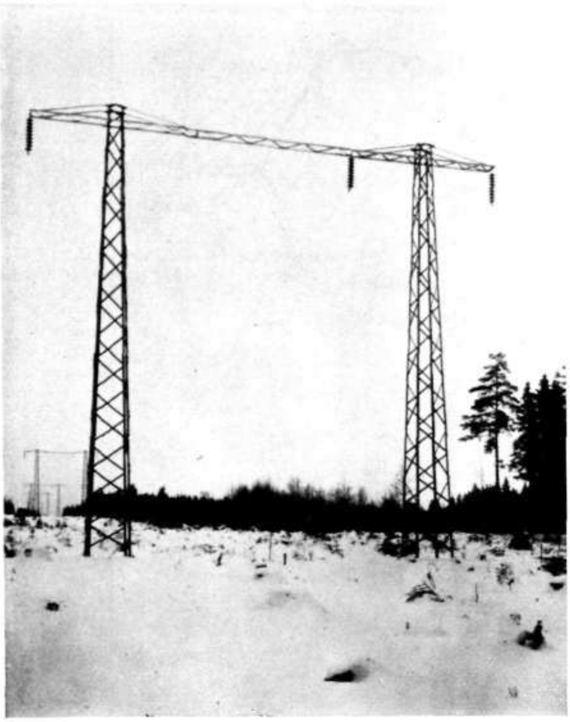
when using static condensers — only about $^1/_{10}$ of those in rotary condensers. Static condensers may therefore be used for phase correcting in lines transmitting high powers also, e. g. main transmission lines.

Interconnexion and cooperation.

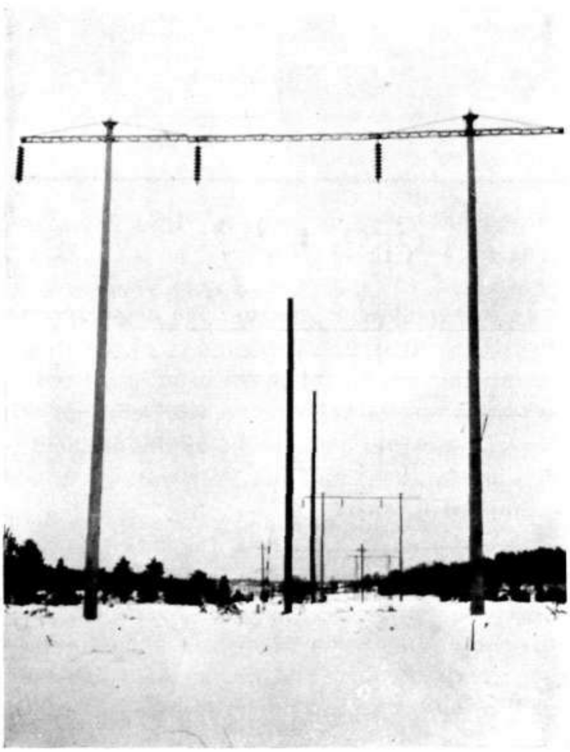
Power transmitting systems are no longer of the early simple type, i. e. a line from power station to consumer, to a factory. The lines are branching out to increasing numbers of consumers, more power stations are connected to the lines and their energy is fed into the joint lines. The advantages of such interconnexions are: both load and supply of power are equalized, many power stations can use the same reserve, when the load is low the number of generators etc. running can be cut down in order to reduce the losses; new power stations will more quickly be working at full load, as the additional load of the whole system, and not only part of it, will be supplied by them.

These reasons have led to the interconnexion and cooperation of an increasing number of power stations.

In Southern Sweden, Hemsjö, and Finsjö have been incorporated in Sydsvenska Kraftaktiebolaget (the South Swedish Power Company). A connecting line is being built to Yngeredsfors Kraftaktiebolag, and another, for the electrification of the State Railway South Main Line, will be con-



R 4036 Fig. 19. Steel tower on the main line from Trollhättan to Västerås, built for 220 kV; present voltage 132 kV.



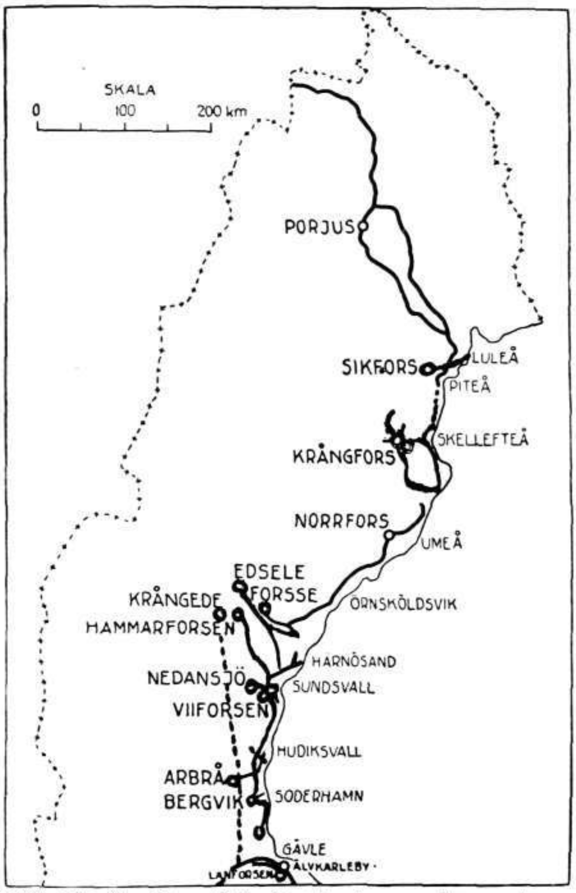
R 4040 *Fig. 20. Concrete pole on the main line from Trollhättan to Västerås, built for 220 kV; present voltage 132 kV.*

nected to the State power system at Nässjö. Practically all the power lines in the seven southernmost counties of Sweden now form a single unit, and gradually the full water-power supply of the district can thus be rationally used (fig. 15). The 132 kV lines built during the last 10 years form the backbone of this system. Steel towers are used in the earlier lines, which are designed for 132 kV, though the present voltage is only 55 kV (figs. 16, 17). A change to 132 kV can be made by simply placing a few more units in the strings of insulators. All the wires are put on the same level, which has proved the most suitable method of coping with the snow and wind of this country. I will return later to the most recent of the 132 kV lines built by Sydsvenska Kraftaktiebolaget.

The Norrköping system has also been gradually connected up with its neighbours, and most of the power stations on the Svartån, Stångån, and Motala Ström are now working in parallel, or at least can do so. Finally, the whole of this system is also connected up with the State power stations.

In central Sweden, the various power stations belonging to the State are connected, so that Trollhättan, Älvkarleö, and Motala work together in a common transmission system (fig. 18). All round the far-flung ramifications of this State Central Block, a large number of cooperating private power stations are connected. The Western and Eastern portions of this system cooperate by means of the main line from Trollhättan to Västerås. This is built for 220 kV, but at present only 132 kV (fig. 19) is employed. The line will be increased by another pylon, making it into a double-circuit 220 kV line. Some sections of this line have been built with poles of reinforced concrete, a material which seems to offer certain advantages (fig. 20). Experiments with concrete poles have been made elsewhere too, but they have never been widely used, chiefly for economic reasons.

Cooperation in Norrland has only begun lately (fig. 21). By enlarging its own lines and buying up others, the Hammarforsen Kraftaktiebolag in Southern Norrland has created a system stretching from Sundsvall almost down to Gävle, where the lines of the Central Block end. Northwards, the Hammarforsen system reaches the State



R 4032 Fig. 21. Map of the Norrland power line systems.

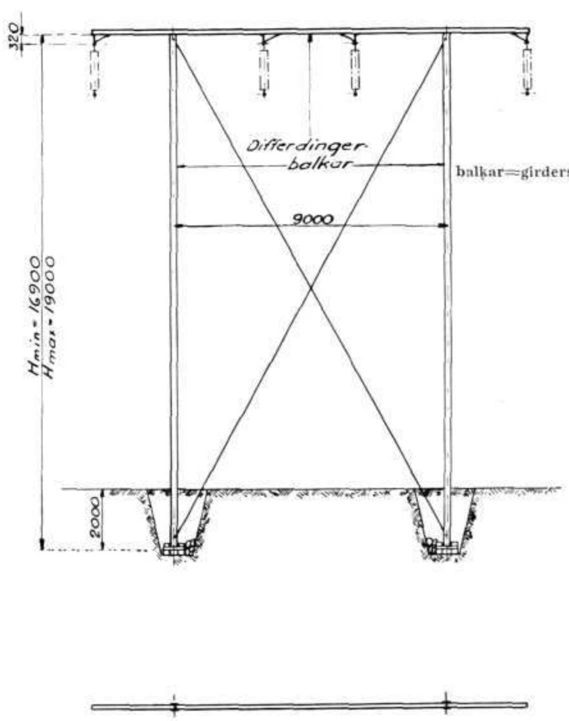
power station at Norrforsen, to which it is connected, and it also communicates with the largest of the wood industry power plants in the Ångermanland district.

Further, the Skellefteå system will be connected to the State-owned Porjus system in the North, and probably in the South to the Norrfors system. We shall thus have one connected system from Lappland to Gästrikland—i. e. covering the whole of Norrland. The present lines, however, are only designed for rather local cooperation, and to supply about 5 000 or possibly 10 000 kW, and cannot be excepted to transmit power from Porjus to Central Sweden. For this purpose lines of very different size and calibre will be required. Certain parts, however, are strongly built, for instance the 132 kV Porjus—Boden line (fig. 22). It is also worth noticing that in this line the towers are of a new type, built up of two galvanized Differdinger girders and anchored by another method than the formerly used concrete foundations.

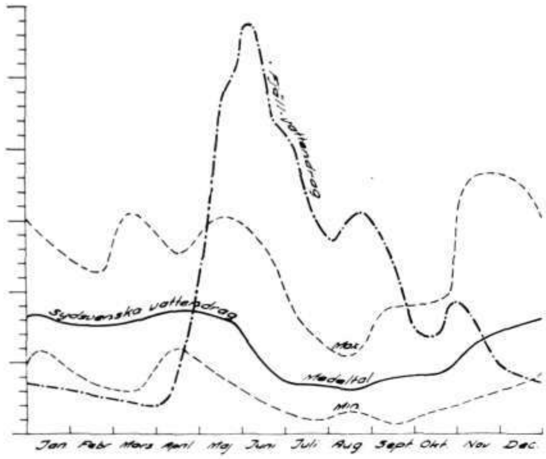
Distribution lines for national cooperation in Sweden.

Such rather local connexions are nevertheless of great importance, and will prepare the way for cooperation over longer distances and involving more power.

This extended cooperation over the whole or greater part of Sweden will require a transmission system of somewhat different form from those previously described. It will here be a question of transmitting power at distances getting on for five or six hundred miles, many times the present distances. The first transmissions to be dealt with will be those from central Norrland, primarily from the Indal river down to the industrial districts of central Sweden, and subsequently further South. The principal object of this transmission is to supplement the power resources of the latter districts from the enormous supply in the Norrland rivers. About 20 years ago certain works in central Sweden acquired between them the great Krångede falls; more than 10 years ago the city of Stockholm purchased Svarthålsforsen, and the Board of Waterfalls



R 4038 Fig. 22. Modern pylon on the Porjus—Boden line, made of galvanized Differdinger girders and anchored by a new method.



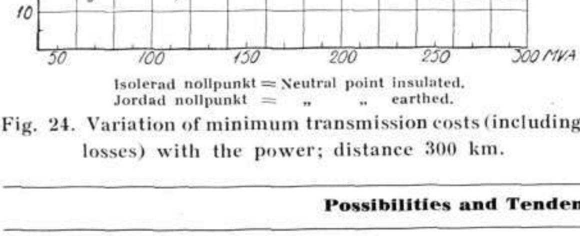
Fjällvattendrag = Norrland Rivers.
Sydsvenska vattendrag = South Sweden Rivers.
Medeltal = Mean.

R 4039 Fig. 23. Curves giving the water-flow in rivers of Norrland and of South of Sweden.

has bought Stadsforsen and others for the State. All these power resources are in the Indal river, and are intended for safeguarding the requirements of their respective owners. This scheme will involve a transmission of power which will gradually approach a million kilowatts.

The immediate task of these Swedish main distribution lines will be to transmit power from Norrland to the South. A distributing system as extensive as this may, however, also serve other important objects. The arguments in favour of and the profits from cooperation will be stronger and greater when power stations and consumers are distributed over as large an area as half Sweden. It will suffice to show how the annual water-flow fluctuations in a Norrland river differ from these in South Sweden (fig. 23). In the winter there is always a shortage of water in the former, and generally a surplus in the latter. The spring flood in Norrland has just begun when the summer low-water period begins to be felt in Southern Sweden. The abundance of summer water in the Norrland rivers often lasts up to the time in the autumn when the South Swedish rivers again begin to fill. Often exceptionally dry years in the South are balanced by good water years in the North, and vice versa.

Clearly the task of main distribution lines between Northern and Southern Sweden—to carry the surplus power from South to North in the winter and from North to South in the summer —will be very important. The load on these lines will therefore fluctuate considerably, and they must be designed to work satisfactorily even under these conditions.



Isolerad nollpunkt = Neutral point insulated.
Jordad nollpunkt = „ „ earthed.

Fig. 24. Variation of minimum transmission costs (including losses) with the power; distance 300 km.

Economic aspects of long-distance transmission.

From the above, it will be obvious that these lines must transmit very large amounts of power if the transmission costs per kW are to be low enough to make the scheme profitable. To give an idea of the economic factors affecting such a transmission, I will give the results arrived at in the recent investigations on transmission costs at a distance of 300 km. (180 miles), which is approximately the distance between the Indal

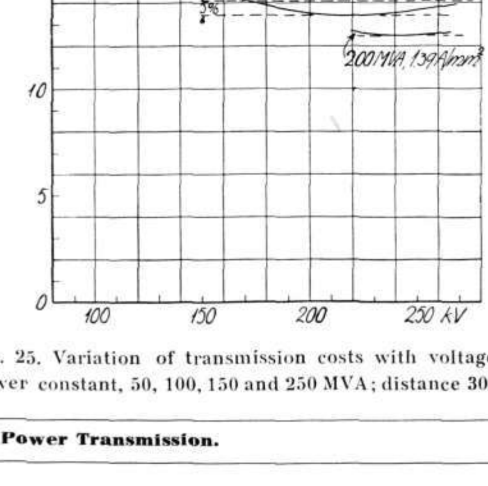


Fig. 25. Variation of transmission costs with voltage, the power constant, 50, 100, 150 and 250 MVA; distance 300 km.

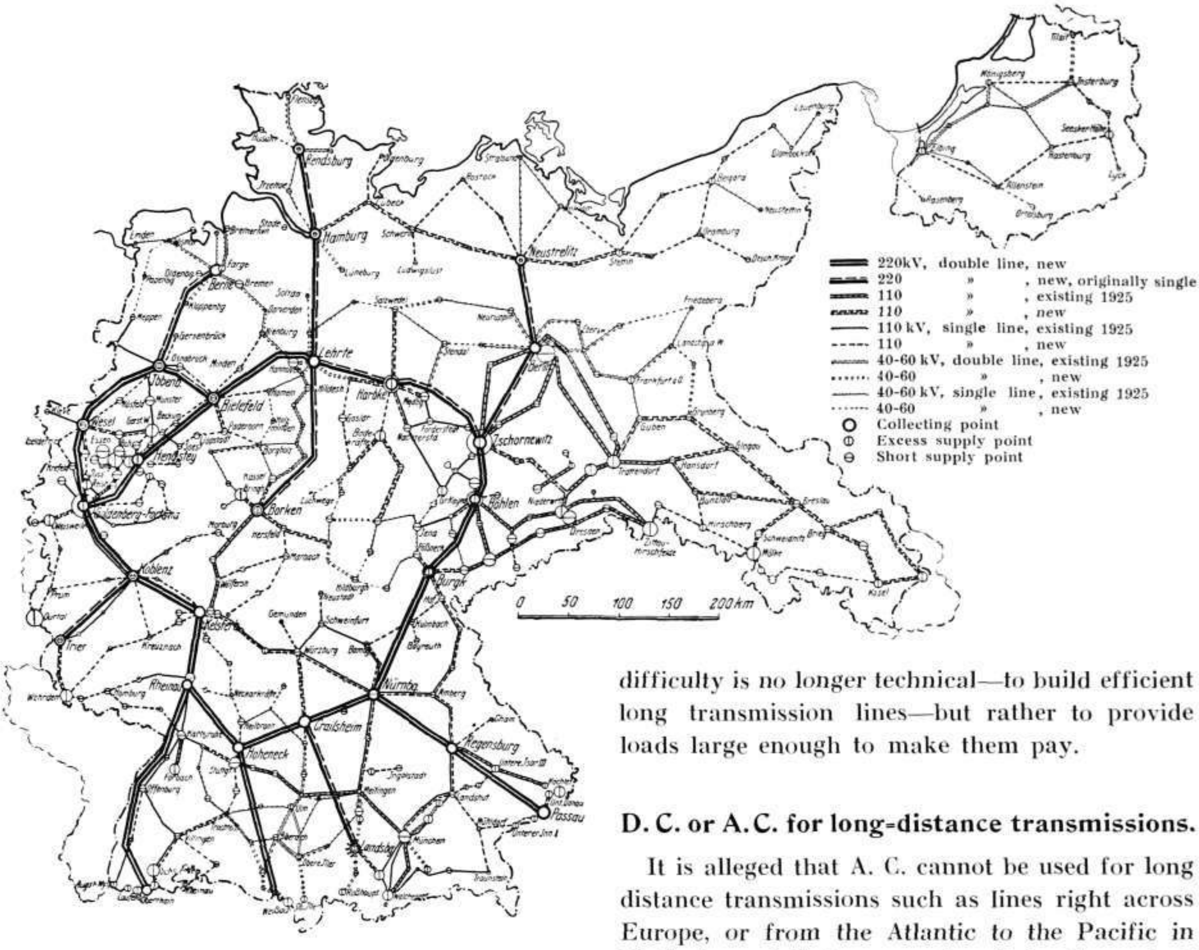


Fig. 26. Map of proposed main transmission lines in Germany.

river and Bergslagen. The curves of fig. 24 show that the transmission cost per kW and year — including costs of line, transformer station, and all losses—decreases rapidly with increasing power and approaches a limit, apparently in the neighbourhood of 10 kr. per kW and year, at about 200 000 kW carried by a single line. Fig. 25 shows that the most economical voltage rises with the amount of power, and to be economically sound a line of this kind should accordingly be built for at least 150 000 kW per line, with a corresponding voltage of 220 kV.

The question will then be: Is there enough power to provide a satisfactory load for one line, or preferably for two? As we have said, the power supply in Norrland is sufficient, which brings us to the factor which in reality sets a limit to our long-distance transmissions. The difficulty is no longer technical—to build efficient long transmission lines—but rather to provide loads large enough to make them pay.

D. C. or A. C. for long-distance transmissions.

It is alleged that A. C. cannot be used for long distance transmissions such as lines right across Europe, or from the Atlantic to the Pacific in U. S. A., and that we must wait for the arrival of high voltage D. C. Self-induction and capacity, always present in A. C., are supposed to make transmission impossible at distances very little greater than those already attained. In lines of such length alternating current is supposed not to give stability in operating.

It is quite true that if the load on a long three-phase transmission is increased above a certain value, the reactive losses from self-induction will be so large that work is inconceivable, and the stability will also be so low that the machines will be thrown out of phase. In very long lines it may also—if there are no intermediate stations —be difficult to deal with the capacity currents. These difficulties are supposed to disappear with direct current.

But the specific load at which these difficulties appear is generally appreciably higher than that which gives the best results economically. The transmission problem being primarily economic, there is consequently no cause to worry about difficulties occurring only in lines which, from an economic point of view, are incorrectly designed.

Extensive systems of main transmission lines are feasible even with alternating current.

Nor need we be intimidated by difficulties which might arise in a line one or two thousand miles long without intermediate stations. If a through line of this length were built, there would seem to be no reason why it should not be connected at several points to existing systems for cooperation and interchange of power. For natural reasons, the distances between transformer stations in, for instance, the Swedish 220 kV main distribution lines are not likely to be more than 200, or at most 250 miles. If such intermediate stations are arranged, the problem of stability and capacity currents will be comparatively easily solved.

In Germany also, the plan for coordinating all the power works includes so many stations, and consequently points of support, that fears of such difficulties in working may be dismissed (fig. 26).

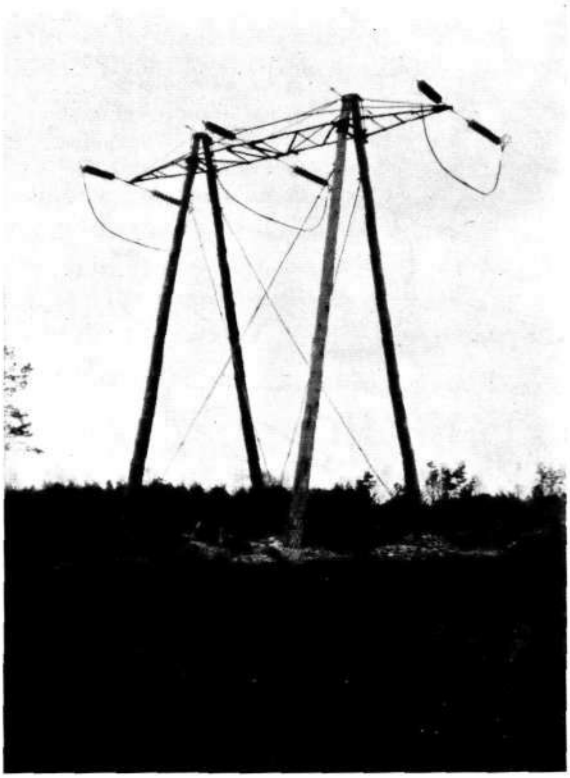
Such a system of large trunk lines will thus, at intervals adapted to the voltage and increasing with this, be provided with transformer stations at which they will be connected for cooperation with the regional power distribution systems. At all points where large power stations are not connected, rotary condensers will be installed, in order not only to stabilize effectively the whole system, but also, by some over-compensation, to regulate the voltage to a constant value throughout the system. Reactance coils, compensating the capacity currents at no load, may also be placed at these points.

Some problems of detail in 220 and 400 kV lines.

In principle, consequently, there seem to be no fundamental difficulties in building very long lines for very high A. C. voltages. But the building of such lines will encounter several important practical difficulties which must be overcome. The corona, for instance, necessitates making conductors for high voltages of very large diameter. It is not certain that the expedients so far used—steel-cored aluminium or hollow cables —will be suitable in their present forms. Vibrations and fatigue-cracks, compelling modifications of design and greater attention to the quality of the material, and its properties under fatigue stresses, have ocurred in these heavy conductors. The ordinary types of insulators may for mechanical reasons be impossible to use. The forces from the conductors, which at 400 kV must have diameters of nearly two inches, and cross-sections of more than one sq. inch, will be so great that it may be necessary to construct new types and designs of suspension insulators. A study of the effect of fatigue stresses on the insulator porcelain is also of the greatest importance.

In any case it is essential that the risk of arcing, which at these high voltages is very destructive, should be reduced. Arcs must be kept away from the porcelain, which is sensitive to great heat, and devices like the protective rings shown in fig. 11 are used. Other parts must also be sufficiently separated. It has, for instance, proved necessary to stiffen and frame the slack loops on the anchor tower, to keep them far enough from cross arms etc. to prevent arcing (fig. 27).

As regards types of towers and general arrangements, it would seem that on the whole the same principles apply when building a line for, say, 220 kV as for 132 kV. We may suitably take as our starting point the latest and most up-to-date constructions, those used by Sydsvenska Kraftaktiebolaget for their new 132 kV lines. The material used there is very largely creosote-impregnated wood (figs. 27, 28). If we are to use this type for 220 kV, the poles must be made higher, and therefore also heavier, than for 132 kV. Instead of heavier single wooden poles, which will be hard to get, it will probably be necessary to use timber constructions or wooden poles with lattice work superstructure, or even to change over to all-steel towers. All these alternatives may have to be tried in practice before any particular type suitable to our country is found. I hardly think, however, that this country need go in for the American types with fine-meshed lattice work of comparatively small-gauge steel. We have good reason to stick to our own simple, neat,



R 4035 Fig. 27. Wooden poles for 132 kV with protective rings and specially shaped loops to reduce the risk of flash-overs. The new Sydsvenska Kraftaktiebolaget main transmission line.

and strong types of pole even for these high voltages.

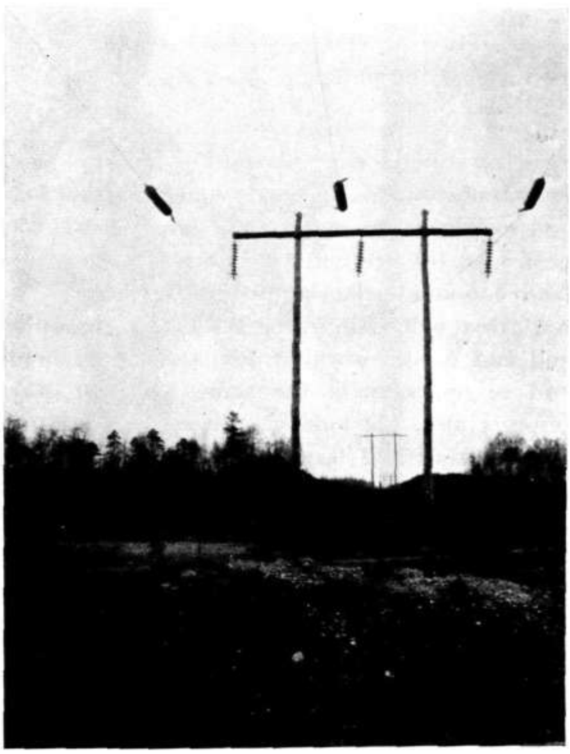
Although practical problems of this kind will have to be solved when building 220 kV lines, and even more if 400 kV lines have to be made, they are not of a nature to prevent the technical achievement of these transmissions while retaining the alternating current.

Aspects of long-distance D. C. transmission.

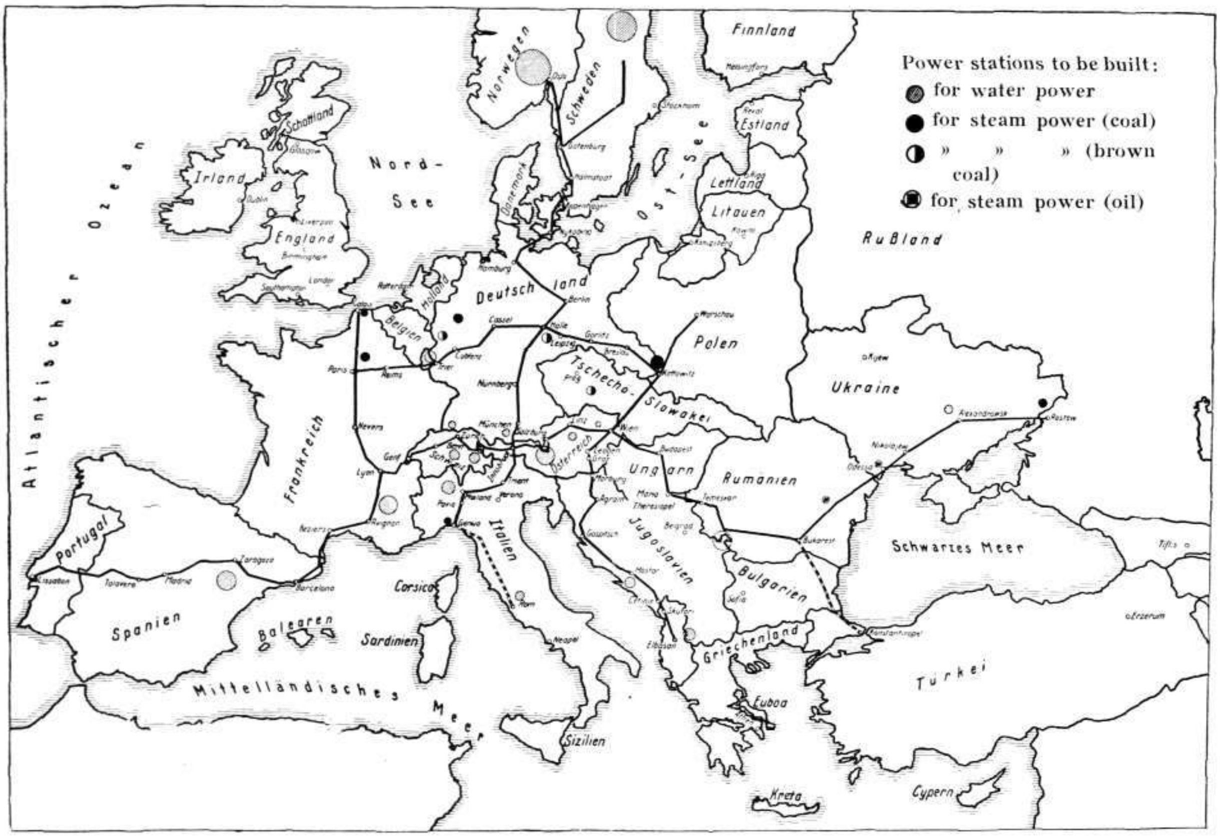
Matters will be different if a cheap and simple machine, able to transform alternating current to high voltage direct current and vice versa is invented. In that case there would be every reason for inquiring into what economic advantages might be gained by using that method. The machines known and used so far, however, have been much too expensive and inconvenient to be of any real benefit in our present transmission systems, but new designs may of course appear. At the World Power Conference in Berlin in the summer of 1930 rumours were current of impending revolutionary inventions. As far as I know, nothing more has been heard of the matter since. I wish to point out that D. C. transmissions suffer from several drawbacks from which A. C. lines are comparatively free. Voltage regulation, for example, is generally far more difficult in D. C. than in A. C. Changing from A. C. to D. C. and vice versa will therefore not be the only difficulty; a good many other problems must also be solved before we can pass to long distance transmission of high voltage direct current.

An European super power system.

As a final illustration of the trend of power transmission, I will give a map of the proposed system of inter-European super power system (fig. 29). This proposal was submitted by Mr. Oskar Oliven, Dr. Ing., in a lecture given to the entire World Power Conference in Berlin. The funda-



R 4041 Fig. 28. Wooden pole for 132 kV with a device for giving the line 1/3 of a turn this side of the pole. The new Sydsvenska Kraftaktiebolaget main transmission line.



R 4042 Fig. 29. Dr. Oliven's proposed super power-system for Europe, submitted at the World Power Conference in Berlin, 1930.

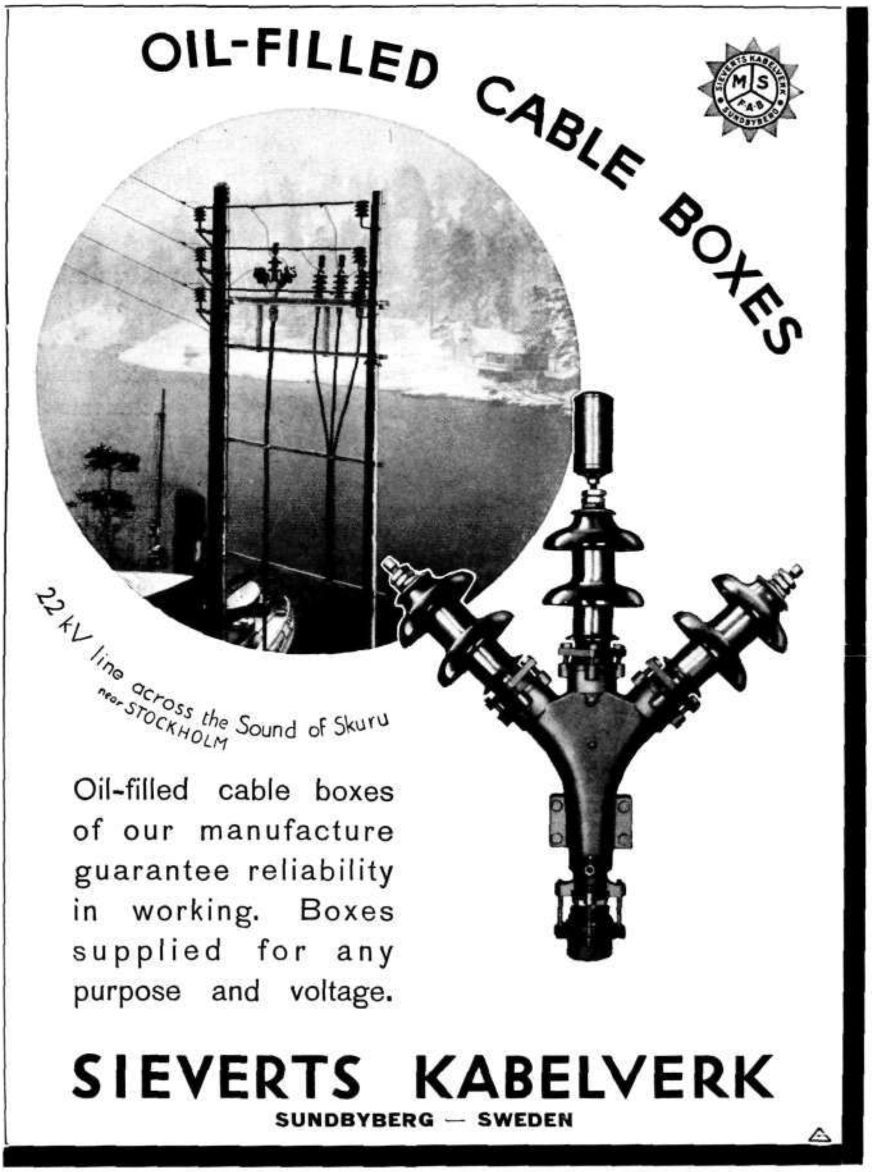
mental idea of this project is equalization of load and exchange of power on a large scale. The peak load for lighting, for instance, occurs more than 3 hours earlier at Rostov, farthest to the East, than at Lisbon in the West. The beginning and end of the working day, the dinner hour, and so on, vary in the same way. In other respects also, the load variations in a network of that kind will largely cancel out. There is no need to fear that a total eclipse of the sun in the forenoon will cause the power stations to break down from over-load, as very nearly happened in New York some years ago. All such difficulties from irregular load peaks will disappear.

The available sources of water power would supplement one another far more than I indicated as possible between North and South Sweden. Long-period variations in particular would certainly be almost completely balanced, as drought and scarcity of water do not appear to occur simultaneously all over Europe. In a system of this kind many waterfalls could also be brought in which would otherwise be inaccessible, and most of the existing power stations could also be utilized to better advantage, whether they employ water or fuel.

These are the advantages. The drawbacks are the £100 million odd estimated to be the cost of the plant, with lines and stations designed for 400 kV.

The quantities of power and energy consumed in Europe today are hardly likely to be enough to make such a system a paying proposition. But in view of the growth of power consumption it seems very probable that the time is rapidly approaching when the financing of such a scheme will be possible. I am therefore able to agree with Dr. Oliven's opinion that the project should be ventilated, principally in order that the various national transmission systems might be planned so as not to hinder, but rather to facilitate, the advent of the international organization. Even in Sweden, and particularly in Scania, through which presumably the large Scandinavian trunk lines will pass, we have every reason to prepare for the future, even if the projects of today will only be realized by the next generation.

In this review I hope to have shown that although the improvements in transmission methods have in a few decades, and not least by Swedish efforts, wrought many changes in our material culture, there are still, in spite of past achievements, many possible and as yet unused ways in which the willing and untiring forces of nature can be made more extensively available for mankind, providing power and light and heat to make life easier and brighter and warmer for us all.



Forest Telephone Lines. — Some Points in their Design.

By *Folke Johansson.*

Speaking generally of forestry, the term "communications" may be taken in two different senses. It may refer to the means of moving people and material from one point to another by road, rail, or the like—that is, exclusively a transport question, wholly outside the range of this paper. But it may also mean the transmission of messages of one kind or another, which need not necessarily be combined with a simultaneous conveyance of substantial objects. Communication is in this case effected by means of telephone, telegraph, wireless, or visual signals, of which there are a number of systems.

General Aspects.

A consideration of the messages usually required in forestry, e. g. in floating operations, fighting forest fires, etc. when speed is essential, and also of the staff employed on such occasions and the distances generally involved, clearly indicates that the telephone is the only efficient means of satisfying all the demands which have to be made on the means of communication. It is perhaps unnecessary, considering how expert readers of this journal are, to point out a few of its advantages—that it is one of the quickest means of communication there is, and particularly suitable for the transmission of long and intricate messages. In addition, practically everyone knows how to use the telephone, and the technique of telephoning is so simple that little instruction or practice is needed. It should also be emphasized that in relation to the costs of construction, operation, and maintenance, the telephone is more efficient and more reliable than any other system. Another great advantage is that a telephone line can be extended comparatively easily and cheaply—within certain limits, naturally—to places with which temporary communication is required for one reason or another. Again, portable field telephones can be used, for tapping the circuit wherever this is wanted. This last feature is invaluable in floating operations, as it enables the lumbermen to keep in constant touch with those who see to the sluice gates and other control arrangements, to give information regarding the formation of jams, and to receive orders regarding the work, thus eliminating as far as possible losses of time and water. Where floating conditions are bad, a telephone line will soon pay for itself, and also in years when it is especially necessary to economize with the water, whether on account of unusual numbers of logs or deficiency of rainfall. Yet again, in fighting a forest fire, the field telephone is exceedingly useful, enabling the commander easily and quickly to direct his various detachments and maintain communication to the rear.

In comparison with the telegraph, the telephone has the advantage of requiring no specially trained staff, and in this it also gains over wireless. Although, theoretically, wireless telephony and telegraphy should be particularly suitable for this purpose, this is far from being the case in practice. Although improvements are made in this sphere almost daily, the wireless set intended for use in the large forests still leaves much to be desired, considering that it should be easy to transport where conditions are primitive, strong, to withstand careless handling and bad external conditions, and should have good properties as regards transmission etc. The establishment of a number of small wireless stations in the wilds would, besides, be comparatively expensive, as would also the maintenance of a staff of trained wireless operators. Here we may, by the way, note that fairly extensive trials have been made for several years under the supervision of the U. S. Forest Service in order to obtain a combined receiver and transmitter suitable for use by sentries against forest fires (in what is called the tower system) in inaccessible districts. These experiments have also included the study of some questions of organization involved in the wireless method. So far, experience seems to indicate that this method may be of advantage in cases where telephone communications can only be established with difficulty and at disproportionately high cost. A set suitable for this special purpose has been designed, which last summer was subjected to very severe tests; with small weight—about 30 kg. altogether—it combines indifference to the most primitive modes of transport (e. g. pack-horses) and unfavourable climatic conditions with ease of handling and good receiving and transmitting properties. According to the P. M. of the tests, the signals from this set could be received at distances of up to 500 km., while the source of power proved sufficient for 24 hours' continuous sending. The general opinion was that the Forest Service set gave exceedingly good service in the field and showed absolute reliability even under extremely exacting conditions. The experiments are not, however, regarded as finished.

What has been briefly mentioned above shows that only the telephone method has the right qualities to enable it to be used as a basis for the special intelligence service of forestry. One of the most striking pieces of evidence in support of this is the telephone network of North America used exclusively for forestry purposes, and at present covering approximately 80 000 km. Unfortunately, no direct statistical information is available as regards Sweden on this point, but there are telephone lines along many of the more important river systems, which are used during the floating season. Considering that there are about 30 000 km. of public floating channels in Sweden—something like twice the aggregate length of our railways—there are evidently good opportunities for development in this sphere. Further, watchmen's lines and other ones for special purposes are not uncommon in forest districts where distances between villages and other habitations are great and the State Telephone network is very wide-meshed. It is therefore in the author's opinion no exaggeration to say that forest telephony has now developed so far that its technical, financial, and organization problems are beginning to call for far more attention than has hitherto been given them—in spite of the fact that they might seem small and insignificant in comparison with the large problems of telephony. This is perhaps most applicable to certain details of the laying of the lines, of which a short and by no means exhaustive account will be given below. For natural reasons it must be based on American conditions, for the simple reason that American engineers and forestry experts have made special efforts to improve the various methods of laying lines on land, and have met with considerable success.

Various Types of Lines.

When putting up telephone lines of the simple type which is generally used in forestry, where the greater part is naturally in more or less wooded areas, it is possible to distinguish two main types of actual line construction, namely, what has received the name of *pole-line,* and what we will by analogy call the *tree-line.* The former is not essentially different from the ordinary type used in country districts; and so poles, insulators, hooks, etc. of the usual models are used for it. The latter, on the other hand, is a type which has been much modified to suit the conditions prevailing in districts with plenty of mature, close-grown forests, in order to simplify and cheapen the work of erection, and at the same time to get a line which will give satisfactory results in practice. The difference between them is considerable, with the practical consequence that, among other things, a staff trained exclusively in putting up pole lines will generally employ methods whose application to the other system will give poor results.

The fundamental principles of the tree line, which are probably not very widely known, are hinted at already in the name, which is due to the use of growing trees instead of special poles for carrying the wire. The trees are selected as far as possible at equal intervals—a span of 30 m. is probably about the best; in no case should the distance exceed 50 to 60 m.—and should be fairly stout, to reduce the sway in high winds. But they must not be so large as to be difficult to climb when the wire is being put up. The branches are lopped off to a height of about 6 m. from the ground, which is the height at which the holders of the hanging insulator are fixed.

These consist of about 50 cm. of iron wire, usually No. 12 B. W. G.; one end is anchored to a 3" bolt in the trunk, the other twisted round a ring-shaped split porcelain insulator as shown in fig. 1. The wire rests freely in the insulator ring, and is not fastened to it.

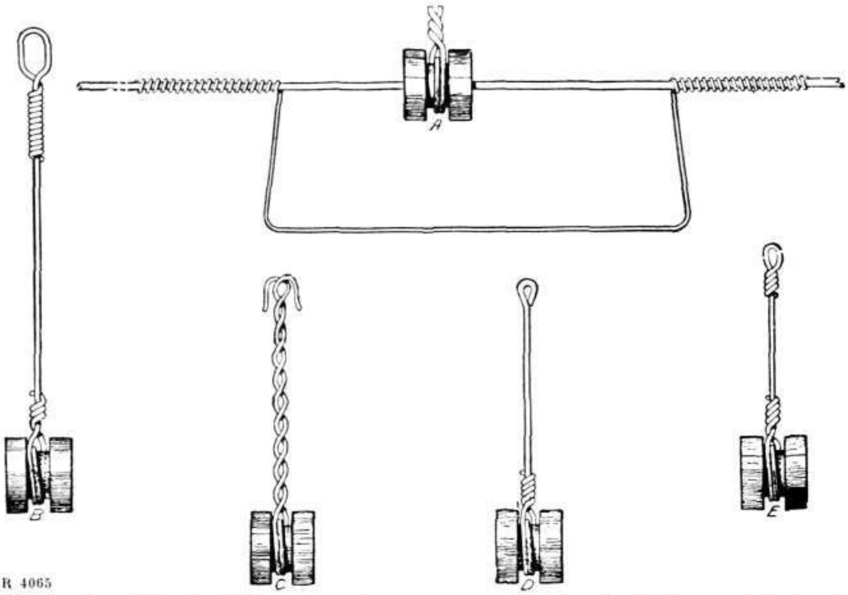


Fig. 1. Insulator ring into suspension arrangements for elastic lines. A device to prevent a broken wire slipping through the ring. B and E when great steadiness is required, C and D the usual types. All are made from No. 12 B.W.G. except D, for which No. 9 is used.

In this connexion we might mention that two methods are used in selecting suitable trees, the zigzag and the curve methods. In the former trees are chosen so as to form a zigzag line in the right average direction (see fig. 2), and they will then be alternately on either side of the wire, forming an "avenue" about 2 or 3 m. wide. The wire consequently runs a zigzag course through the insulators on the inner sides of the trees and is thereby kept hanging freely in the air out of contact with the tree trunks. In the other method the line is built as a regular series of reversible curves (see fig. 3)—with 6 to 8 trees between the points of inflexion—in which the insulators are fixed on the concave side. This provides a free passage for the wire without having recourse to the zigzag method.

A tree line will accordingly never be as straight as a pole line. It should also be noted that considerably more "sag" is used in the former—about $1^1/_4$ m. in a span of 30 m.—than would usually be needed to compensate the contraction of the wire caused by falls in temperature. The points of support of the wire in this type of line are usually 60 per cent. more in number, and the sag 4 to 6 times greater, than in the pole line.

Between these 2 "pure" types of line there are a number of mixtures, more or less adapted to local conditions and more or less well designed. The so-called "wilderness" lines will probably be well known from the Northern parts of Sweden; in these single lines are put up on growing trees by stripping the branches from that side of the trunk on which the line is, screwing a telephone hook into the wood and stretching the wire over insulators of the usual type. Branches on the other side and those higher than the hook are left untouched,

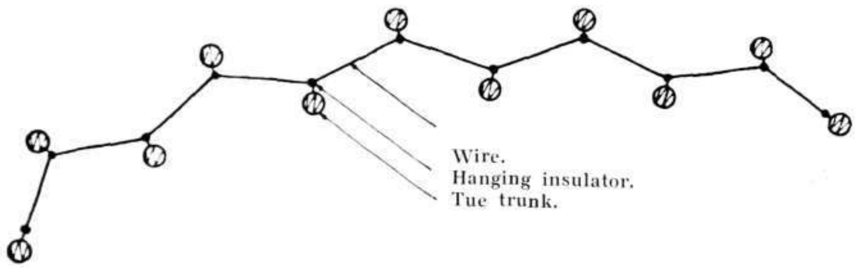


Fig. 2. Diagram of zig zag method.

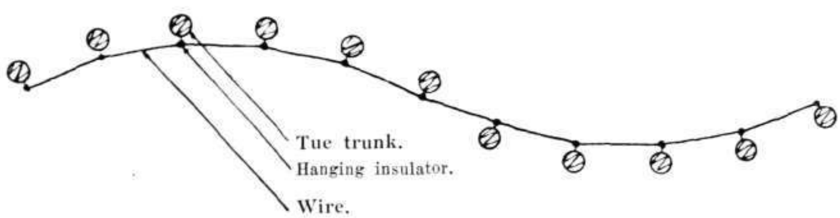


Fig. 3. Diagram of curved line method.

and the tree is then not considered to suffer any damage.

The Uses and Properties of the Various Line Types.

As regards the use of pole- or tree-lines in various types of country, the former is used mainly in open ground, where there is no wood and not enough growing trees available, as well as along roads and other communication routes. When the line has to be laid through forest it is best to cut a lane, giving the line a free passage and preventing damage from windfalls, etc. A characteristic of the pole line is its "inelasticity", i. e. it is anchored to each insulator. Trees falling across the wire will therefore break it and cause interruptions, a risk which must be eliminated by felling everything near the line on either side.

By its very nature, the tree line can only be used in relatively well stocked, dry forest ground with a good supply of mature trees, but it should be observed that no lane needs to be cut, a point of great importance in practice, both as regards the reduction of building costs and the saving of the growing forests. In this instance the danger from windfalls is obviously increased, but the greater risk is balanced by the line being so arranged that the wire runs freely through the insulators, with ample sag, and is therefore "elastic". The beauty of this arrangement is, that if the line is caught by a falling tree, it will be forced down, giving instead of breaking, on account of the elasticity. If the worst comes to the worst, one or two insulators will be torn off and much of the wire will be lying on the ground, but it will not be broken.

The fundamental idea of this design is that under high stresses it will give without breaking, and that any damage done will be confined to the fastenings of the insulators, which do not form part of the circuit. It might then be asked what the use is of such a method of laying lines in telephony.—The answer is that a broken line means interrupted traffic until the damage is repaired, while a wire will often function moderately well even if large portions of it are lying on the ground, and even buried in dry snow. If the surface of the ground is wet or if the wire falls into water, it will of course stop working, just as if it were broken, but experiments have shown conclusively that a single line may lie for long distances on dry or frozen ground without being rendered completely useless. The amount of undergrowth and how this is made up are two important factors in this connexion.

Some comparisons between the two Types of Line.

The maximum length of a tree line is for various reasons considerably less than that of a pole line. Copper wire cannot of course be used for this type, and ordinary galvanized iron wire must therefore take its place. The smallest dimension that, in view of the large stresses, can be used with safety, is No. 9 B. W. G., and the maximum length of line is then, unless special arrangements are made, 150 to 200 kms., a distance more than ample for our conditions, but which might prove too short, say in the wilds of Northern Canada. When heavier wires are used the range will be longer, but the cost will then be heavier, usually unnecessarily so.

In connexion with the line material it should be noted that, although, the use of growing trees for carrying the line necessarily makes this crooked—either zigzag or sinusoidal in shape—with large sag, yet the consumption of wire is not increased as much as one might expect. The increase over a pole line is, under normal external conditions, an average of about 20 m. per km. If for some reason it is necessary to build a double line, the two branches should not be put up on the same trees, but two parallel lines erected; this causes a large increase in the initial outlay, which will be almost doubled. In this respect, therefore, the pole line method holds a considerable advantage over the tree line method. It should also be pointed out that the insulation will always be worse in the former on account of the simplified construction, and that the line will therefore be exposed to large current losses and leakage; hence its shorter maximum length. This is the same however well the line is built, and must therefore be ascribed to the method.

The Question of Cost.

The most important reason for the introduction of the tree-line method has been the demand for a type in which reduced building costs are combined with very great reliability. But, on the other hand, it is a mistake to assume that this type of line must necessarily be cheaper to build than a pole line, even if the supply of good, well-placed trees to hang the wire on is perfectly satisfactory. As regards efficiency, cost of operating, and maintenance, the pole type is almost always superior.

The higher building costs of the pole line actually only apply to certain parts of the work, i. e. procuring and transporting the poles, making the holes, raising the poles, and clearing a lane for the line. The cost of this may vary considerably and depends largely on the supply of suitable poles in the neighbourhood, and, as regards the digging of the holes, on the nature of the ground. The clearing of the lane depends mainly on what the forest and undergrowth consist of.

In all other respects, however, the tree line must be acknowledged to be practically always more expensive than the pole line. As we have pointed out above, the gauge of wire used for the former cannot be less than No. 9, while for the latter, at least over fairly short distances, No. 12 will do, which only weighs half as much and is therefore cheaper both to buy and to transport. Another feature of the former type of line is that about twice as many points of support for the wire have to be used as for the pole line, and the cost of insulators will therefore be greater too; the fact that the hanging, split-insulator model through which the wire runs is more expensive than the ordinary telephone insulator will make this particular item even more expensive. The greater quantity of the heavier wire and the more expensive insulator material actually make the cost of the tree line nearly 100 per cent. greater than that of the pole line.

Further, it must be pointed out that putting up and stretching the wire is very much harder work when hanging insulators are used. This is so even if specially trained men are employed for this part of the work, and depends partly on the fact that with tree lines more insulators have to be put up and fixed. The laying of the wire also takes more time and trouble, as great attention must always be given to taking the line on the right side of each tree trunk, a detail which may sometimes prove rather troublesome. Also trees are harder to climb with climbing irons than are poles, especially if the trunks are thick and covered with coarse loose bark and the workman has to saw or chop off twigs and branches as he climbs. Finally, putting the wire through the insulators and stretching it to have the proper sag will take more time in the "elastic" system.

One of the most important economic factors in the putting up of a tree line is the organization, as rational planning and methodical execution of the work are essential if the costs are to be kept within reasonable limits. With pole lines various parts of the work are now standardized, and are besides fairly simple when it is a question of one or two wire lines, as is generally the case with forest telephones. The only matter requiring special attention will probably be the proper inclination and strutting of the poles in curves. In the elastic line the work is quite different. Here, practically every single tree that is to be used to support the wire offers a fresh problem to be faced and solved. Experience has shown that, if trained workmen are not available, it is safest even in genuine forest districts to stick to the pole line if good results are to be obtained. The use of this type of line is even more justified when the forest is sparse and the clearing of the lane consequently easier, and where the necessary poles can be prepared along th lines as the work proceeds.

R 4057

Fig. 4. Simple pole-line.

If, however, a comparatively long line has to

R 4059 Fig. 5. Type forest suitable for elastic lines, with straight branchlets trunks of suitable size. Practically no underbrush.

be put up exclusively through thick, superannuated and partly damaged forests, or through other districts, where the risk of windfalls is great and the cost of thoroughly clearing a lane is prohibitive, the tree line method will probably be most suitable both practically and economically, and should then obviously be used. The best type of forest will thus be not too closely grown stands without undergrowth and with straight, branchless trunks of 10″ to 12″ average diameter (see fig. 6). But in districts where the treecrowns meet overhead, or where there are low branches or thick undergrowth, these lines are more difficult to build (see fig. 7).

Outline of Development.

In this connexion a short outline of the development of the "elastic" line method of building might be of interest. Although thousands of km. of provisional lines of this type have been laid during the building of roads, railways and other similar pioneer work in the wilds, the U. S. Forest Service must be given the credit for having so far improved the method that it can be used satisfactorily for more permanent lines as well. Behind it are nearly two decades of practical experience. It should be noted that in the State Forests the telephone network of the Forest Service alone amounts at present to almost 40 000 km., of which a considerable portion consists of tree lines. The network is being extended as available means permit.

The first efforts at using growing trees when building telephone lines were made on the whole on the same principles as in inelastic lines; in other words, it was a kind of pole line where the poles had been replaced by growing trees placed by Providence at suitable intervals. In the line so obtained interruptions were far too common, and this type of line soon proved rather unpractical. To increase the reliability, a more elastic line was wanted, and the line was therefore carried in wire loops fixed to the insulator caps instead of being stretched between the caps. The loops were gradually replaced by fixed porcelain rings, which had in turn to give way to the now generally used suspended and split insulator. In course of time this too has been modified in some respects, and has lately been made oval in shape (see fig. 8).

At the same time the methods of fixing the

R 4058 Fig. 6. In this type of forest, tree-lines should obviously not be used.

hanging insulators in the trees have been improved. At first a piece of ordinary telephone wire was used for this purpose. Nowadays there are—as shown in fig. 1 — a number of different methods of arranging and fixing the wire carrying the insulator ring, each intended for some special purpose.—In the beginning, the importance of ample sag and even spacing of the trees was not recognized, but it was soon found that proper regulation of these factors was of vital importance if the line was to resist various threatening calamities. Although the modern tree line differs widely—in its sag and, from the ordinary telephone builder's point of view, in its peculiar looks—from the usual permanent telephone lines, experience has nevertheless shown that these methods of construction are essential for achieving a method combining relatively low building costs with high efficiency.

As the methods of building have improved, so also have the telephone materials made much progress. But that is another story!

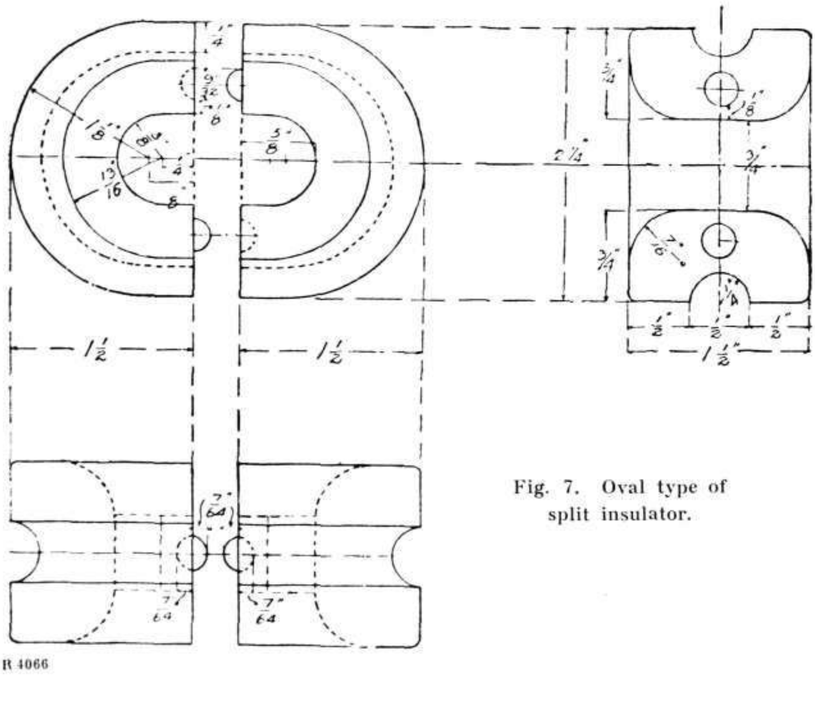


Fig. 7. Oval type of split insulator.

Present Tendencies in Electrical Wiring Methods.

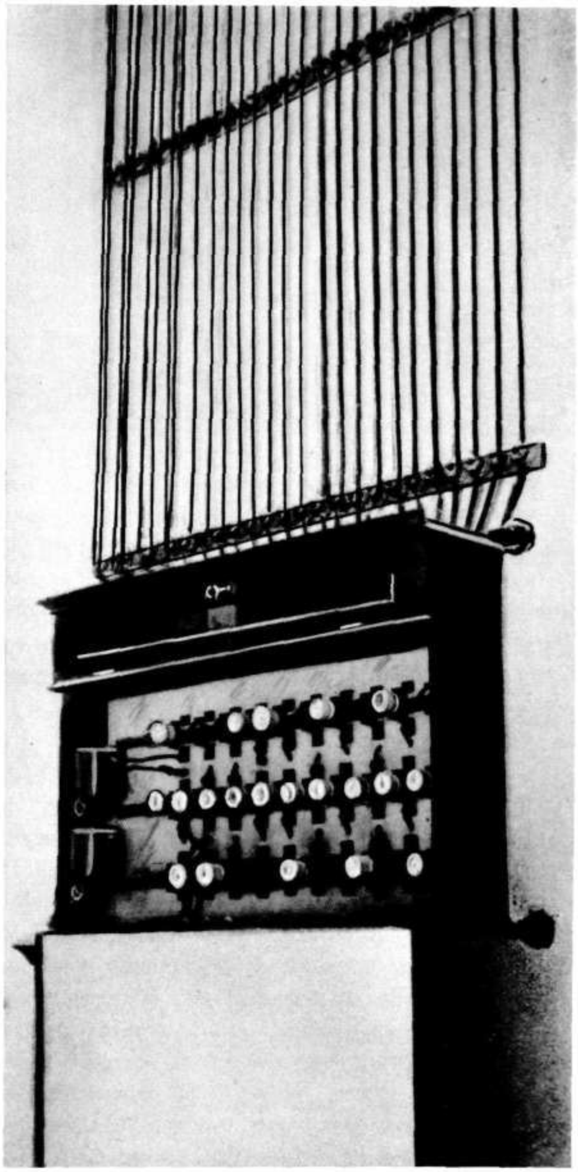
By *T. Husberg.*

In the 1880's, when high tension electric current came into use for lighting supplies and to some extent also for power, the experience gained in low tension installations was, of course, all that was available. It is therefore perfectly natural that mechanical damage to the conductors was primarily considered. It was thought that to let the wires follow the walls, and to provide them with some kind of protective covering, was the best means of safeguarding the working reliability. This led to the use of wood casings, where the wires were put into grooves between two strips of wood screwed to the wall. Where this method was considered too expensive, the wires were fixed to the walls with staples, with some kind of fibrous tape between them and the wall.

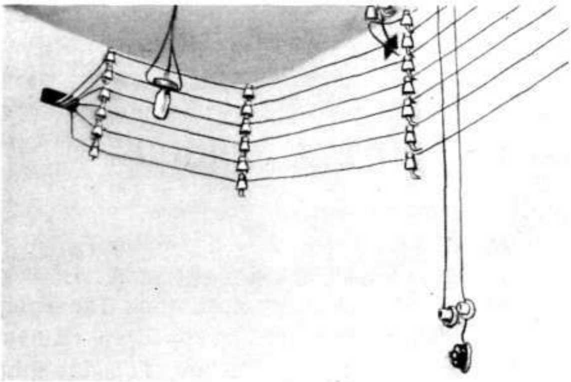
Originally, the conductor was just spun over with cotton, and this insulation was sufficient as long as only 110 volt D. C. was used and the premises to be wired were perfectly dry.

But certain portions of electrical plants were necessarily exposed to chemical action, especially as wiring was soon also needed in other than dry places. The wood casings obviously not only offered insufficient protection against, for inst., moisture, but under certain circumstances they actually involved a risk of fire. The idea of removing the wires from the wall and fixing them on studs made of some insulating material, e. g. porcelain, was then mooted. Wood casings were therefore discarded in favour of the method which, with certain modifications, has been used ever since, and which we call *single conductors on porcelain insulators.*

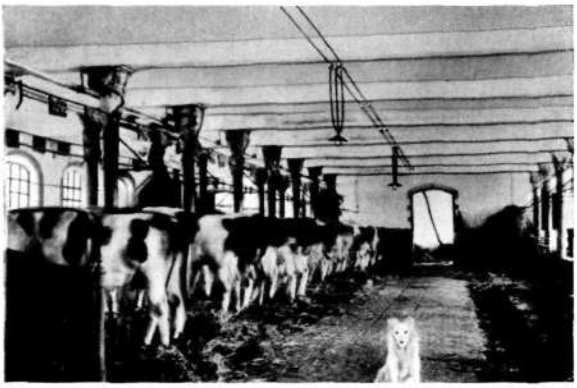
However, conductors fixed on porcelain studs at a certain distance from the wall were not satisfactory, as, when the wires had to be crossed or passed through uninsulated walls etc., occasional short circuits could hardly be avoided. To reduce these risks, the conductors were therefore provided with an insulating cover of considerably greater dielectric strength than the spun cotton, viz. a rubber tape wrapped in one or two layers round the conductor. This brought the *rubber-taped conductor* into being.



R 1886 Fig 1.



R 1884 Fig. 2.



R 1887 Fig. 3.

As electricity became more widely used for illumination purposes, the working conditions for conductors and other wiring material gradually became more exacting. Both the insulating and mechanical strength of the rubber-taped wire fixed as a single conductor on porcelain studs soon proved insufficient to withstand the siresses to which it was exposed. Improvement was sought in both the above directions, i. e. by altering the method of fixing the wires and by strengthening the insulation.

Before the introduction of high tension systems, lines in the open air had furnished valuable experience of how to provide sufficient insulation even for heavy moisture. Certain indoor premises were considered to present working conditions similar to those of the open air, and for damp indoor premises *single conductors on open-air insulators* were therefore resorted to.

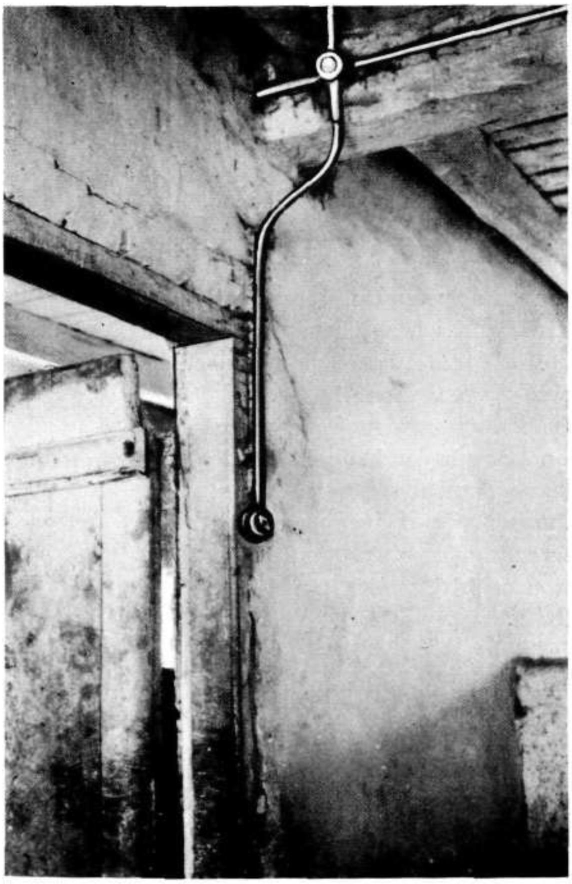
That these wiring methods, if carefully and skilfully applied, gave good and valuable results, is amply proved by the several examples of conductors on outdoor insulators or on small porcelain studs still in use. Some recent photographs from such installations show how the rows of porcelain studs were fixed on strips of wood, (fig. 1) how the outdoor insulators were bolted to the walls in the same vay as to poles in the open air, (fig. 2) how the problem of carrying the conductor through walls was solved, (fig. 2) and how switch wires could in a simple way be led down from the group conductor in the ceiling (figs 2). It is fairly obvious that wires fixed on outdoor insulators in a cowhouse (fig. 3) will offer a considerable resistance to earth. Passages through walls, switches, and lamp-holders will obviously be the weakest points.

Rubber-tape insulation was liable to dry and crack, thereby losing the greater part of its insulating properties. It was therefore necessary to find some jointless and at the same time tough and flexible covering. When the manufacturers succeeded in producing a conductor enclosed in a vulcanized pressed rubber cover

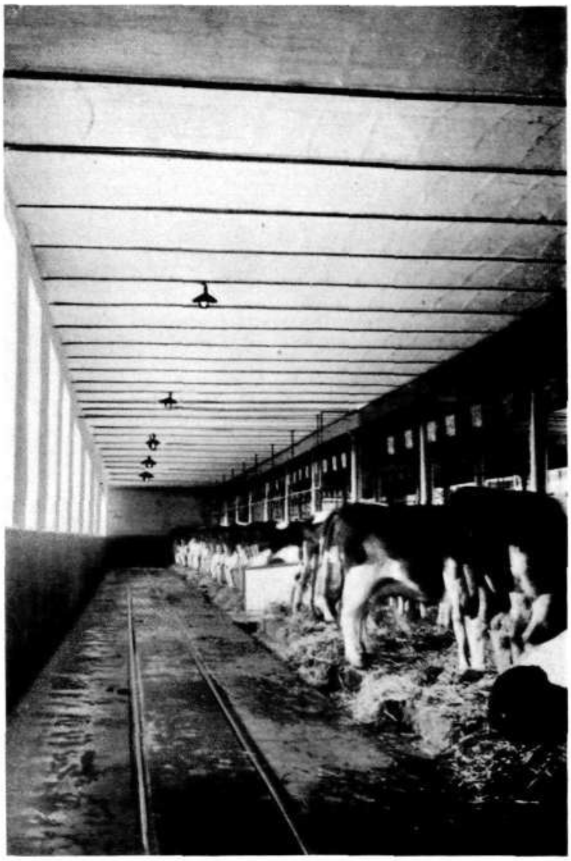
R 1890 Fig. 4.

which fulfilled these conditions, this *vulcanized conductor* proved to be the most valuable means to date for making the wiring of electrical plants safe and reliable. This was particularly convenient, for as electrification became more general, even in rural districts, during the early years of this century, the working voltage was raised and alternating current became more usual for lighting purpose also. The strength of the insulation required for 220-volt A. C. must, as we know, be of an entirely different magnitude than for 110-volt D. C.

Vulcanizing had provided such an excellent insulating material that conductors insulated in this manner could be put up in immediate contact with one another, as for example as *twin-wires on studs,* or enclosed in a common cover of cotton yarn or the like, forming *2-, 3-, and 4-wire conductors,* without the risks run when placing rubber-taped conductors in the same way. One of the indications of the raised demands on the quality of the insulating cover is the well-known increase of the rubber content from 25 to 33 per cent.



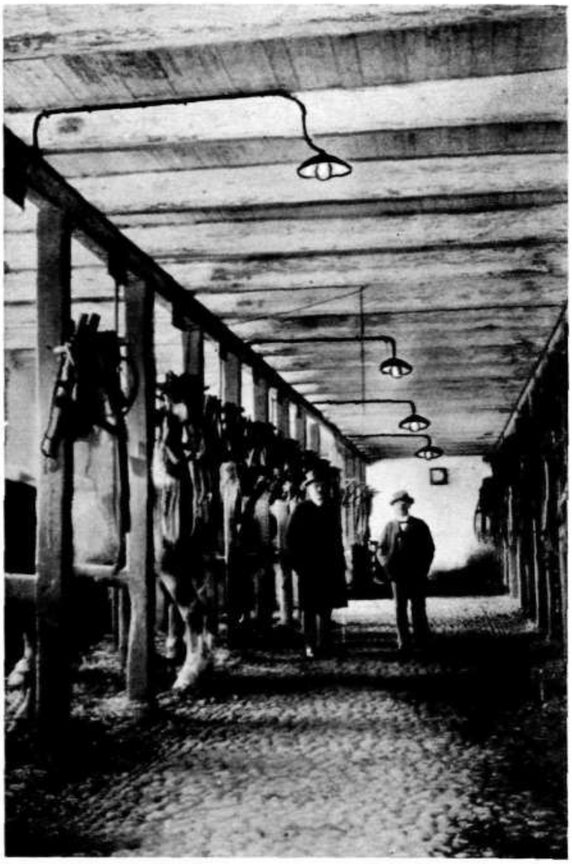
R 1889 Fig. 5.



R 1908 Fig. 6.

Even though the vulcanized conductor mounted on porcelain studs of suitable size had proved fairly satisfactory as far as the insulating stresses were concerned, this method of wiring was still too liable to suffer mechanical damage. Metal covered insulating tubes were considered to offer an equivalent to the merits of wood casings in this respect. According to the degree of mechanical strength required, the sheath would consist of leaded sheet iron or steel conduits. Wherever the leading was not considered *sufficient protection* against the corrosive effect of chemicals, the insulation was covered with brass sheeting, and as the benefit of the sheath as an insulator was sometimes doubtful, the mechanical protection alone afforded by the pipe was considered, and the vulcanized conductor was enclosed in uninsulated steel piping.

The various forms of *conduits* have been of



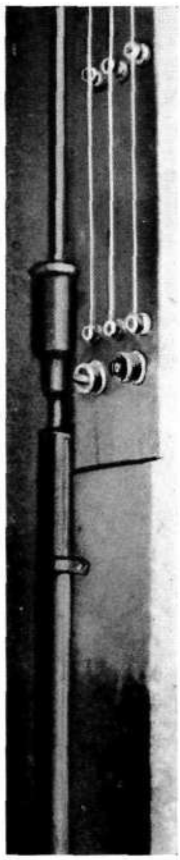
R 1893 Fig. 7.

extraordinary assistance in wiring operations, and will certainly play an important role in future also. By this method the early tendency of the wood casings—to keep the wires out of sight—could be developed to comply with any reasonable aesthetic demands. The trend of modern practice obviously is towards using vulcanized cables in steel-or steel-armoured tubing for all wiring in residential buildings, and to embed the pipes in the walls and floors. The insulated tubes covered only by leaded sheet metal are easily damabed by, for instance, nails, and are therefore gradually being superseded for use under plaster by steel pipes with or without an inner insulating tube.

Aesthetic reasons have naturally also contributed to the advent of the so called *Kuhlo conductor,* which will soon have completely ousted the twin conductor on porcelain studs. For a long time to come this type of conductor will undoubtedly be most in favour for residences and suchlike premises where considerations of cost or other reasons prevent the use of hidden conduits for the conductors.

The immediately apparent advantages over the previous methods offered by the conduit system led to its employment by some over-enthusiastic electricians even where its weak points would be particularly shown up by the working conditions. I refer to the extensive use made about 1910 of this system in stables and similar damp premises. When carefully made, and with first class materials, however, even conduits in stables may last a fairly long time before perishing of old age. Some photographs illustrate this. (Figs 4 and 5.) A pigsty is acknowledged to be a very trying locality for electric wiring, and the pipes may corrode very quickly there. The installation shown dates from a few years before the war, and the photos were taken some weeks ago. (Figs 6 and 7.) Armoured steel pipe wiring was installed in 1912 in the cow-house shown in the picture, and is still in perfect working order.

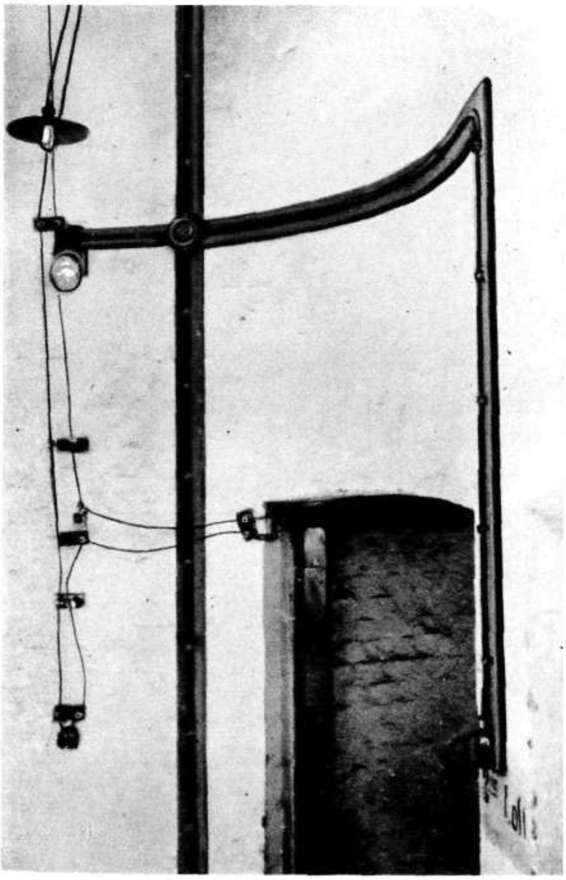
Far from all conduit wiring of damp premises, however, was done as carefully and with as good materials as those now illustrated. The weak points of the various methods therefore soon became apparent, and it became clear that the method must be varied according to local circumstances. Where mechanical damage was the principal risk, pipes were used, and where chemical corrosion was most dangerous, wires with specially prepared insulation covers were placed on ample and specially designed cup insulators. In premises of definitely one characteristic or the other, no objection could be made to this method, but working conditions involving risks of both mechanical damage and chemical corrosion will occur, and in such cases neither of these methods will be satisfactory. Another weak point was where one system was changed to another.



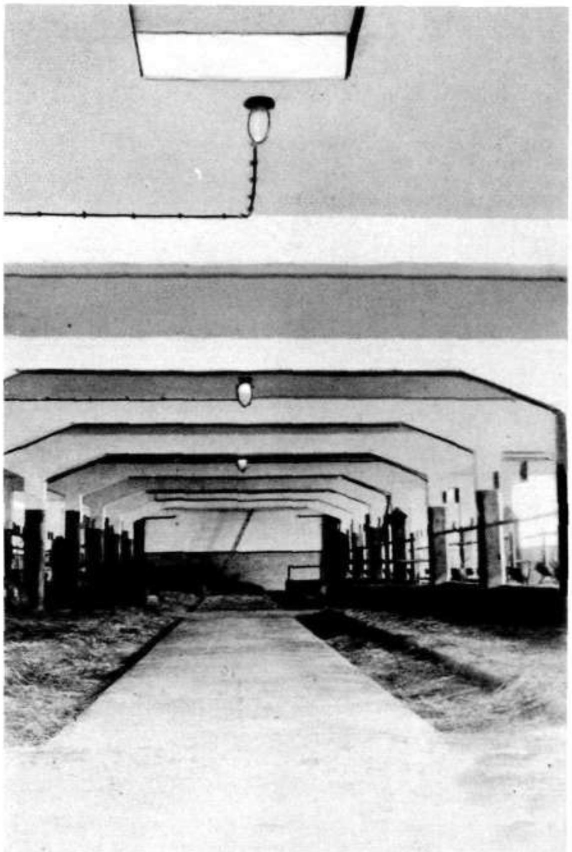
R 1894 Fig. 8.

During the war, when lack of raw materials caused a deterioration of quality in all wiring materials, the drawbacks of the different wiring methods soon showed up, and this led to the introduction of many improvements. Subsequently, when these inferior installations were overhauled, the experience gained led to a close study of the factors determining their length of life, and this was undoubtedly a consequence of the war which was of great value. The insulating properties of pipe conduits proved unsatisfactory when they were exposed to moisture or large variations of temperature. This is only natural, for, however carefully fitted, a pipe system can never be so tight that no damp can penetrate from the surrounding atmosphere. Once inside the pipes, the moisture will remain and corrode the insulating cover of the conductor and the inner surface of the pipe. Experience has also shown that conductors in pipes are unsuitable except in perfectly dry premises.

To avoid this drawback, the insulation of the conductor must obviously be protected so that the surrounding air is completely excluded. The method used for earth-cables, to cover the insulated conductor with lead, did this successfully, and was therefore applied to the vulcanized conductor also. This conductor covering was proof against outside chemical influences, but a lead covering alone is not sufficient protection against mechanical stresses, and this had of course also been experienced in the case of underground cables. The mechanical stress problem was satisfactorily solved by armouring the conductor with two spiral steel bands wound in opposite directions. Just as the insulation of an ordinary vulcanized conductor was protected by an impregnated cover, the armouring of the lead-covered wire was protected by a braiding of black or red-lead impregnated hemp or cotton yarn which prevented or at least delayed the corrosion of the steel bands. Indoor conductors had thus developed into the *armoured rubber-lead conductor* or, as it used to be called, the "visi-cable" or "byre-cable".



R 1896 Fig. 9.



R 1897 Fig. 10.

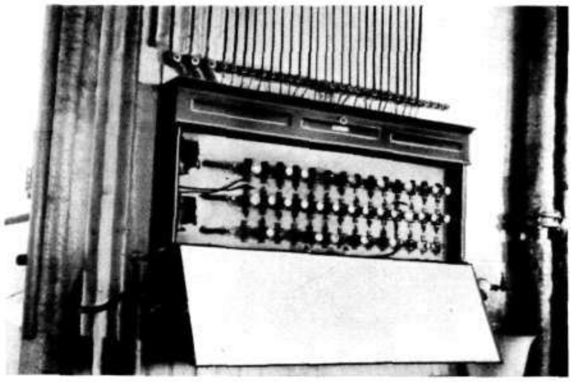
R 1899 Fig. 12.

The development of rubber-lead conductors from the earth-cables may also be traced in the development of the connexion boxes used for rubber-lead conductors. To exclude atmospheric influences, the joints must be made air-tight, and this was at first done in the same way as for earth-cables by pouring cable compound round the connexions. Most electricians will remember the compound-filled connexion boxes with glass or paper lining which was a characteristic accessory when the so-called "visi-system" was first introduced in Skåne from Denmark. To put one up was a small work of art, in which frequently even an accomplished fitter failed, and if this device had not soon been improved, the byre-cable would certainly have been very little used. We all know the radical simplification introduced by open connexions enclosed in a hermetically sealed box. The box must be exceedingly well sealed and very durable, as any deficiencies in these respects will make all the advantages of this wiring system somewhat illusory. The rapid progress of recent years in the manufacture of insulating and wiring materials leads us to hope for further perfection in connexion boxes for rubber-lead conductors. What has so far been produced can hardly be regarded as the last word on the subject. We need a less clumsy—even elegant—durable and cheap design, which will allow reliable earthing of the cover while retaining the good connecting devices of the present boxes. A rubber-lead conductor with an earth wire enclosed in it, and bakelite connexion boxes are steps towards a satisfactory solution.

The technical and economic advantages of using such wiring material as require the least possible fitting work on the spot may well be emphasized here. Standardized production will result in a more constant quality and much lower costs.

We have now followed the progress of indoor wiring methods from wood casings to vulcanized

R 1898 Fig. 11.



R 1901 Fig. 13.

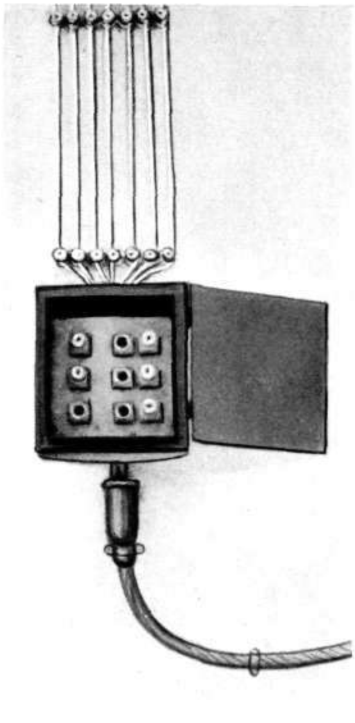
conductors in steel pipes—Kuhlo conductors—rubber-lead conductors, and will only now add that the equivalent of the rubber-lead conductor at higher voltages and powers obviously is the earth-cable, which offers the same advantages over other insulating methods as the rubber-lead conductor.

The previous illustrations have given examples of older methods of wiring, and we shall now see how these compare with the modern methods. (Figs. 8 and 9.) Steel conduits in a piggery, side by side with underground cable. The trend of progress is obvious. Rubber-lead conductors succeed the single wire conductors on studs.

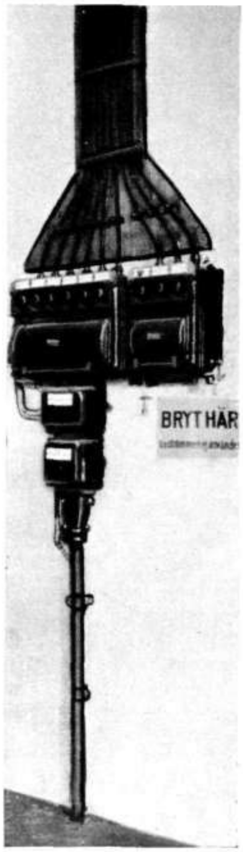
Figs. 10, 11 and 12. The latest results of progress have been utilized here. Rubberlead conductors in these large new cow-houses are perfectly in accordance with the conditions of the surroundings and the quality of the building. A correctly put up rubber-lead conductor answers the purpose well in the inflammable chaff-loft. (Fig. 12.) Obviously, the connexion through the wall between the damp and the inflammable premises will cause no difficulty.

The wiring material being the largest and most comprehensive portion of an electrical installation, its development offers most interest. But good accessories are also required to get the full benefit from first-class wiring materials, and the improvements in these have therefore naturally kept pace with the advance in the conductors.

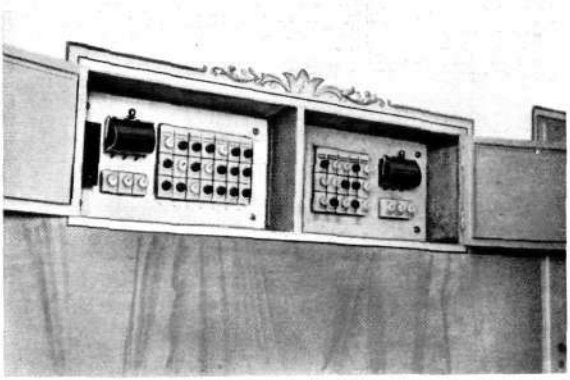
Those of us who remember the early days of high tension electricity, will probably also recollect the fuses made of a tinfoil sheet backed by a fibre slab, which might just as easily melt at double or half the rated current. The small glass tube fuses in spring holders were an improvement, but the first really great progress was the advent of the bridge-fuse device, which made a reliable rating of the protective fuse in accordance with the load capacity of the conductor possible. To reduce the cost of the part which must be replaced when the fuse melted, this was divided into a separate fuse cartridge and a screw cap. To avoid mistakes when put-



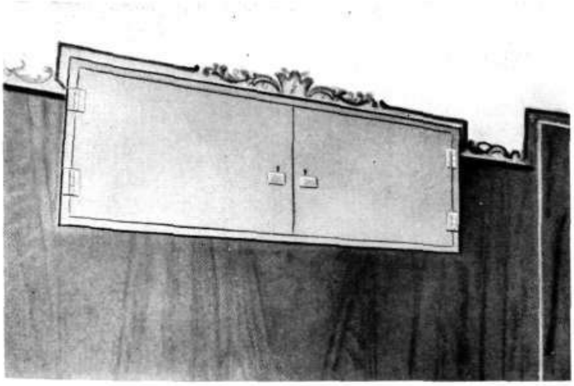
R 1905 Fig. 16.



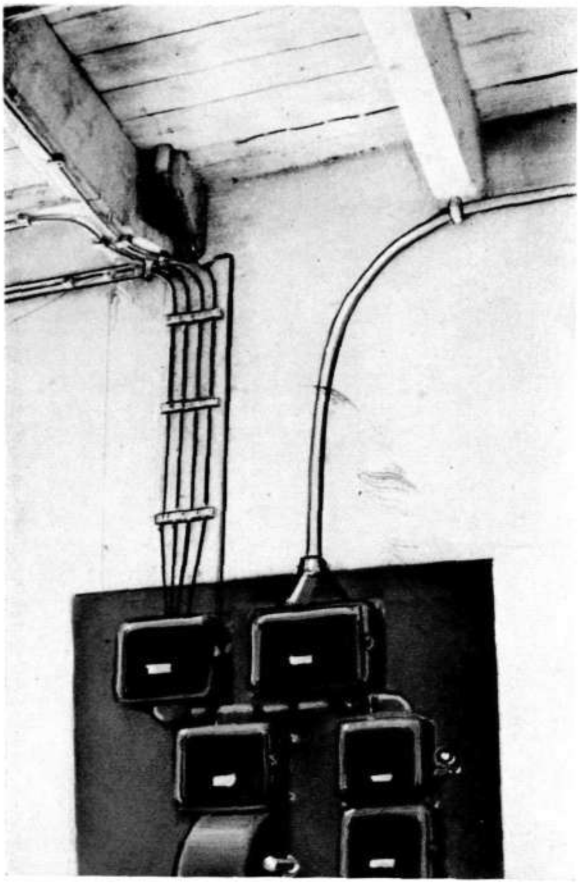
R 1904 Fig. 17.



R 1903 Fig. 14.



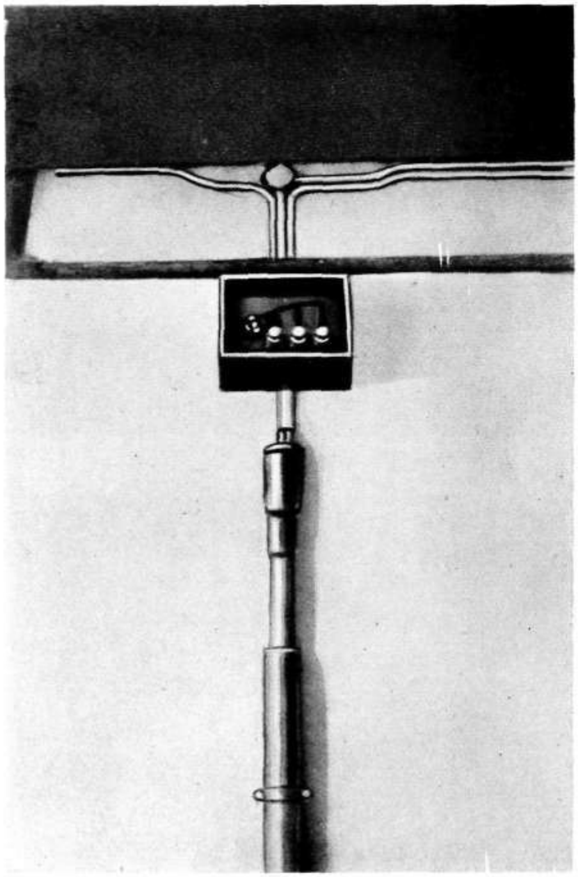
R 1902 Fig. 15.



R 1906 Fig. 18.

ting in new fuses, the cartridges were at first made of different heights according to the strength of the current, but this somewhat primitive arrangement was superseded by the diazed-system, where the diameter of the live part of the fuse cartridge and the corresponding hole in the fixture increase with the strength of current, which renders any illegitimate "reinforcing" of the fuse protection practically impossible. In the two-part *fuse-box,* graduated according to the diameters of the fuse cartridges, the solution of the safety problem is perfectly satisfactory in principle. This has also made it possible to standardize dimensions and threads, and further improvement of the guiding of the fuse cartridge to make the contact between fuse and box contact absolutely reliable in fittings for high amperages also, must now be made. This demand can be fulfilled only by making the thread of the screw top fit well into the other part. For this reason a stipulation is introduced in all carefully detailed specifications to the effect that "all screw sockets in the fuse-boards must be cast solid, and the thread cut fine for currents from 100 A. upwards". Fuse boards with thin sheet brass screw sockets may now be regarded as quite out of date.

The *automatic cut-out* as protection against over-current has this advantage over the fuse, that it may immediately be taken into use again after having functioned, without any replacement of parts. The risk of making mistakes in the rating of the overload protection is also considerably reduced by the use of automatic cut-outs. For motors and other apparatuses liable to occasional overloads, the automatic cut-out is rapidly supplanting the fuse. As protection for a three-phase motor, for example, the correctly designed automatic cut-out has the great advantage over the fuse that an overload in *one* phase will cause the current to be cut off in *all three* phases, and the motor will thus be protected against overheating by "running on

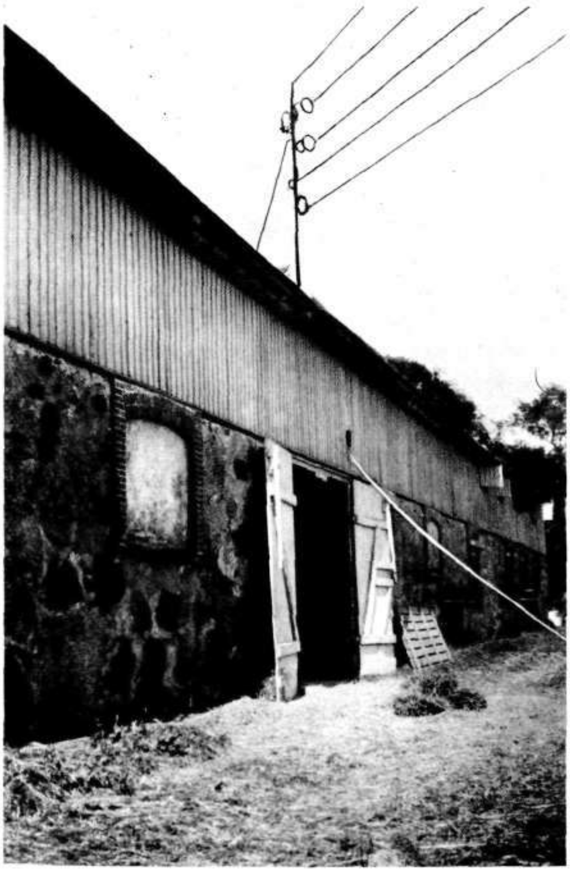


R 1907 Fig. 19.

two phases". The trend of progress in over-current protection for motors thus distinctly points to a more general use of cut-outs, designed on electrothermal or electromagnetic principles, instead of fuses.

For reasons similar to those which led to the design of cut-outs for motors and the like, attempts have also been made to replace the fuses in ordinary domestic installations by small automatic devices. In a comparatively small compass, however, these German so-called "Klein-automaten" must necessarily contain a fairly complex mechanism. But this apparatus needs, in its present form, fairly favourable working conditions to work well. The premises, anyway, must be dry.

The old bridge design is still doing duty in many places although more than thirty years old, as we see from this picture (fig. 13), and the modern diazed-apparatus, even in large and modern plants, still affords satisfactory protection against over-current (fig. 14 and 15).

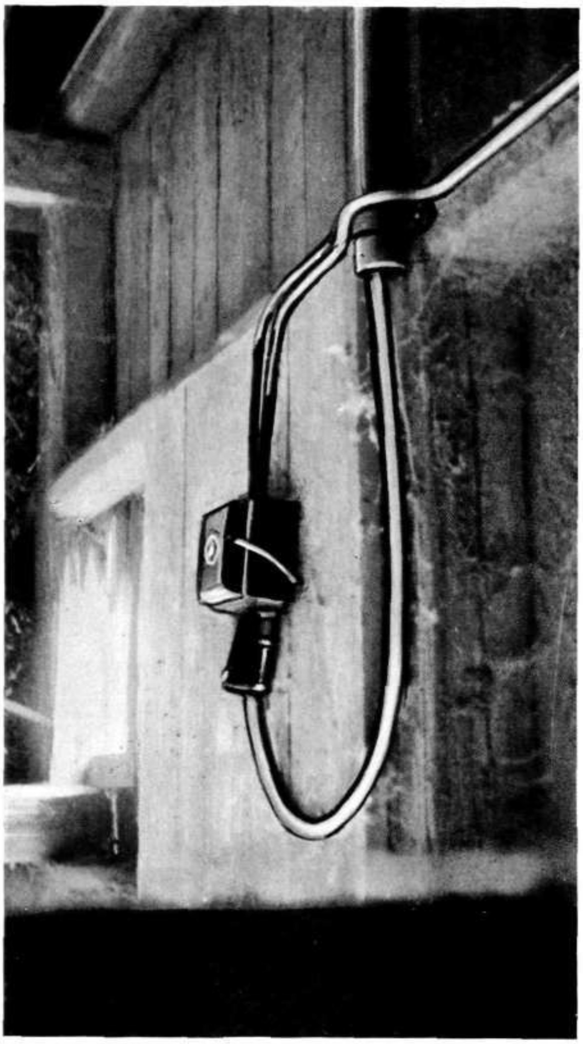


R 1900 Fig. 20.

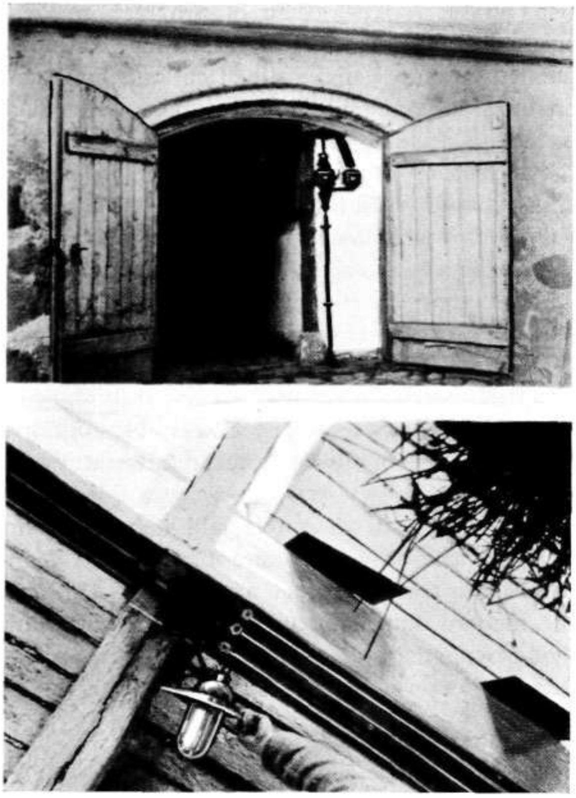
R 1892 Fig. 21.

We have pointed out above that conductors are gradually being improved, and the same is the case with all accessories used in ordinary domestic installations. Consequently, a blown fuse will obviously become an increasingly rare occurrence, and the exchange of burnt fuses will not represent any appreciable cost or trouble. The small automatic devices (Klein-automaten) will have to be considerably simplified and their designs standardized—which might also cheapen them—before they can replace the diazed-apparatus to any great extent.

The general effort to improve the quality has also left traces in the development of *switches*. For weak currents, the rotary switch has maintained its position as a reliable fitting, and the recent efforts at uniformity of types for this mass-article must be greeted with satisfaction. The very weak designs of box-switches for 2 A and 4 A, which for reasons of cost used to be extensively employed, are now condemned by experience.



R 1882 Fig. 22.



R 1881 Fig. 23.

The general principle that a switch should always be either full on or full off has been retained, while the manner of operating them has been slightly modified. Under certain circumstances it is undoubtedly more convenient to operate a switch by moving a lever up or down (the analogy of the knife-switch is obvious) or to push a white or black button, than to twist a handle. It is therefore easy to understand that the tumbler switch and the push-button switch are *gaining ground.*

The knife-switch still maintains its supremacy for breaking strong currents. It is a simple and reliable appliance, and there is no particular reason why it should be displaced by any other kind of switch, except for special purposes.

The most remarkable feature of the development of installation accessories, however, is the incessant efforts to enclose them so that they may be used in any premises, irrespective of *prevailing conditions.* The *cast iron casings* for different voltages, manufactured on a large scale, can therefore be designated one of the most important improvements (fig. 16 and 17). About 20 years (1910—1929) intervene between these two designs. The improvement is obvious. In 1910 the apparatuses had to be fixed on the marble panel on the spot, or anyway specially designed for this particular plant, and were protected by a rather primitive sheet iron cover. 20 years later the central control station is made up of robust standard switching units.

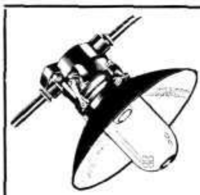
(Figs. 18 and 19.) Fittings in cast iron *casings are not damaged by being distempered,* but open appliances in a wooden box must of course be carefully protected from any such treatment.

Suitable wiring materials, and accessories which are reliable even under difficult conditions, have enabled the electrician satisfactorily to solve certain problems which used to be very troublesome. Formerly, outside supply lines were sometimes connected to the inside wiring in a way which made the actual point of connexion a fruitful source of faults. The one-time popularity of gallows on the roofs constituted such an irregularity in installation methods, presumably unavoidable when no previous experience was available. (Figs. 20 and 21.) Earth-cables and iron-cased apparatus, however, may render even previously risky intakes from roof gallows innocuous, (fig. 22).

By connecting an underground-cable judiciously to the wiring in an old building, an iron-cased switch will, at no great extra expense, satisfy even the demands of the fire insurance companies for cut-out facilities. (Fig. 23.) The illustration next to it indicates how a still serviceable installation of TVM ki may suitably be extended by rubber-lead conductors.

The superior quality of modern installation materials naturally demands a higher price than corresponding older materials of inferior quality, and the former might therefore be expected to prove more expensive to use, but the additional cost is very small—sometimes none at all—if the wiring is carefully planned and every opportunity offered by the new materials is taken to shorten the lengths of conductors required, and to arrange the accessories rationally.

The tendency is characterized by: underground distribution lines—apparatuses enclosed in cast iron cases—great resisting power to all occurring stresses—and indoor wiring materials unaffected by local conditions.



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The Railway Telephone Cable on the Electrified Malmö Lines.

Communication from the Swedish State Railways.

By *Ivar Billing.*

The electrification of the Swedish State Railways is now proceeding on the Malmö route, comprising the lines:

Järna—Nyköping—Malmö,
Katrineholm—Åby,
Örebro—Mjölby,
Nässjö—Falköping,
Malmö—Trälleborg, and
Arlöv—Lomma,

in all 534 miles of track. The system adopted is the same as on the Ore Line from Luleå to Kiruna and the Norwegian frontier and on the Stockholm—Gothenburg line, i. e. single phase A. C. of 16 $^2/_3$ cycles and 16 kV in the contact wires.

The current will be supplied not only from the previous three transformer stations at Södertälje, Sköldinge, and Hallsberg on the Gothenburg line, but from six new transformer stations as well, at Eksund near Norrköping, Mjölby, Nässjö, Alvesta, Hässleholm and Malmö (see map, fig. 1).

Regarding disturbances in neighbouring telephone and telegraph circuits and the measures so far taken to overcome them we will here only recall the following. On the Ore Line (271 miles), the electrification of which was completed in 1923, overhead telephone wires have been retained, but the poles have been moved to about 60 yds. from the track, which has been fitted

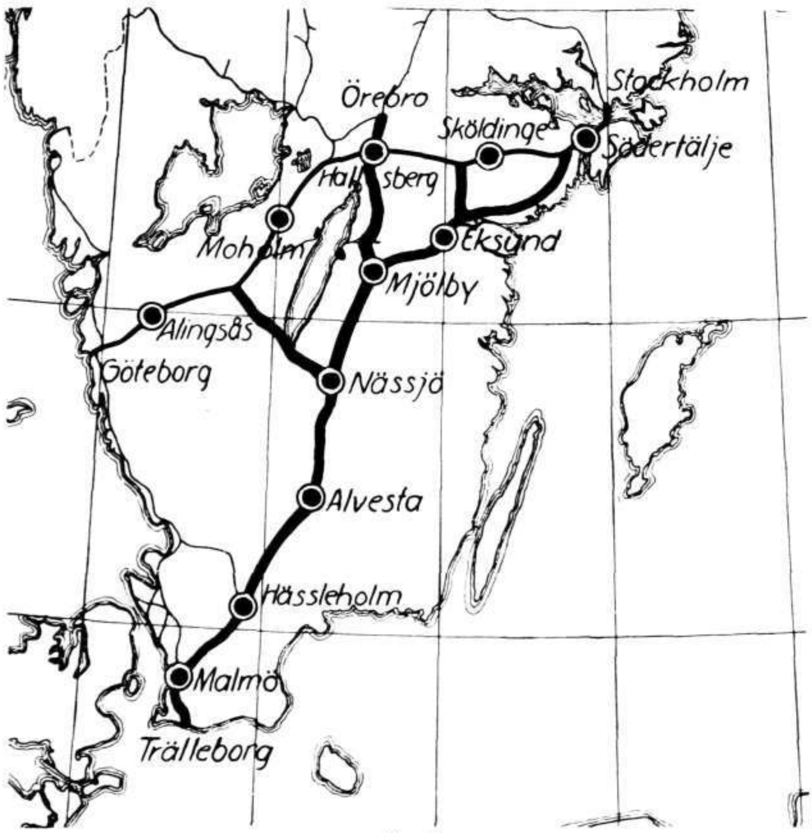


Fig. 1.

with compensating transformers connected to the contact wire and the rails. The *Gothenburg line* (284 miles), on the other hand, which was electrified 1924—26, has an underground telephone cable for the needs of the railway buried in the track, which has been fitted with compensating transformers connected to the contact wire and a special return circuit connected to the rails approximately mid-way between every two adjoining compensating transformers. Full details of the protective devices on these railways and their results as regards counteracting the disturbances have already been given in previous articles.[1]

The electrification of the Malmö lines was decided on by the 1931 Riksdag, which also granted the necessary money for the purpose, and the task was begun in the spring of the same year. This work includes the fitting of a cable for the railway telephone lines, for which a conditional agreement had been signed as early as December 1930. The greater part of this work was done in 1931 and is expected to be completed about September 1932.

Below we give some details of this cable, the method of laying it, and results obtained.

The total length of cable is greater than the length of the above railway lines, as it was found expedient to lay a new cable on the section from Stockholm to Järna also, so as to have a uniform main line cable the whole way from Stockholm to Malmö. It was also found to be an advantage to lay a separate cable for each of certain short sections where two or more of the above railways run parallel. Such, for instance, is the case on the sections Norrköping—Åby, Malmö—Arlöv, and in the yards of some of the larger stations of the line.

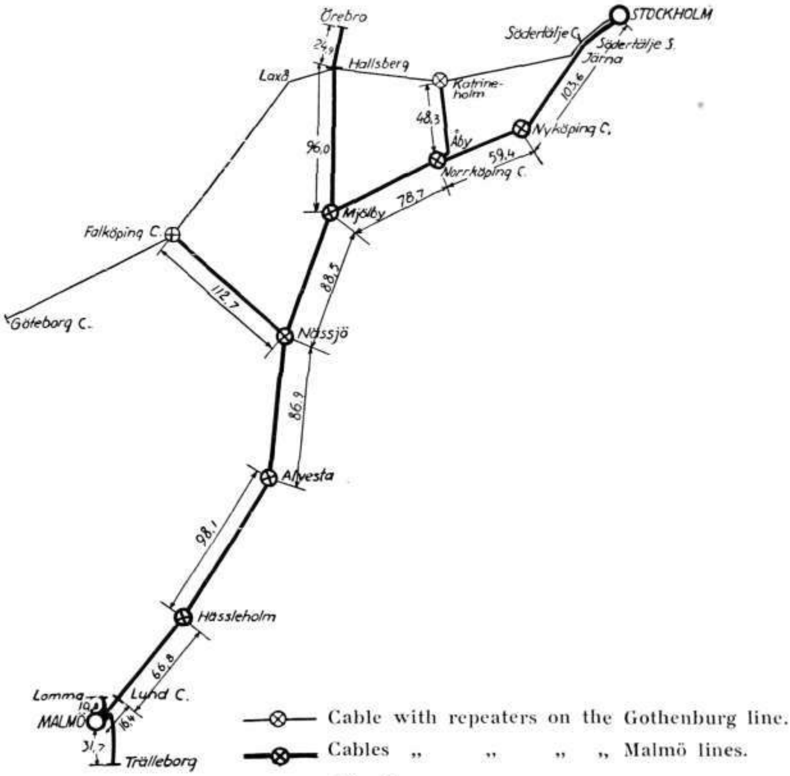
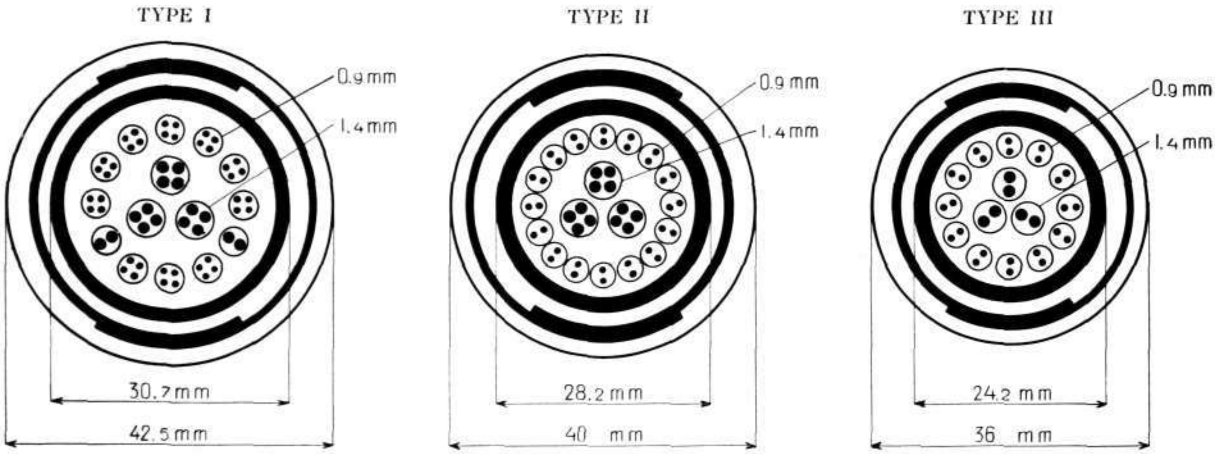


Fig. 2.

The whole plant thus comprises the following lengths of cable (see fig. 2):

Stockholm—Järna—Åby—Norrköping—Malmö,
Norrköping—Åby—Katrineholm,
Örebro—Mjölby,
Nässjö—Falköping,
Malmö—Trälleborg, and
Malmö—Lomma,

[1] See: Electrical Communication 1926, p. 199. Nord. Järnbanetidskrift 1926, p. 41, Siemens Zeitschrift 1926, p. 261 et seq., and 1927 p. 498. Elektr. Nachrichtentechnik 1927, p. 1, and Elektrische Bahnen 1928, Ergängzungsheft.



R 4090

Fig. 3.

corresponding to an aggregate track length of 573.4 miles.

Cable design and types of cables.

The experience gained in working the railway cable along the already electrified line from *Stockholm to Gothenburg* (see *foot-note* 1, page 81), was of course drawn upon when the design of the new cable was determined. It was, for instance, found possible to stipulate a lower disruptive voltage between the conductors of the cable in the Malmö lines 1 000 V. instead of 2 000 V., retaining 2 000 V between the conductors and the cable sheath.

The import of this should here be recalled. The reduction of the dielectric strength, combined with the fall in metal-prices, made it possible, without exceeding the original estimate for materials, not only to increase the length by the 30 miles of the Stockholm—Järna section, but also to increase the number of circuits in the cable considerably, thus providing a larger reserve against future needs. The main cable from Stockholm to Malmö thus contains 28 metallic circuits, as against 21 in the Stockholm—Gothenburg cable. The use of phantom circuits in the Malmö cable has also increased the circuits available there to 35, as against only 21 in the Gothenburg cable.

The Malmö cable is planned to have a greater number of direct telephone lines than the Gothenburg cable and it has therefore been possible to introduce phantom circuits, of which the Gothenburg cable has none.

Owing to the change from telegraph to telephones, a relatively large number of loaded circuits have also been found necessary in the Malmö cable. For the reasons given above, the greater expense involved by this has, however, come well within the original estimate.

With due allowance for reserves for future use, the present demand for circuits in the main cable from Stockholm to Malmö and the branches mentioned above resulted in the adoption of 3 different types of cable, (see fig. 3) namely:

Type I, the Stockholm—Malmö line, consisting of $3 \times 4 \times 1.4 - 2 \times 2 \times 1.4 - 10 \times 4 \times 0.9$ with 7 phantom circuits, in all 35 circuits.

Type II, the Örebro—Mjölby, Nässjö—Falköping and Malmö—Lomma lines, consisting of $3 \times 4 \times 1.4 - 16 \times 2 \times 0.9$ with 3 phantom circuits, in all 25, and

Type III, the Norrköping—Katrineholm and Malmö—Trälleborg lines, consisting of $3 \times 2 \times 1.4 - 12 \times 2 \times 0.9$ with no phantom circuits, in all 15 circuits.

The most important details of the technical specification of the cables are given in Table I below.

The contract for the plant was given to SIEVERTS KABELVERK, Sundbyberg, and ELEKTRISKA A.-B. SIEMENS, Stockholm, representing SIEMENS & HALSKE A.-G., Berlin—Siemensstadt, jointly, the former firm to supply all the cables, the latter to supply all the loading coils and installation materials and to carry out

Table 1.

Electrical Properties of the Cables, measured at the Cable Works.

	Specified values	Mean values measured		
		Type I	Type II	Type III
Resistance per km. at 15°C.				
in 1.4 mm. wire, ohms	max. 11.4	10.86	10.92	10.78
„ 0.9 „ „ „	„ 27.5	26.3	26.4	26.27
Difference of resistance per manuf. length between the conductors of a pair, as a percentage of the mean of their resistances	„ 3	0.5	0.6	0.4
Insulation resistance per km. with 100 v. D.C., megohms	min. 10 000	25 600	26 200	29 000
Capacity per km. with 800 cycle A. C.				
per pair of 1.4 mm., max., μF.................	max. 0.042	0.0330	0.0329	0.0328
„ „ „ 1.4 „ mean, μF.................	„ 0.038	0.0325	0.0324	0.0322
„ „ „ 0.9 „ max., μF.................	„ 0.039	0.0296	0.0303	0.0305
„ „ „ 0.9 „ mean, μF.................	„ 0.036	0.0290	0.0296	0.0296
for phantom in relation to the corresponding pair	„ 1.05×1.62	1.02×1.62	1.03×1.62	—
Capacity unbalance for cable length of 550 m. in twin conductors:				
Between adjacent pairs, mean, $\mu\mu$F...........	„ 100	—	18	14
„ any two pairs, $\mu\mu$F....................	„ 200	—	53	47
in quads:				
physical to physical in the same quad, $\mu\mu$F	„ 350	51	43	—
„ „ phantom „ „ „ „ $\mu\mu$F	„ 900	175	116	—
„ „ physical, physical to phantom, and phantom to phantom in adjacent quads .... $\mu\mu$F	„ 600	52	72	—
from physical to earth .... $\mu\mu$F	„ 1000	200	271	188
Leakage coefficient per km. at 800 cycles corresponding to $\frac{G}{\omega \cdot C}$	„ 0.005	0.0035	0.0039	0.0039

R 4076 Fig. 4.

all the installation work. The two firms were made jointly responsible for the plant as a whole.

The State Railways did the actual laying of the cable and all trenching work, etc., required.

A scheme was prepared for carrying out the contracted work during 1931 and 1932. Thus, the cables for the sections Norrköping—Katrineholm, Stockholm—Nyköping—Norrköping—Mjölby, Örebro—Mjölby, Nässjö—Falköping, Malmö—Lund, and Malmö—Lomma, a total of about 342 miles, were to be completed in 1931. Not only was all this done during 1931 according to plan but by a later agreement the cable for the Mjölby—Nässjö section of about 55 miles was also delivered, laid, and partly installed. The coil-loading and the rest of the installation work on this line will be finished in the course of the winter, before work on the remaining cables, on the Malmö to Trälleborg and Lund to Nässjö lines, is started in the spring of 1932, to be completed according to the plan by about September 1st 1932.

The Cables.

The conductors, of 1.4 and 0.9 mm. diameter, are insulated with cellulose paper, spun in pairs and partly in D.-M.-quads. The lead-sheath is 2 mm. thick and alloyed with 2 per cent. of tin. It is pressure-tested in the Works at 2 atm. extra internal pressure for 2 hours. The armouring consists of 2 iron bands, each 1 mm. thick. The marine cables used for water-crossings are provided with an extra layer of 5 mm. round steel outside the band.

The sections of the three types of cable are shown in fig. 3, from which it can be seen that external diameters of the three types I—III are 42.5, 40, and 36 mm. respectively. The weight of the cables per m. is 4.64, 4.2, and 3.48 kg. respectively.

The electrical properties required in the cables and the corresponding mean values obtained in the inspection tests at the cable works are given in Table I.

The dielectric strength of every cable was also tested with 50-cycle A. C. at 2 000 V between the conductors and the lead-sheath for 30 minutes, and between the conductors at 1 000 V for one minute.

The cables were delivered in lengths of about 600 yds., varying between 591 yds. and 602 yds. according to the fixed length of each loading-section (see below).

The coil loading.

The length of the loading-coil spacing was fixed at 2 406 yds., with a maximum tolerance of 1 per cent., and the inductivity of the loading-coils determined, with due regard to the sites already picked for the repeater stations (see fig. 2). Certain circuits used for recording the power consumption of the transformer stations, or for blocks and signals etc., have not been loaded. Each type of cable thus contains 8 pairs of 0.9 mm., conductors the are unloaded, while other pairs or physical circuits and quads are loaded as shown below:

Quads	1.4 mm.,	physical 160 mH,	phantom 63 mH,
„	0.9 „	„ 177 mH,	„ 63 mH,
Pairs	1.4 „	177 mH in type I, 160 mH in type III,	
„	0.9 „	177 mH,	

all values measured with 800 cycles A. C. and a tolerance of ± 2 per cent.

Every quad with phantom circuit has one coil for each physical circuit and one, common to them both, for the phantom circuit.

Table 2.

Properties of the loading coils.

	Specified values	Mean values measured
Insulation at 150 V. D. C., megohms	≧ 10 000	80 000
Self induction at 1 mA 800 cycles		
in physical coils mH	177	175.6
„ „ „ „	160	159.4
„ phantom „ „	63	63.0
variation, per cent.	≦ ± 2	≦ + 0.8 / − 1.6
Stability of self induction on magnetization of one winding with 0—2A D. C.:		
before magnetization mH	177	180.1
5 min. after magnetization mH	—	180.3
26.5 hours after magnetization mH	—	180.05
Change of induction after 5 min., per cent.	≦ 2.5	+ 0.113
Resistance to D. C.:		
coil-group 177/63 ohms	≦ 10.5	8.82
„ 160/63 „	≦ 10.2	8.32
coil 177 ohms	≦ 7.5	4.67
„ 160 „	≦ 7.2	4.23
Resistance to A. C.:		
at 800 cycles:		
coil-group 177/63 physical ohms	≦ 12.5	10.74
„ 177/63 phantom „	≦ 6.0	5.12
„ 160/63 physical „	≦ 12.2	10.01
„ 160/63 phantom „	≦ 6.0	4.79
coil 177 ohms	≦ 9.0	6.78
„ 160 „	≦ 8.7	6.55
at 2 000 cycles:		
coil-group 177/63 physical ohms	≦ 18.5	15.45
„ 177/63 phantom „	≦ 9.5	6.82
„ 160/63 physical „	≦ 18.2	14.13
„ 160/63 phantom „	≦ 9.2	6.44
coil 177 ohms	≦ 15.0	12.87
„ 160 „	≦ 14.5	13.46
Difference in resistance between the two branches of the coils		
in a physical circuit, ohms	≦ 0.1	0.07
in a phantom circuit, ohms	≦ 0.15	0.11
Difference in inductance between the two branches		
in a physical circuit, per cent.	≦ 0.1	0.073
in a phantom circuit, per cent.	≦ 0.15	0.095
Cross talk attenuation between two speech circuits in the same coil box, at 10 mA and 800 cycles, nepers	≧ 10	≧ 11

R 4073 Fig. 5.

All the loading-coils at a loading point are fitted into a common box. Three sizes of loading-boxes are thus used, namely:

Type I, holding 27 loading-coils,
Type II, „ 17 „ , and
Type III, „ 7 „ .

A loading-box of type I is illustrated in fig. 4.

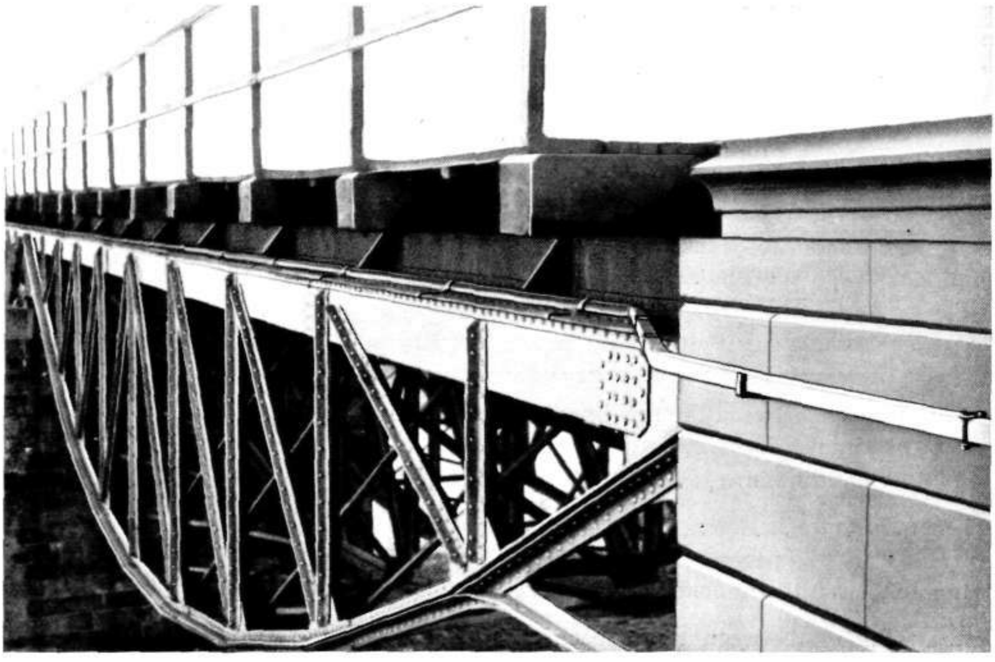
The electric requirements for loading-coils, and the mean values obtained in the tests are shown in Table 2.

Further, all the loading coils were also tested for disruption according to the stipulations with 50-cycle A. C. at 1 000 V. between the windings, and at 2 000 V. between windings and coil box.

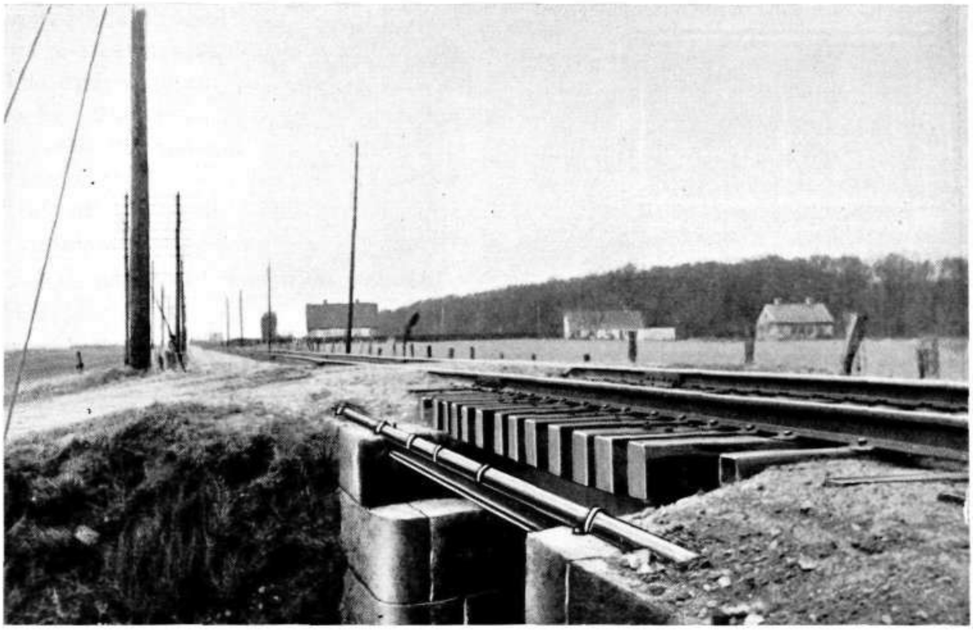
The Laying of the Cable.

The cable is laid in the permanent way 6′ 3″ from the centre of the track and at a depth of at least $27^1/_2$ in. below the lower surface of the rails. The trenching-machine purchased for the Gothenburg line was used for digging the cable trench (see note on page 81).

A new feature of the cable-laying may be mentioned here. Instead of the stones and gravel that fall into the trench being picked out by hand before the cable can be laid, a digging and cleaning-out plough has been used on part of the Malmö lines, so designed that the cable drops straight into the trench over a pully wheel inside the plough before the gravel can fall in again. This plough, which is illustrated in fig. 5, has also been used in suitable ground without previous use of the heavier trenching-machine.



R 4072 Fig. 6.



R 4075 Fig. 7.

As a rule the trench has been filled up by hand, but machines have been used for this purpose too wherever possible. A "permanent-way cleaning-machine", which automatically covers the cable with the gravel previously dug out, has then been coupled to the tail end of the cable train.

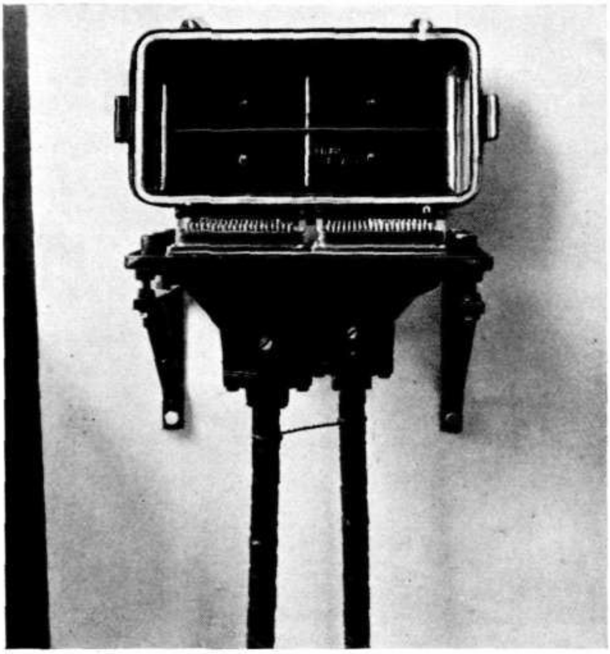
In station-yards and rock-cuttings, where the permanent way is of macadam or some similar hard material, trenching has of course been done by hand.

The cable has been laid from a cable train.

Where it has not been possible to lay the cable 27 $^1/_2$″ deep, as well as where it crosses roads, railways, bridges, or culverts, and at all intakes into buildings, etc., the cable has been protected by suitable profile irons or pipes (see figs. 6 and 7).

R 4071 Fig. 8.

In laying the cable, due allowance has been made for necessary bights to be laid out at all joints and loading-points over and above the overlap necessary for the splice, so that all installation work could be carried on far enough from the track, which was in normal use, to avoid any risk to the fitters. The actual length of cable installed is therefore greater than the length previously given, or 578.9 instead of 573.4 miles, an increase of 0.95 per cent.



R 4078 Fig. 9.

The time taken for the laying has of course depended on the nature of the country, the training of the men, and so on. Thus, in 1931 progress on the line from Åby to Katrineholm, with many rock-cuttings and tunnels, was at first rather slow, but gradually became much quicker. Last year, when a total of no less than 400 miles of cable were laid between May 4th and November 13th, the average was 42 cable drums—or 14.3 miles of cable—working per week. The most over laid in a week was 78 drums, or about 26.7 miles of cable.

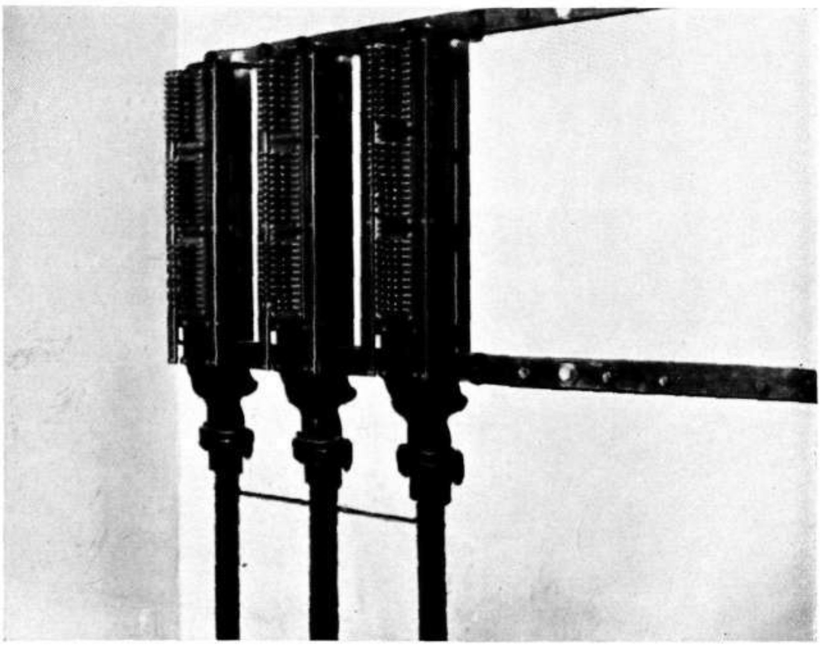
The Installation Work.

The contractors checked the lengths as the cable was laid, marking out the places for joints, condensers and loading-coil boxes. In each whole loading-section there are four lengths of cable. These have been connected in twos by ordinary simple joints. In the middle of each section a condenser box (see fig. 8) has afterwards been fitted, so that jointing and balancing of capacity has been done there in one common box when the necessary branch cables had been connected. Any further balancing of capacity required when the loading-coil boxes were afterwards put in, was effected by means of condensers inside these, according to the Siemens & Halske patent method for condensers.

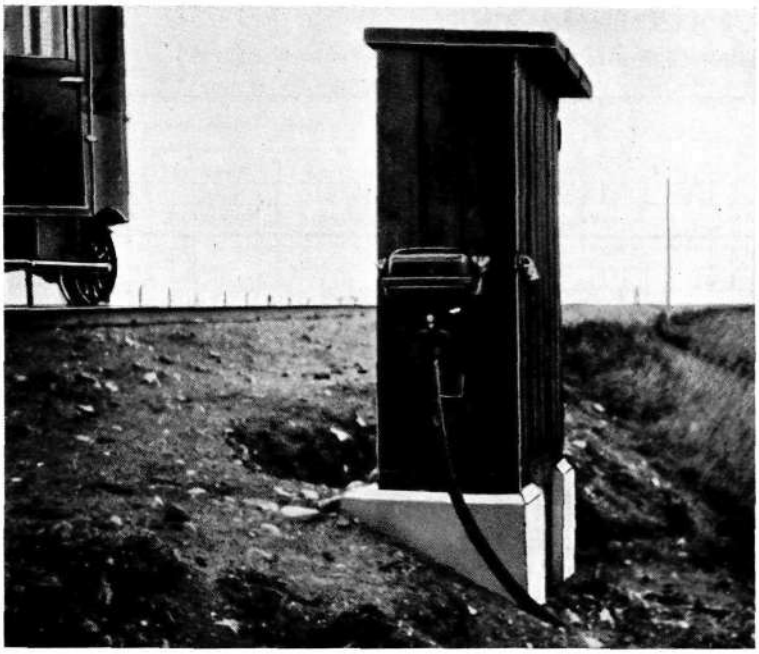
All the necessary insulation and air-pressure tests were made before the fitting of the loading-coil boxes. The loading process completed, the terminal and test boxes in the stations were put in (see figs. 9 and 10).

Boxes for joints, condensers, and loading-coils are generally buried deep enough for the cable at the ends of the boxes to be 27 $^1/_2$″ below the bottom of the rails. Supports, in the shape of sawn-off sleepers or the like, were fitted as required under the larger loading-coil boxes, which weigh about 550 lbs. The boxes are protected above by impregnated boards or pieces of sleeper.

To get the full benefit of the protection afforded by the cable sheath against disturbances from the power lines, the lead sheath and armouring are well soldered together on each side of every joint. Similarly, the sheaths and armouring of all cables in the intake boxes in the stations are connected by earthed and soldered copper.



R 4074 Fig. 10.



R 4077 Fig. 11.

Intakes and branches have been made in the following way. At every station the main cable has been cut, and the two ends connected to an intake or test box with two terminals, where instruments can be connected as required for tracing faults. Branches of the following kinds have been made: type B to trackmen's cabins, type Bm to trackmasters' offices, type Block to block posts, type Signal to certain signals, and type Omf to transformer stations. Of these. 4-pair cables are used for types B and Bm, 7-pair for signal and Omf in cables of type III, and 10-pair cables for Block and Omf in cables of types I and II.

To facilitate the tracing of faults, one track-telephone circuit can easily be broken in all the stations, track men's cabins and block posts. All branch cables end in waterproof terminal boxes (see fig. 11). To make it easy to test the submarine cables used at canal crossings, of which there are seven, test boxes have been fitted at the junctions of the marin and underground cables (see fig. 12).

The length of the loading-sections, as we have already mentioned, has been fixed at 2 406 yds., but this may vary a little as, when the measurements are checked, it has been found convenient to adjust the length slightly in order to obtain equal half-sections on either side of future repeater stations (telephone repeaters). The actual installed lengths of the loading-coil spacing in the various sections are thus:

Stockholm–Nyköping and Nyköping–Norrköping	2 428 yds.
Örebro–Mjölby	2 419 „
Norrköping–Katrineholm, Norrköping–Mjölby and Malmö–Trälleborg	2 414.5 „
Alvesta–Hässleholm	2 410 „
Hässleholm–Malmö and Malmö–Lomma	2 406 „
Nässjö–Alvesta	2 401.5 „
Mjölby–Nässjö	2 393 „
Nässjö–Falköping	2 180 „

Properties of the cable when laid.

On completion of the various cable sections, each repeater section, i. e., the part of the line between two adjoining repeaters or between a repeater and the cable terminal, is thoroughly tested. The results are collected in Table 3 below, and show that the values obtained for the transmission properties of the cable are well up to the standard demanded.

As regards the *disruptive voltage* to earth, each loading-section of the cable was tested with 1 200 V before the coils were connected.

R 4079 Fig. 12.

Table 3.

Properties of the cables when laid.

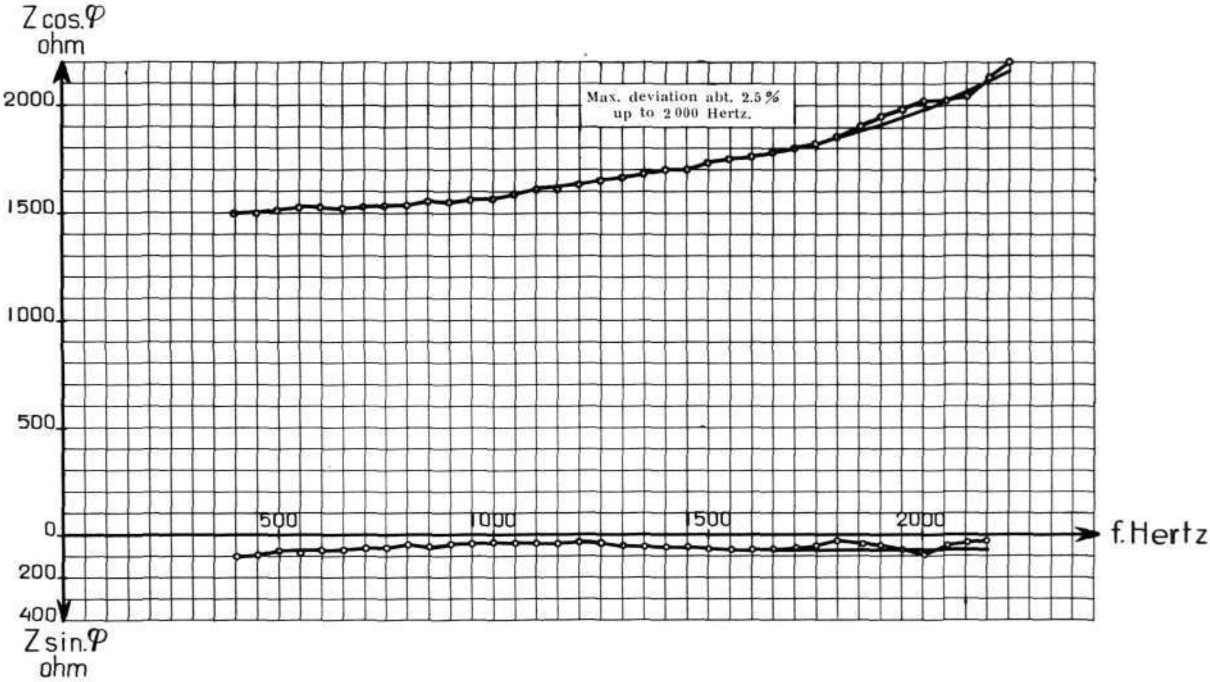
	Specified values	Mean values measured		
		Cable type I Norrköping–Nyköping	Type II Nässjö–Falköping	Type III Norrköping–Katrineholm
Insulation, megohm/km.	≥ 10 000	38 500	70 000	40 000
Difference of resistance between conductors in the same pair, ohms				
0.9 mm. unloaded	—	0.60	1.20	0.40
0.9 „ loaded	—	0.80	0.60	0.50
1.4 „ „	—	0.35	0.25	0.20
Characteristic impedance at 800 cycles				
1.4 mm. physical circuit 160 mH	1480	1530	1560	1530
1.4 „ „ „ 177 „	1560	1610	—	—
0.9 „ „ „ 177 „	1640	1700	1710	1690
1.4 „ phantom „ 63 „	715	750	750	—
0.9 „ „ „ 63 „	750	780	—	—
Attenuation exponent in nepers				
1.4 mm. physical circuit 160 mH	≤ 0.0110	0.0094	0.0092	0.0086
1.4 „ „ „ 177 „	≤ 0.0097	0.0085	—	—
0.9 „ „ „ 177 „	≤ 0.0200	0.0177	0.0170	0.0172
1.4 „ phantom „ 63 „	≤ 0.0110	0.00934	0.0091	—
0.9 „ „ „ 63 „	≤ 0.0215	0.0188	—	—
Cut-off Frequency				
1.4 mm. physical circuit 160 mH	≥ 2950	> 2950	> 2950	> 2950
1.4 „ „ „ 177 „	≥ 2800	> 2800	—	—
0.9 „ „ „ 177 „	≥ 2950	> 2950	> 2950	> 2950
1.4 „ phantom „ 63 „	≥ 3530	> 3530	> 3530	—
0.9 „ „ „ 63 „	≥ 3690	> 2690	—	—
Cross-talk attenuation between any two speech circuits, nepers	≥ 8.0	≥ 9.4	≥ 9.3	≥ 9.7
Echo attenuation in a repeater section for frequencies between 300 and 2 000 cycles, nepers	≥ 2.7	≥ 4.0	≥ 4.0	—[1]

[1] Values of about 3.3 nepers were obtained in the measurements, but these comparatively low amounts must have been due to rather unsuitable terminals being used for the lines. There was no further opportunity to take new measurements, as the circuits were immediately taken into use.

CHARACTERISTICS

Cable Type I { *centre: 3×4×1.4* / *layers: 10×4×0.9+2×2×1.4*

Norrköping C.—Nyköping C.: 59.94 km.
Pair 21+22; 1.4 mm.



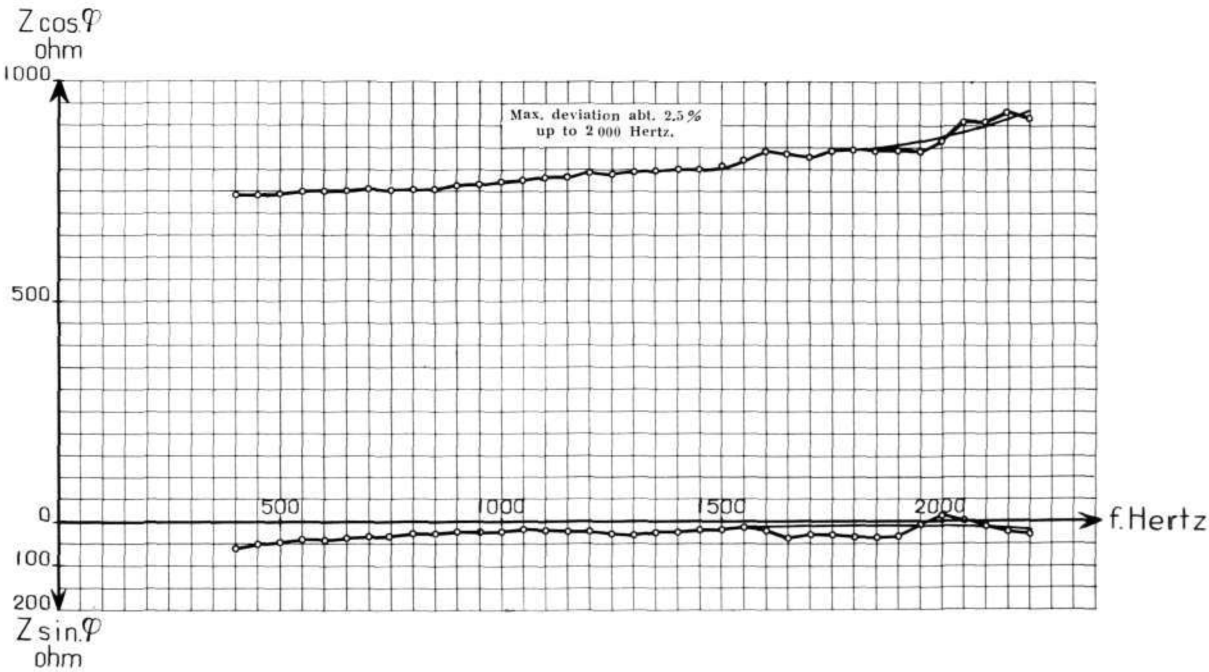
R 4096

Fig. 13.

CHARACTERISTICS

Cable Type I { *centre: 3×4×1.4* / *layers: 10×4×0.9+2×2×1.4*

Norrköping C.—Nyköping C.: 59.94 km.
Phantom 21, 22 and 25, 26; 1.4 mm.

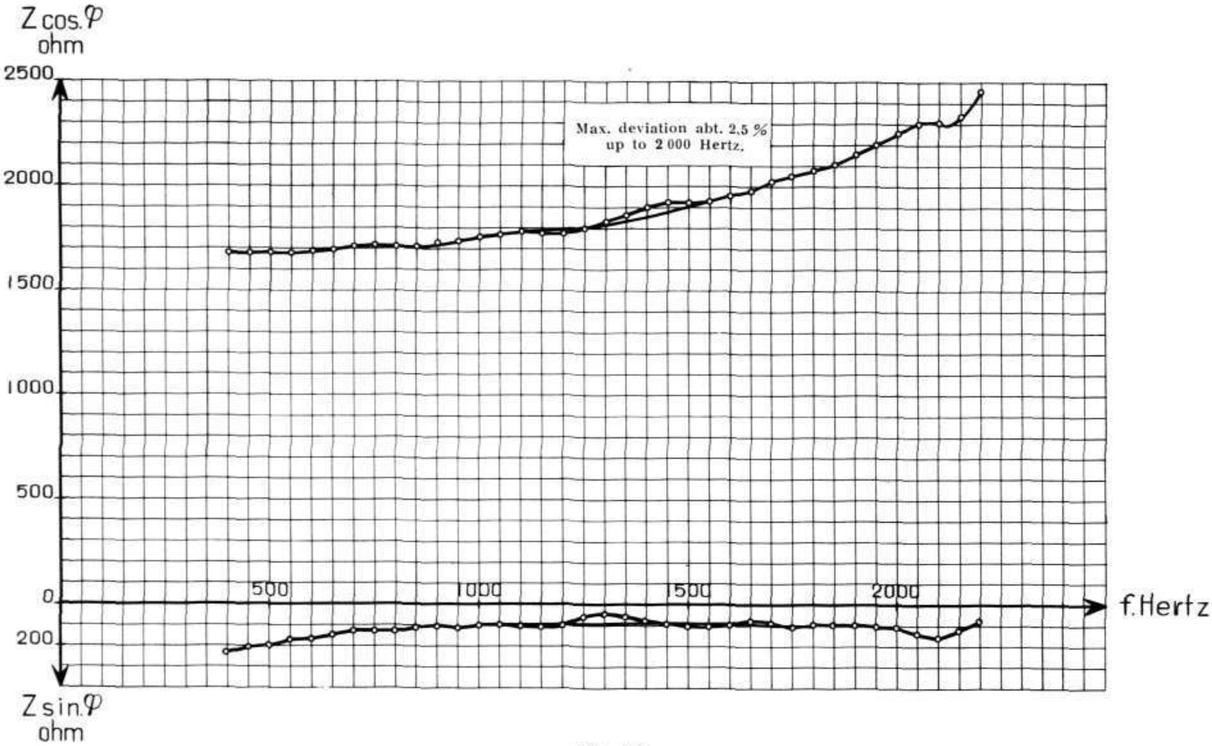


R 5097

Fig. 14.

CHARACTERISTICS

Cable Type I { *centre: 3×4×1.4* / *layers: 10×4×0.9+2×2×1.4*   *Norrköping C.—Nyköping C.: 59.94 km.* *Pair 13+14; 0.9 mm.*

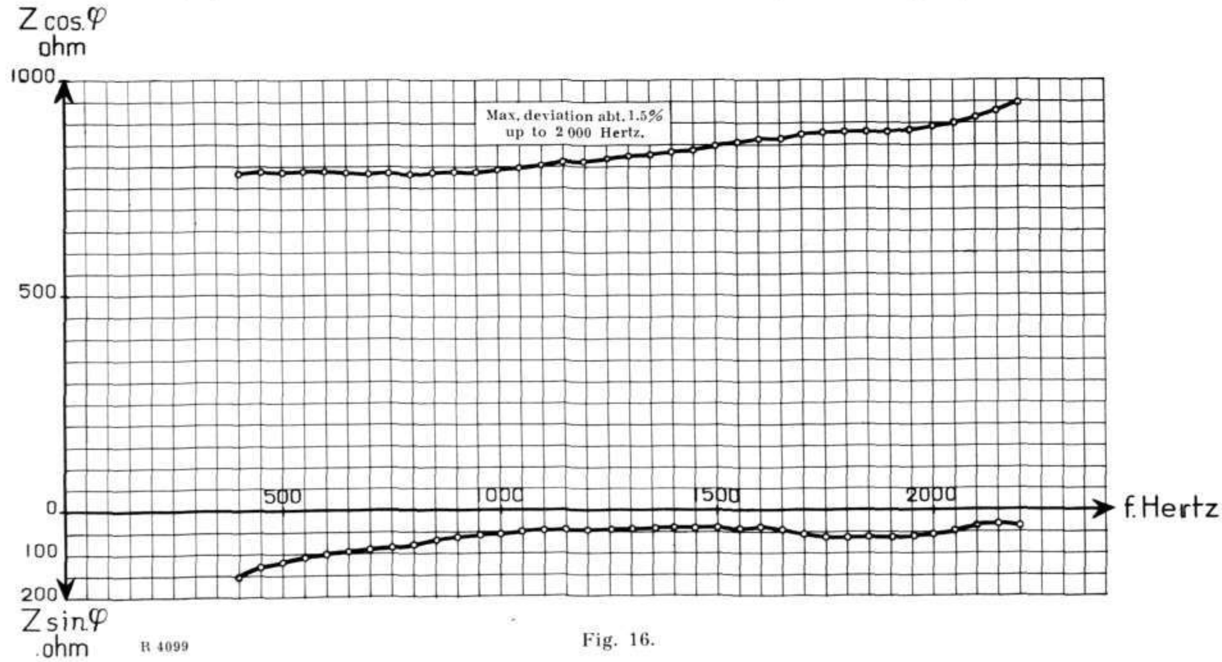


R 4098

Fig. 15.

CHARACTERISTICS

Cable Type I { *centre: 3×4×1.4* / *layers: 10×4×0.9+2×2×1.4*   *Norrköping C.—Nyköping C.: 59.94 km.* *Phantom 15, 16 and 19, 20; 0.9 mm.*

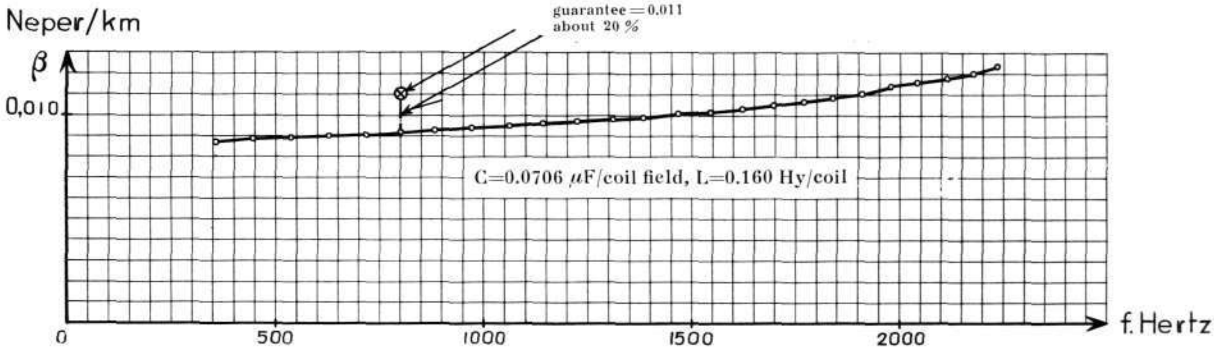


R 4099

Fig. 16.

ATTENUATION CURVE

Cable Type II { *centre: 3×4×1.4* / *layers: 16×2×0.9* } *Measured at Nässjö* *Nässjö—Falköping C.: 112.7 km.* *Pair 17+18; 1.4 mm.*

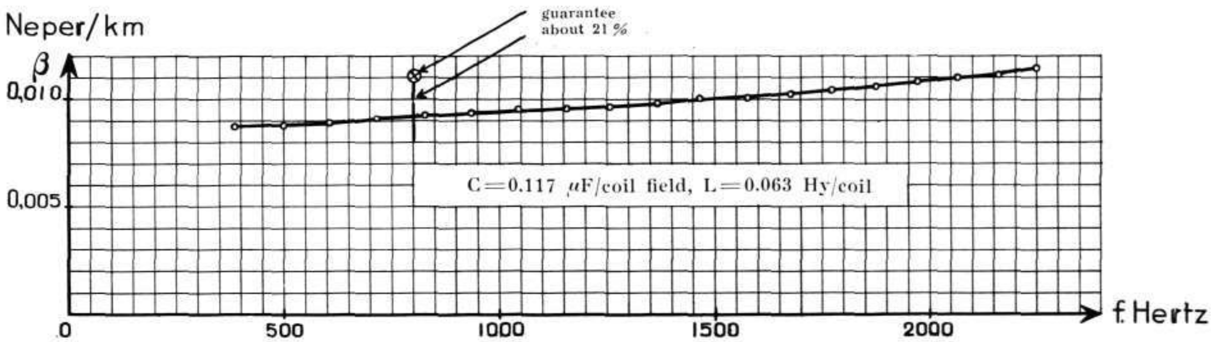


R 5000

Fig. 17.

ATTENUATION CURVE

Cable Type II { *centre: 3×4×1.4* / *layers: 16×2×0.9* } *Measured at Nässjö* *Nässjö—Falköping C.: 112.7 km.* *Phantoms 19, 20 and 21, 22; 1.4 mm.*

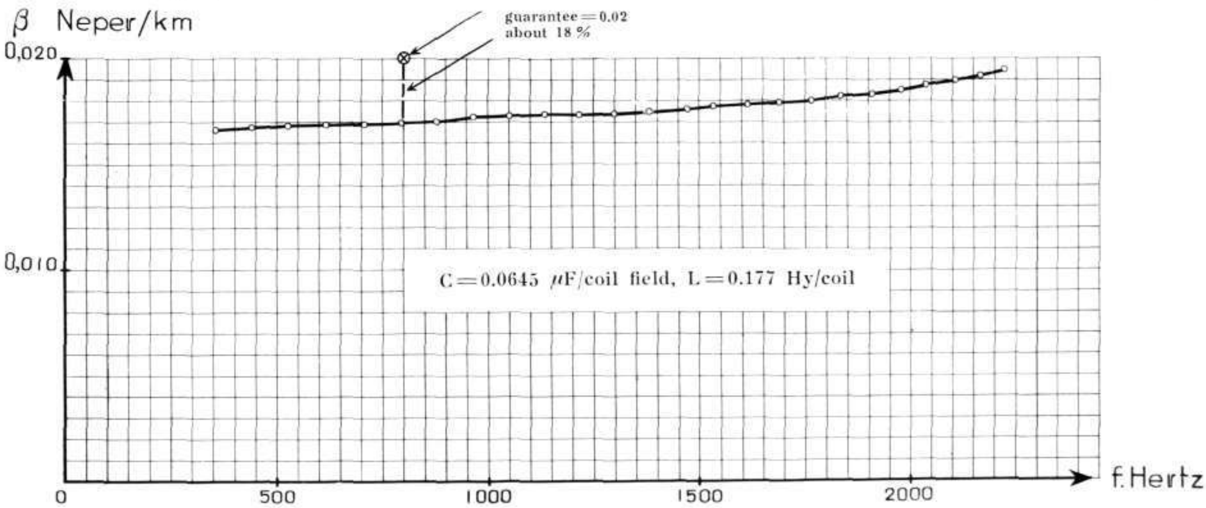


R 5001

Fig. 18.

ATTENUATION CURVE

Cable Type II { *centre: 3×4×1.4* / *layers: 16×2×0.9* } *Measured at Nässjö* *Nässjö—Falköping C.: 112.7 km.* *Pair 16+15; 0.9 mm.*



R 5003

Fig. 19.

The following were the maxima specified for the *mean capacity* of a repeater section: for pair or physical circuits of 1.4 mm. wire 0.033 μF/km, and for the corresponding phantom circuit 0.056 μF/km, and for pair or physical circuits of 0.9 mm. wire 0.030 and 0.051 μF/km respectively. That these demands are more than complied with is proved by the figures given in the Table.

It is worth noting that the capacity of the cable when laid was about 1 per cent. less than when measured wound on drums in the cable works.

When tested, the *capacity unbalance* to earth between the two wires of a circuit in a loading-section of spliced cable turned out to be considerably less than the maximum values prescribed, which were for loaded circuits 150 μμ F and for unloaded circuits 500 μμ F.

The *insulation resistance* was measured with D. C. of about 120 V. The lowest measured values came to 38 500 megohms/km., but in other sections they rose to 40 000, 70 000, and even 100 000 megohms/km.

The *characteristic impedance* (wave resistance) was measured with a current of 1 mA at different frequencies from 400 to 2 200 cycles per sec. The values stipulated for 800 cycles were exceeded, as we see from Table 3. Some typical impedance curves are shown in the diagrams, for physical circuits of 1.4 mm. wire in fig. 13, for their phantom circuits in fig. 14, for physical circuits of 0.9 mm. wire in fig. 15, and for their phantom circuits in fig. 16.

These show that the maximum deviation up to 2 000 cycles is not more than about 2.5 per cent.

The *attenuation* was measured at frequencies between 400 and 2 200 cycles per sec. also. The measured values at 800 cycles were considerably —about 20 per cent.—below the maxima stipulated.

Some curves giving the attenuation at different frequencies are reproduced: for a physical circuit of 1.4 mm. wire fig. 17, for phantom of 1.4 mm. fig. 18, and for a 0.9 mm. metallic circuit fig. 19.

The *cut-off frequency* was calculated from the values obtained from these curves, and was found to be well over the guaranteed values given in Table 3.

Cross-talk.

It was stipulated that the cross-talk attenuation between any two speech circuits in a completely installed repeater section should be at least 8.0 nepers.

Very comprehensive measurements were made for this purpose in the prescribed manner, firstly with A. C. corresponding to a speech current and containing mixed frequencies sent out by a buzzer, and secondly with current from a valve transmitter at a series of definite frequencies corresponding to each thousand of ω from 4 000 to 12 000 (640—1 900 cycles). These measurements have also comprised near-end cross-talk (Nebensprechen) and far-end cross-talk (Gegennebensprechen) between pair, physical, and phantom circuits in all occurring combinations. Some of the values obtained are given below in Table 4.

Table 4.

Cross-talk attenuation at mixed frequencies, in nepers.

Combinations	Cable type I		Cable type II	
	Minimum	Average	Minimum	Average
Pair to pair in the same quad	10.0	10.3	9.9	10.45
Pair in a quad to the phantom of the same quad	9.5	9.8	9.4	9.7
Phantom to another phantom	9.5	9.7	9.4	9.6
Pair in a quad to phantom in another quad	9.4	9.8	9.3	9.6
Pair in a quad to pair in another quad	9.6	9.9	9.3	9.6
Between pairs and quads in separate layers of the cable	10.1	10.4	9.9	10.55

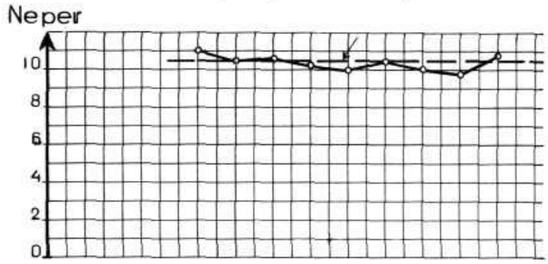
For cable type III a minimum of 9.7 was measured from pair to pair. In more than 50 per cent. of these measurements a value ≥ 11 nepers was obtained.

CROSS TALK

Cable Type I { *centre: 3×4×1.4*
layers: 10×4×0.9+2×2×1.4 }

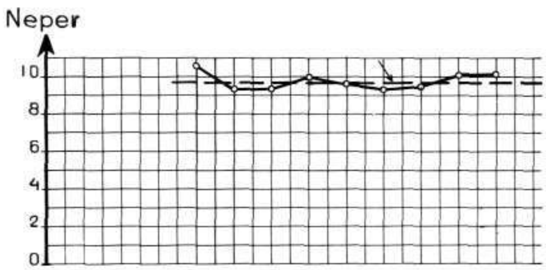
Norrköping C.—Nyköping C.: 59.94 km.

From physical to physical in the same quad ($b_1 = ^1/_2$).
Mixed frequency $b = 10.4$ Nepers.



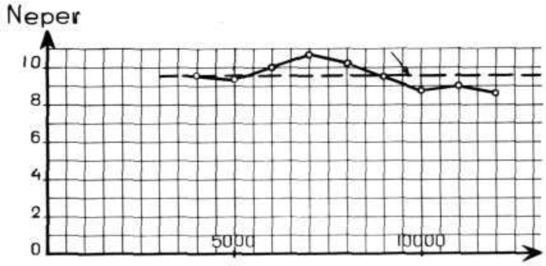
R 5002 a

From physical to 1 phantom in the same quad ($b_2 = 1/\text{v}$).
Mixed frequency $b = 9.7$ Nepers.



R 5002 b

From physical 2 to phantom in the same quad ($b_3 = 2/\text{v}$).
Mixed frequency $b = 9.6$ Nepers.



R 5002 c

Fig. 20.

CROSS TALK

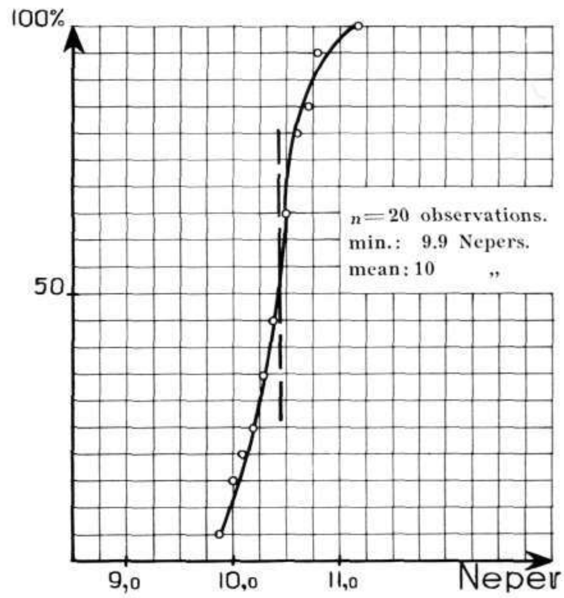
Cable Type II. { *in Quads and between adjacent pairs.*
Coil loading. }

Nässjö—Falköping C.: 112.7 km.

Measured at Nässjö and Falköping C.

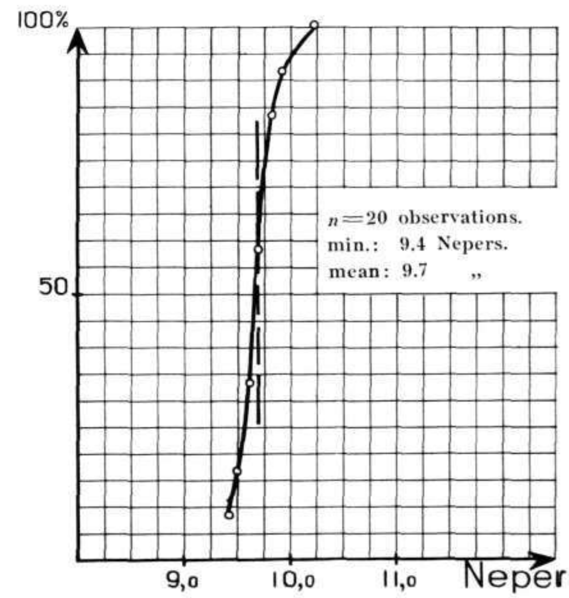
From physical to physical in the same quad.

b_1



From physical to phantom in the same quad.

b_{23}



R 5004

Fig. 21.

The Railway Telephone Cable on the Electrified Malmö Lines.

The dependence of cross-talk on frequency is illustrated in fig. 20, which gives the result of measurements with given frequencies in a cable of type I.

To show the results of the measurements with mixed frequencies, a couple of curves are given in fig. 21 which illustrate, for a cable of type II, how many times a certain attenuation has been observed, as a percentage of the total number of observations (Häufigkeitskurven).

Echo Attenuation.

As regards echo attenuation, which is also a measure of the variations in wave resistance and from which can be judged how easily the networks required for the use of telephone repeaters can be made, it was stipulated that in a repeater section this should be at least 2.7 nepers over the range of frequencies from 300 to 2 000 cycles.

These measurements were made over the range of frequencies from 320 to 2 240 cycles per sec. The values obtained were mostly over 4 nepers; only in certain 0.9 mm. physical circuits that had branches in the repeater section were values of less than 4.0 nepers obtained, but in any case these were considerably above the stipulated value.

To illustrate the results of the measurements in direct lines without branches Table 5 has been made out, referring to a cable of type I in the Norrköping—Nyköping line.

Table 5.
Echo attenuation in nepers.

Circuits	Minimum	Average
Physical circuits 0.9 mm....	4.15	4.3
„ „ 1.4 „	4.0	4.1
Phantom „ 0.9 „	4.8	5.0
„ „ 1.4 „	4.4	4.5

Note. In certain 0.9 mm. physical circuits with several branches the values measured were about 0.3 nepers below those given above.

Finally, it should be pointed out that before electrification the Malmö lines had a total of 5 490 miles of wire, on 3 788 miles of single-wire telegraph and double-wire telephone circuits. In comparison with this, the cables on these lines will contain 14 643 miles of double-wire circuits, or 29 286 miles of wire—considerably more than once round the equator. These cable lines contain, including phantoms, no less than 17 734 miles of metallic and phantom circuits, that is, the circuits available for distant communication have been increased by no less than 13 946 miles on 3 788 miles, or 368 per cent.

The cables are provided with station terminals in 124 stations (end-boxes were stipulated in about 131 stations). The number of branches, fixed at a maximum of one for every 1 750 yds. of cable, total about 540, corresponding to one branch per 1 914 yds. of cable. The branchings have been made thus: 444 of type B, 28 type Bm, 42 type Block, 12 type Signal, and 14 type Omf. There will be 423 loading-coil boxes.

Disturbances from the railway operating current have not yet been measured, as the contact wires and transformer stations are not ready. There is, however, no reason to suppose that higher induced voltages will occur in the Malmö lines than have previously been formed in the Gothenburg line (see reference in the foot-note on page 81).

Summary.

It is plain that in every respect the plant complies amply with the stipulations made, and that in every way it probably reaches in technical perfection as high a standard as has yet been attained. The good values for echo attenuation and cross-talk, and the excellent insulation resistance, deserve special mention. Compared with previous telegraph and telephone circuits on these routes, the cables have a considerably larger number of circuits available and will therefore be enough to meet all requirements for some considerable time to come.

The Elektromekano Copper Rolling Mill.

Svenska Elektromekaniska Industriaktiebolaget, Hälsingborg.

Number 1—3 of this journal contained a short notice to the effect that Telefonaktiebolaget L. M. Ericsson had acquired the shares of Svenska Elektromekaniska Industriaktiebolaget or "Elektromekano", Hälsingborg, which was thereby merged in the Ericsson Concern.

A factor which influenced the purchase of this business was the wish of the Concern to supply from within its own circle the rolled copper wire consumed in large quantities by the L. M. Ericsson Cable Works at Älvsjö and the Sievert Cable Works at Sundbyberg.

As early as 1918 Elektromekano installed a small wire-drawing plant to provide the copper (dynamo) wire required in their own manufacture of electrical machinery, and so become independent of outside suppliers, who at that time maintained very high prices and also had difficulty in making quick deliveries.

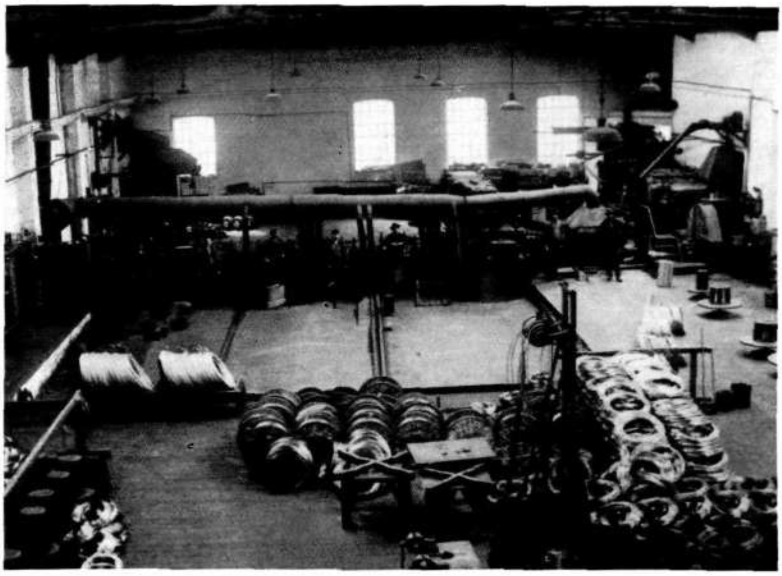
Four years later this wire-drawing plant was enlarged to allow bare copper wire to be sold also, and was further supplemented by a modern wire-rolling mill to enable them to import raw copper in the form of "wire bars", on which so far no important duty is charged in this country.

In 1925 Elektromekano, and particularly its copper works, was ravaged by an extensive fire. In rebuilding it, several new roll stands were added to the rolling mill to allow of the production of smaller gauge wire than before, viz. 6 mm., which is the "raw material" of most large cable works. From this time on, the firm succeeded in securing most of the orders for this commodity from the Danish market also.

Elektromekano is still the only copper rolling mill in Scandinavia able to supply such fine gauge rolled wire.

When at the beginning of this year the Ericsson Concern acquired Elektromekano, the latter firm took over the supply of all the rolled copper wire for the Concern's two cable works, the L. M. Ericsson Cable Works at Älvsjö and the Sievert Cable Works at Sundbyberg.

This work will fully occupy the Elektromekano rolling mill, in spite of its large capacity, and the output may in future be estimated at about 7 500 tons per annum. Of this, about 1 200 tons will be made into bare drawn copper wire, in the firm's wire-drawing plant, partly for sale and partly for its own requirements. This latter copper wire is spun over in their own spinning mill to make so-called dynamo wire, which is used for winding electrical machines, partly in the Elektromekano workshops and partly in a large number of repair shops for electrical machinery. It may be of interest to note how year



R 3092 General view of rolling mill.

by year the production of rolled wire has increased, as is shown in the table below.

"Output of rolled wire."

In	1922	480 050 kg.
„	1923	732 963 „
„	1924	1 240 454 „
„	1925	751 704 „
„	1926	1 607 642 „
„	1927	1 378 818 „
„	1928	2 628 008 „
„	1929	2 973 773 „
„	1930	4 193 420 „
„	1931	4 246 450 „
	Total:	20 233 282 kg.

As we see, the production has increased nearly tenfold between 1922 and 1931, and an output of about 7 500 tons will henceforth, as we said above, be reached.

In its simplest form the rolling process consists of introducing the material between two rolls revolving in opposite directions. This movement grips the bar or billet, and carries it forward, while subjecting it to a pressure which alters the shape or dimensions of its cross section. The rolling may thus be considered a modified forging process adapted to mass production. The first rolling mill was built in Nuremberg in the 16th century and was used for the production of high-quality iron. The first iron rolling mill in Sweden was designed by Kristoffer Polhem, and even today they are largely made on the same principles.

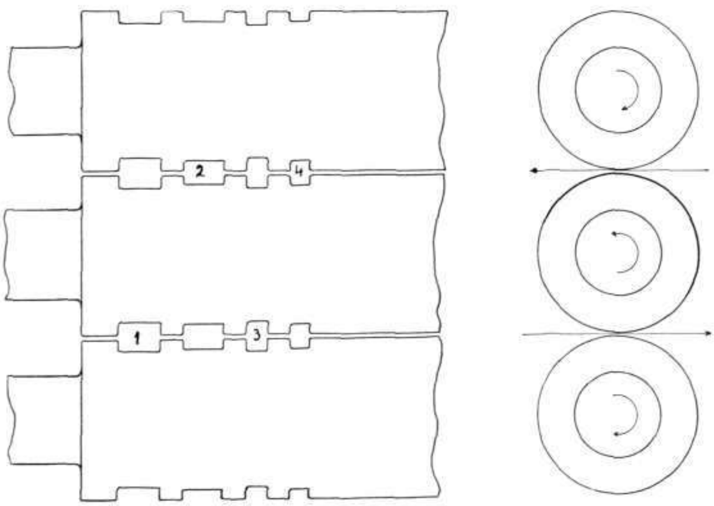
A rolling mill usually consists of a number of specially designed pedestal bearings or standards, in which the rolls are placed. Two standards form between them a roll stand, in which there are usually two or three rolls placed one above the other. One speaks of two-high or three-high stands, according to the number of rolls in each.

In this particular rolling mill, the first roll stand, called the roughing mill, is three-high, with grooves cut in the rolls, as shown in the sketch below.

The other stands (five in number) are called the finishing train, and the first of these is three-high and the other four are two-high.

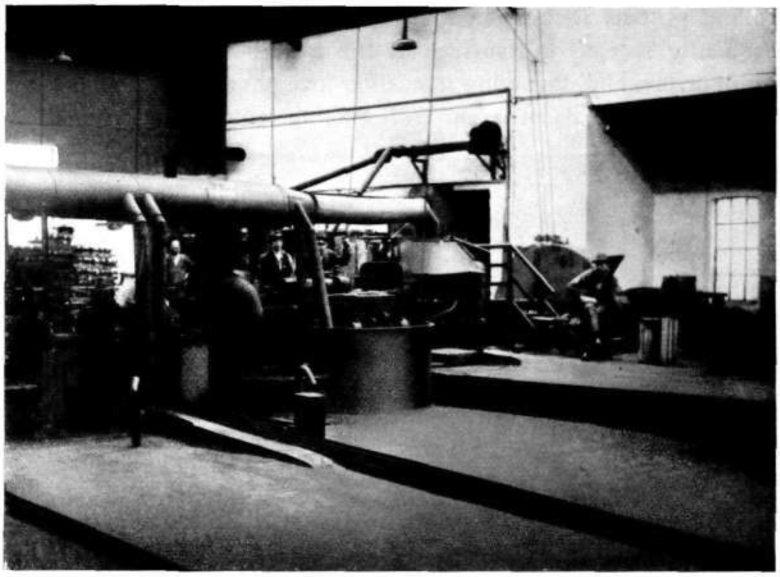
The rolling mill is driven by an electric motor of 35 H. P. and 365 r. p. m. By an elastic coupling this is direct-coupled to a through shaft, at the other end of which there is a kind of gear box, or bushing for the gear pinion, of the finishing train. On the same shaft a large flywheel and a spur gear are also fixed. The latter transmits the driving power to the middle roller of the roughing mill, from which in its turn it is transmitted to a gear pinion bushing for the other roughing mill rolls. It also reduces the speed of the roughing mill to about 130 r. p. m. The speed of the finishing train is the same as that of the motor, or about 365 r. p. m.

The raw material for the rolled wire is supplied in long narrow copper billets called wire bars, weighing from 132 to 200 lbs, which are heated in a furnace to about 850°C. The wire bar is then passed through the first groove of the roughing mill, between the lower and the middle roll. This groove is smaller than the thickness of the bar, and the bar is flattened out by the rotating rolls, its cross section being reduced, and its length instead increased. Wen the billet has passed through to the back of the roll stand, it is lifted up and inserted in the second groove, smaller than the first, between the upper and the middle roll. Its direction of movement is now reversed and, while it is still further compressed and lengthened, the billet is therefore forced back to the front of the stand.



R 4043 Diagram of a three-high stand.

This process is repeated again and



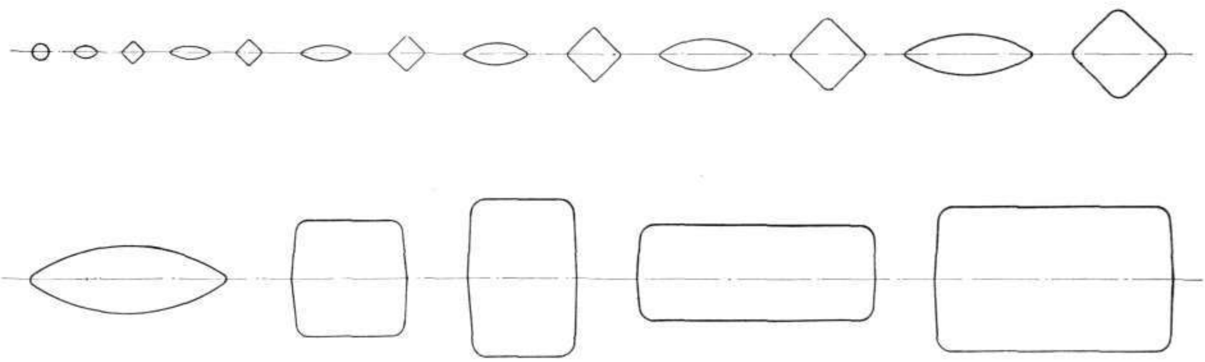
R 3087 The first stand of the finishing train, and the roughing mill.

again in smaller and smaller grooves, and finally the bar, now some 10 meters long, is carried *on to the finishing train* and there passed through the grooves of the first roll stand. The remaining stands of the finishing train have, as mentioned above, only two rolls each so that the wire can only be passed in one direction through each stand; alternate stands are therefore revolving in opposite directions. The first "pass" in the second roll stand of the finishing train is thus followed by a "pass" in the third stand, the next pass is again in the second, and so on. The sketch below shows how the cross section is altered groove by groove. At the same time the bar becomes longer and longer, until the finished wire has a length of up to about 200 m.

As we see, the grooves are not of uniform shape, but are sometimes square, sometimes rectangular, and sometimes oval. During these forcible changes of shape, the material is as well worked as if it were forged. By using alternately square and oval grooves, the cross section in particular is reduced very rapidly, which is necessary both in order to loose as little heat as possible in the bar during the rolling process and to attain the largest possible output.

When the bar has passed the last round groove in the finishing train, the wire is ready and is wound on a reel which automatically coils the wire. It is then cooled quickly in cold water. When tied, the coil is ready for sale. The wire is rolled to a number of different gauges, ranging from 6 to 19 mm. round.

Both the rolls and their journals get very hot during the rolling process, partly by contact with the hot billets and partly by the heat generated by the friction. Both rolls and bearings are therefore cooled by cold water constantly running over them. To prevent the scale formed in the



R 4044 Series of grooves in the rolling mill.

rolling process sticking in the grooves and subsequently scoring the surface of the next billet more or less and damaging it, each groove passed by the billet is also flushed with cooling water.

R 3088 Unloading copper billets at the mill from a railway truck.

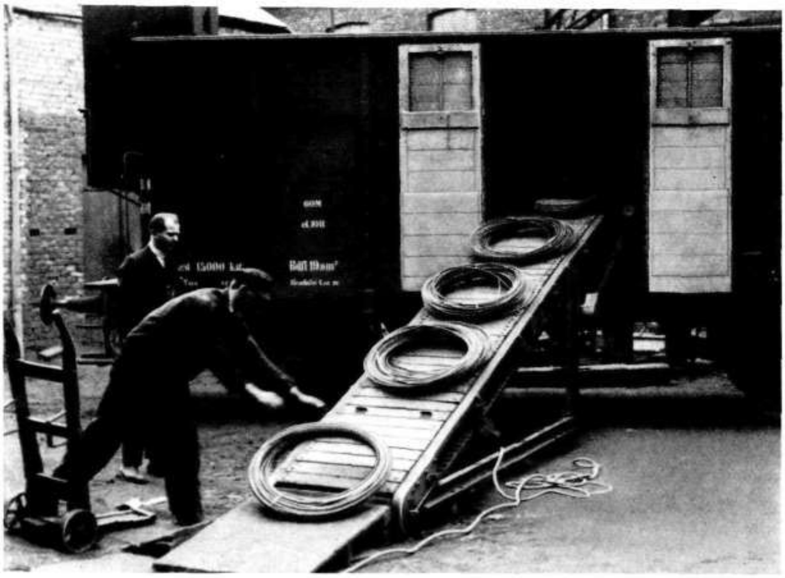
One of the largest orders for bare copper wire ever received by Elektromekano was to supply the State Railway with wire for the electrification of the main line from Stockholm to Malmö. The order comprised about 615 tons of contact wire and copper cables for this electrical installation, the delivery being spread over the next few years as work proceeds.

The great increase in the quantity of copper handled in the rolling mill has made it a necessary economy to reduce manual labour by various mechanical contrivances. The copper is thus now unloaded by electric cranes direct from the ships into railway trucks, which are then shunted on to the factory line. Electrical overhead travelling cranes take the billets thence straight to the furnace in the rolling mill.

The water consumption of the rolling mill is as a matter of fact so large that in order to reduce costs Elektromekano has built its own water conduit from a river near by to supply all the water required.

The effect of the air and the cooling water on the hot billets during the rolling process is to make the wire black, and this layer of oxide has to be removed, before the drawing process, by pickling in dilute sulphuric acid.

In cold-drawing, the end of the wire is pointed and put through a hole in a drawplate of case-hardened iron or steel. The hole is slightly smaller than the wire, which is drawn through the hole by fixing the end to a rotating winding block. This naturally reduces the diameter while increasing the length. The process is repeated several times until the required gauge is obtained. For lack of space we will not enter into any further technical details of wire-drawing.



R 3099 Loading wire coils by the "moving gangway".

Mechanical devices have also been introduced to deal with the finished wire coils. A "moving gangway", for instance, loads the coils into the railway trucks which carry them to their various destinations.

The Elektromekano Copper Rolling Mill.