DEVELOPMENT PROBLEMS OF TELEPHONE EXCHANGES

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I. Introduction

The characteristic feature of the telephone service of a large city area is that traffic is handled by a number of main exchanges capable of serving *ten to thirty thousand* subscribers, and by satellites of an overall capacity of 1000 to 4000 subscribers. The main exchanges are interconnected by a system of trunks. In a city area well provided with telephones in the centre, telephone density may amount to as much as 1000 to 2000 subscribers to the sq. kilometre. On the other hand, this density tends to decrease with the increase of the distance from the focal point of the city, so that towards the suburbs telephones become gradually rarer. Consequently, the area served by the exchange, and with this the average length of a subscriber's loop may be held on a satisfactorily low value only if the capacity of the exchange has been chosen sufficiently small. Such exchanges of moderate capacity are called satellites. Satellites are co-ordinated to a main exchange, and are connected by trunks *only* with their parent main exchange. Another characteristic of these satellites is that the rate of calls put through to subscribers within their own area is relatively low, and therefore in the majority of cases the calls initiated in the area of the satellite, or destined to it, are built up over the main exchange.

Unless the number of transit exchanges is raised, the number of trunk groups will tend to increase with the growth of the number of main exchanges. On the other hand, with the growth of the number of groups of trunks the traffic for each group tends to drop, so that with it *the rate of efficiency of the trunks also drops*. If, however, the trunks are connected in tandem, dependent on whether or not the system operated is of the register type, difficulties may crop up as regards pulsing, and the devising of an appropriate numbering scheme. In modern Rotary type equipment the building up of a transit connection may require as much as *one to three seconds*, a span of time which may extend the period needed for putting through the call unreasonably.

With the technical means now available in the field of telephony the chances of *improving the service conditions are practically nil*. Consequently, the costs of running a telephone system on this basis are comparatively high.

When now the costs of a network operated with Rotary type equipment and of an order of magnitude of about *two hundred thousand subscribers* (this is about the capacity of the Budapest telephone area) are made the subject of study then it will be found that the costs to be redeemed are composed of the following items:

Subscriber's telephones	5 per cent
Exchange equipment	25 per cent
Network	55 per cent
Maintenance, general running expenses	15 per cent

Obviously, the costs of the network come to be a substantial item, even if a period of amortization of 30 to 40 years has been reckoned with. Therefore, if it has been made the policy of the operating company to reduce the charges of the service, it stands to reason that this object could hardly be achieved by merely introducing new designs of exchange equipment. *E. g.* a drop of 25 *per cent* in the costs of investment of exchange equipment may be equal to a tariff reduction of six per cent only. *Consequently, the primary object of new designs of exchange equipment is to alleviate the burden represented by the network and maintenance.*

The appearance of various types of crossbar switches in the field, and the growing exploitation of electronics in telephony open up new ways in development work, which may ultimately lead to the desired reduction of tariffs. In this paper the author would like to point out a few aspects which will necessarily have to be followed as guidance in development work going on along the lines set forth above.

II. Present network

The rate of efficiency of a subscriber's line is very low. As estimated a subscriber in the city area will during the busy hours engage his line for *six minutes* on the average (three minutes for calls initiated and three for those received). This means that referred to the busy hour the efficiency of his line is ten per cent. On the other hand, expressed as the function of the magnitude of the groups of trunks the efficiency of the inter-exchange trunks may amount to as much as 60 to 70 per cent. The problem has been set a long time ago, *viz.*: telephone exchanges *have to be decentralized* to as great an extent as possible, because with decentralized exchanges not only may the subscriber's loops *be shortened*, but by exploiting the limits allowed for by the grade of service for the subscriber's loops, the *cross section of the wires may also be reduced.*

With decentralization the costs of the subscriber lines drop rapidly, however, at the same time the number of trunks tends to increase. Finally, a state of equilibrium will be reached in the network.

A quantitative analysis of the problem is feasible only in an ideal network. In order to have a clear-cut picture of the quantity of wire material required for a telephone network, a theoretical network will be assumed here of a square form and of a uniform density of subscribers. For multi-core cables *the price of wire material is proportional to the copper weight* of the wire material. Data of wires used in cables of this type have been compiled in Table 1.

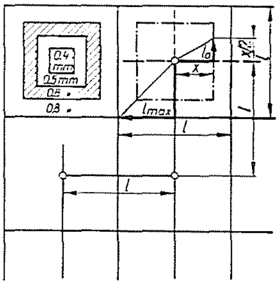

Fig. 1. Geometry of an ideal network

Table 1

Diameter mm	Resistance ohms per kilometre	Attenuation nepers	Weight, kg	Serviceable length, km
0.4	280	0.3	2.25	2.0
0.5	180	0.17	3.5	3.0
0.6	125	0.12	5.0	4.5
0.8	70	0.075	9.0	8.0

For reasons of mechanical strength wires below 0.4 millimetre in diameter are hardly advisable to use. (Actually the diameter of the *0.4 millimetre* wire is below this value.) On the other hand, wires thicker than *0.8 millimetre* in diameter are not much needed, as will be seen in the following.

Let in an ideal network

Q denote the area of the network in sq. kilometres,

N the number of exchanges in service, and

S the number of subscribers.

From the geometrical relation shown in Fig. 1 one of the sides of the exchange area may be expressed as

$$l = \sqrt{\frac{Q}{N}} .$$

The average length of a subscriber's loop — l_a — within the given exchange area may be obtained from the following calculation:

$$l^2 - 4x^2 = 4x^2$$

$$x = l/\sqrt{8}$$

$$l_a = \frac{3}{2} x = \frac{3}{2\sqrt{8}} l = 0.53\, l .$$

(The cables are assumed to be laid along co-ordinates, and not diagonally.)

As may be inferred from the above the maximum length of a subscriber's line equals l itself.

For exchanges of a number N let n be the number of groups of trunks between the exchanges:

$$n = \binom{N}{2} \cong \frac{N^2}{2} .$$

If transit points are formed then the number of groups of trunks may be reduced to $n_{\min}$, *i. e.*

$$n_{\min} = 2\sqrt{N}(\sqrt{N} - 1) = 2(N - \sqrt{N}).$$

If Y_S denotes the two-way traffic of a subscriber line then the sum total of traffic handled by the exchange will be of a value Y:

$$Y = \frac{S}{N} Y_S .$$

If Y_T denotes the transit traffic originated by an exchange, then

$$Y_T = \frac{S}{N} Y_S \frac{N - 1}{N} .$$

The average length l_T of a transit connection may with fair approximation be expressed by

$$l_T = \sqrt{N} - 1 .$$

The scope of application of the cores of various diameters is determined by the permissible maximum length of the subscriber lines. The respective values are given in Table 1.

From these relations the copper wire weights may then be calculated for the ideal network, which on the whole is identical with the Budapest telephone area. Accordingly,

$$Q = 400 \text{ sq. kilometres}$$
$$S = 200000$$
$$Y_S = 0.1 \text{ erlang}$$

The values obtained have been compiled in Table 2, and their representative curves plotted in Fig. 2.

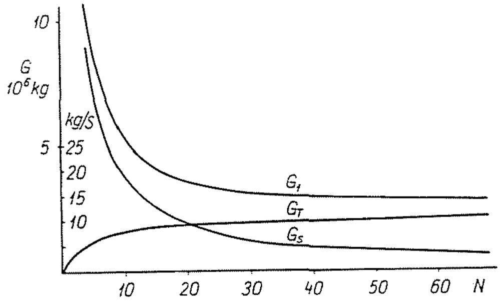

Fig. 2. The copper weight of the network plotted as the function of the number of exchanges operated in the network

Table 2

N	G_S	G_T	G_1
4	$9 \cdot 10^6$ kg	$1.2 \cdot 10^6$ kg	$10.2 \cdot 10^6$ kg
9	4.3 ,,	1.5 ,,	5.8 ,,
16	2.3 ,,	1.7 ,,	4.0 ,,
36	1.0 ,,	2.0 ,,	3.0 ,,
64	0.7 ,,	2.1 ,,	2.8 ,,
100	0.5 ,,	2.2 ,,	2.7 ,,

where G_S denotes the copper weight of the subscriber's lines,

G_T the copper weight of the transit trunks,

G_1 the total copper weight.

From Fig. 2 it may be seen that with the increase of the number of exchanges operated in a given network the weight of the copper processed into wire material decreases rapidly. In the given example with as many as *thirty* exchanges the minimum of copper weight has nearly been approached. Here the quantity of copper corresponds to exchanges of a capacity of *seven to eight thousand.* Actually there are about *eight to ten* exchanges of greater capacity in service in the central area of Budapest, and about twice as many satellites of minor capacity in the outskirts of the city.

However, in reality conditions are by far not so favourable as might be inferred from the calculations. Firstly, owing to the long distances, a large percentage of the trunks cannot be made of *0.8*-millimetre wires, and, secondly, a large number of transiting points has to be formed lest groups of trunks incorporating a low number of circuits should result, which in turn might deteriorate the overall efficiency of the trunks. In the *7A-2 Rotary* system operated in Budapest the selectors have *30* arc points in each level and, consequently, by accepting a grade of service of $P = 0.005$ and using graded switching an efficiency of *74 per cent* can be ensured. The figures in Table 2 have been calculated on this assumption. On the other hand, if no transiting is involved, then *e. g.* for *thirty* exchanges the traffic handled by each group of trunks may be expressed by the following formula:

$$Y = \frac{S \cdot Y_S}{N} \frac{1}{N-1} = \frac{2 \cdot (10^5 \cdot 0 \cdot 1)}{30 \cdot 29} = 23 \text{ erlangs.}$$

At a grade of service of $P = 0.005$ 35 circuits are needed for handling this traffic, and, consequently, the efficiency of a group of trunks will drop to *66 per cent.* Furthermore, if the trunks transmit one-way traffic only, the average efficiency will drop to as low a rate as *57 per cent.* This means that transiting points have to be formed in order that the efficiency of a group of trunks might remain about *74 per cent.*

In case of transiting the costs of the switching equipment, further the switching times extending the time required for building up the call enter into the picture. Since for reasons of maintenance preference may have to be given to large exchange equipment, exchanges of a capacity of *ten to thirty thousand* lines are fairly well substantiated in a telephone area of 200 000 subscribers. *The average copper weight of*

$$\frac{3.7 \cdot 10^6}{2 \cdot 10^5} = 18.5 \text{ kilograms}$$

for each subscriber calculated for twenty exchanges *may*, however, *serve as a basis for comparison only*, since each subscriber line is equipped with an individual connecting wire starting from the last cable terminal. This wire is a by no means negligible item.

III. Principles of network development

In the following an attempt is going to be made to review the means and ways of how present network conditions could be improved, now that crossbar switching techniques and electronics have made their appearance in the field of telephony.

From all what has been set forth in the foregoing it stands to reason that it is highly desirable to keep the number of transit exchanges as low as possible. If this is observed the result will be savings in switching equipment and switching time. At the same time the length of the subscriber lines, which in general operate with bad efficiency, can be cut down to a minimum by concentrating these lines *in the immediate vicinity of the subscribers in so-called line concentrators.*

The number of subscribers that may be clamped together in such a line concentrator is ultimately determined by the efficiency of the groups of lines. The smaller the line concentrator the closer it may be advanced to the subscribers, *i. e.* the shorter the subscriber lines can be. On the other hand, the larger the line concentrator the higher the efficiency of the trunks. The rise of the efficiency of the trunks is expressed by the well known formula of Erlang worked out for ideal groups as the function of the number of trunks constituting a single group. In Fig. 3 the curve r shows the number of trunks required for concentrators of varying capacities for a two-way subscriber traffic of

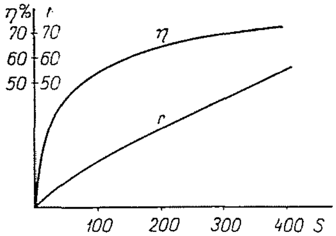

Fig. 3. Efficiency of groups of trunks

$$Y_S = 0.1 \text{ erlang}$$

and a grade of service of

$$P = 0.005.$$

The curve marked η indicates the growth of efficiency. It may be seen from these curves that for a line concentrator of about 150 subscribers a trunk efficiency of 60 per cent may be achieved with a group incorporating *25* trunks. Moreover, the efficiency of the *43* trunks of a line concentrator of *300* subscribers is *70 per cent.* Trunks under all circumstances form ideal groups for two-way traffic, this being ensured by the *modern* marker principles.

In the network of a large city area line concentrators of various capacities may have to be operated. Thus it is highly probable that there will be line concentrators *equipped for 100, 200, 300, or 400 subscribers.*

In order to have some sort of wire weight data on hand, convenient as a basis for comparison, let it be assumed that line concentrators of an average capacity of *250* subscribers are installed to build up the earlier theoretical network of *200 000* subscribers.

A network of this type would therefore be built up of two types of exchanges, viz.

(a) line concentrators (or otherwise terminal exchanges), and

(b) transit (or main) exchanges.

Now with line concentrators of an average capacity of *250* subscribers there will be exactly *800* such units in the theoretical network. In the following the copper weight of the network will be calculated as the function of the growth in the number of transit exchanges, on the same basis as has been done earlier in this paper. However, here it should be borne in mind that the concentrators are also equipped with some sort of a distributing network (the area served by a single concentrator is

$$\frac{400}{800} = 0.5 \text{ sq. kilometre}$$

i. e. the average length of a subscriber line is about *300 to 400 metres)*. The values calculated are compiled in Table 3, while the corresponding curves are plotted in the diagram in Fig. 4.

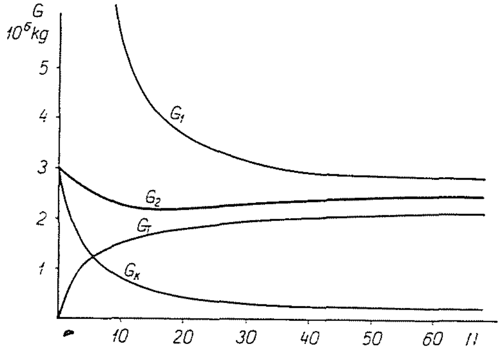

Fig. 4. Copper weight of a network built up of line concentrators

Table 3

N	G_K	G_T	G_2
4	$1.4 \cdot 10^6$ kg	$1.2 \cdot 10^6$ kg	$2.5 \cdot 10^6$ kg
9	0.8 ,,	1.5 ,,	2.3 ,,
16	0.5 ,,	1.7 ,,	2.2 ,,
36	0.3 ,,	2.0 ,,	2.3 ,,
64	0.25 ,,	2.1 ,,	2.35 ,,

Graph G_T in Fig. 4 shows the copper weight of the trunks interconnecting the transit exchanges. This graph is identical with its counterpart in Fig. 3.

Graph G_K represents the copper weight of the trunks between transit exchanges and line concentrators, further that of the local wiring of the line concentrators. The sum total of the two values has been plotted as graph G_2 in the diagram.

As may be seen from Fig. 4 a minimum of copper weight will be arrived at if the number of transit exchanges operated in the network is anything between ten and twenty. Since for technical reasons it is otherwise also desirable to keep the number of transit exchanges as low as possible (there being, however, a lower limit determined by *reasons of security)*, it appears to be reasonable to fix the number of transit exchanges at any number from eight to twelve. The graphs also reflect the decrease in the copper weight, which

for 10 transit exchanges (3.3 : 5.5) is 60 per cent,
for 16 transit exchanges (1.8 : 4) is 45 per cent,
for 20 transit exchanges (1.4 : 3.6) is 40 per cent.

Obviously, it is worth while to investigate what conditions have to be satisfied at laying out a network formed of *eight* transit exchanges and *800* line concentrators.

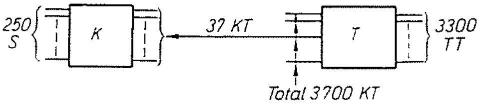

Fig. 5. Block schematic of an ideal network

For the following investigation let it again be assumed that *100* line concentrators equipped with *37* trunks each have been assigned to a *single* transit exchange, *i. e. the function of the transit exchange is to handle traffic between 3700 trunks* incoming from hundred line concentrators, and *about 3300 transit trunks.* (The figure *3300* has been accepted for the sake of better efficiency.) A theoretical system of this type is shown in *Fig. 5.* (As a matter of course, traffic between the concentrators served by one and the same transit exchange, or that between the subscribers of one and the same line concentrator will engage no transit trunks.)

In the transit exchange there is neither call concentration, nor final selection, its functions being confined merely to group or path selection. The specific traffic rate of the exchange is rather high, and for this reason it is crossbar equipment that for its design might be able to cope with the exigencies of traffic.

IV. Line concentrators

As has been stated in the introduction, the principal object of this paper is to present a study of the technical conditions under which a line concentrator may be realized, and also of the considerations mainly of maintenance and service that have to be borne in mind.

A number of types of line concentrators have been described in the literature [1, 2]. The forerunners of line concentrators are the various types of apartment house satellites. In general, the capacity of these apartment house telephones was rather limited, and, consequently, it was out of the question *to form a complete main exchange line finder and final selector stage* in the apartment house equipment. In fact, the switching assembly incorporated in the apartment house equipment and its associated portion in the main exchange *meant additional equipment*, to those costs of investment had to be set off by savings achieved in the wire material. Moreover, with the generally small line groups the efficiency of the system was a very low one [3].

The tentative circuit diagram of a line concentrator of this type is shown in Fig. 6. Here the block schematic of the circuit of a concentrator associated with an existing Rotary *7A2* exchange is shown. However, a line concentrator of this type is suitable for being connected to any present or future type of telephone exchanges.

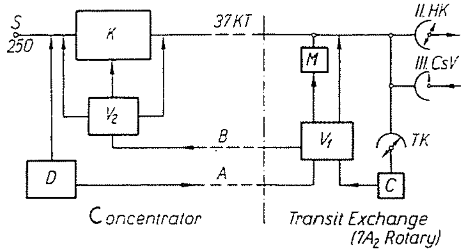

Fig. 6. Block schematic of a line concentrator

A concentrator of this type operates in the following manner:

In addition to the *37* trunks the line concentrator is connected by further two trunks, A and B in the schematic, to the transit exchange. (The copper weight of these two trunks has been included in the calculations.) In the diagram D is a detector built up of electronic devices, *e. g.* semiconductors, which then periodically scans the lines of the *250* subscribers in order to discover a line in the state of calling. If such a line has been found then D over trunk A reports this to control circuit V_1 of the transit exchange, and if this circuit happens to be free, then D in some sort of a coded form transmits the identity of the calling subscriber to V_1. Circuit V_1 will then in like way search for any free one of the trunks KT over a switch composed of electronic elements, and then, over trunk B, transmit the identity of the calling subscriber and of the free trunk KT to the control unit V_2 of the concentrator (in like way in a coded form). Thereafter V_2 on hand of the two identification numbers and over contact field K builds up the connection between the calling subscriber and the marked trunk.

Control element V_1 also imparts the identity of the calling subscriber to a storage unit M associated with each trunk KT. Storage unit M may be called on for co-operation for several purposes (*e. g.* metering, identification, etc.). With this step the connection has been built up, and control devices V_1 — V_2 are then released. Trunk *KT* engaged for this operation then connects in the known way over a 2nd line finder to a connecting circuit and then to the register.

For calls routed to the line concentrator the penultimate group selector engages a free trunk *KT*. A free code translating circuit *C* connects to trunk *KT*, and collects the last two digits of the call number from the register of the calling main exchange. (In the Rotary *7A2* system the capacity of the line finder is *200 to 400* subscribers, and in conformity with the vigesimal system, two digits are used for selection.) After the digits have been picked up *C* reports the call to V_1 in the same way as *D* has done the other way round. If V_1 is idle, then *C* transmits the number of the called subscriber in a coded form, and also the identification number of trunk *KT*. This latter number is determined by the position of switch *KT*. Thereafter V_1 transmits the two digits over trunk *B* to V_2 in the line concentrator, which then builds up over contact field *K* the connection between the called subscriber and the engaged trunk *KT*, in like way as has been done for subscriber's calls.

There are as many of the circuits *C* available as are required for handling the traffic. The collection of the last two digits from the register requires *two seconds* on an average, *i. e.* the full operating period of any of the circuits *C*, including the period of rotation of *TK*, is about *three seconds*, for *250* subscribers the traffic being

$$250 \frac{3}{3600} = 0.21 \text{ erlangs.}$$

At the end of the conversation it is trunk *KT* that reports to V_1 for release; this latter controlling device receives the identification number of *KT*, and transmits it to $V_2 \cdot V_2$ in response breaks off the connection. (If, for reasons of circuitry, it is deemed simpler, then V_1 may also transmit the number of the connected subscriber.)

As may be seen the control system will have to step into action twice for each call, once at the call being built up, and, again, at release. In numerical terms, for a line concentrator of a capacity of *400* subscribers and *1.5* calls for each subscriber during the busy hours this means *2400* operations of the control system during the busy hour. On the assumption of a load of *50 per cent* of the control units there remain about *0.75* seconds for a single operation, which on the whole is amply sufficient. The portion of information transmission of a single operation amounts to 15 or 16 bits, *viz.*

for the identification of the subscriber .... 8 or 9 bits

for trunk identification	6 bits
for release signalling	1 bit.

The next part of the operation is the cross-connection of contact field K. If the contact field is formed of crossbar switches then the period of cross-connection will be well within half a second. (Release will of course be completed within a still shorter time.) The transmission of *16* bits over a conventional subscriber's trunk within less than *0.25* seconds involves no serious problem.

The trunks KT will not necessarily have to form a single group. A subdivision into *three* subgroups is wholly feasible. In this case a subgroup each will be assigned to the outgoing, incoming, and two-way traffic. (In the present instance the *37* trunks may be subdivided on the following pattern: $10 + 10 + 17 = 37$.) In this scheme only the outgoing and the two-way trunks have to be connected to the arcs of the penultimate group selector, while by discarding the 2nd line finders, the incoming trunks may be advanced directly to the connecting circuits. Consequently, only the two-way trunks have to be connected to line finders.

The hardest problem facing the operating organization of the telephone system is the *maintenance* of the line concentrators. On an annual basis and in general each subscriber connected to a crossbar exchange requires maintenance of *0.5* hours. Referred to *250* subscribers this means *125* hours in the year, however, in reality the *0.5* hours have to be understood for the entire network, which also incorporates transit exchanges. On this basis for the 200 000-subscriber network the resulting figure for maintenance is *100 000 hours, i. e.* in terms of manpower a maintenance staff of about fifty persons. On the assumption of this order of magnitude, of the total manpower available *twenty* would have to be allocated to the maintenance of the transit exchanges, and the remaining *thirty* to that of the line concentrators. On this understanding *the maintenance time of a single line concentrator may amount to about a week on a semi-annual basis.* The conditions are obviously very rigorous.

In order to reduce maintenance work to the reasonable minimum *line concentrators have to be relieved of all functions not necessarily associated with them, and these functions will then have to be transferred to the exchange.* Consequently, the transit exchange will have to provide

the microphone current,
the ringing current, and
all signalling tones,

further

the message registers may preferably be accommodated in the transit exchange, where if necessary, provision may be made for multiple metering, charging the rates on punched tapes, or for identification.

All power sources known at present want maintenance. The line concentrator has to be designed in a way that the power required for its operation should preferably be supplied by the transit exchange over trunks A and B. If the microphone current were supplied from a source accommodated in the line concentrator itself, then for the *37* connections a current of at least *2 amps.* would be needed. In addition, this current would necessitate the use of a feeder bridge, which in turn would entail the usual problems of through-dialling and through-ringing. However, a solution of the problem is conceivable in so far as both digit sending and ringing could be transposed into the voice frequency band [4, 5, 7], yet in this case the subscriber's telephone set would stand higher in costs, and since the *answer* and *release* signal would have to be transmitted over the feeding bridge anyhow, further complications would be introduced into maintenance work. *It stands to reason therefore that that type of line concentrator would be the simplest in design which connects without attenuation, e. g. in a metallic way, and has no other functions to perform.*

Subscriber's telephones want current supply in all circumstances. Actually there is no other method imaginable for the actuation of carbon microphones, and even if in the future sound converters operating on other principles should come in vogue, in all certainty transistors or similar devices would have to be resorted to. For the time being, however, no substitute can be suggested for closing and opening the loop for advancing d. c. signals.

Another point in favour of metallic through-connection is the circumstance that with this method direct measurements can be carried out over the subscriber's lines and on apparatus from the wire chief's desk accommodated in the transit exchange.

At the present stage of technics crossbar type switches appear to be the most suitable for metallic through-connection. For the time being cross-points built up of electronic elements have not proved wholly satisfactory. However, attempts have been made at reconciling the advantages afforded by metallic contacts and electronic elements [6], yet the solutions so far suggested are rather expensive. For a space dividing contact field employed in the given example of a *250*-line concentrator about *4000* cross-points would have to be provided, *i. e.* in terms of crossbar switches *twenty 10 × 20 units*, or a proportional number of switching devices of other type.

No matter what type of contact field should finally be adopted, this field will have to be designed in a way that *no current should be needed for locking it in an activated state.* In this case the power consumption of the line concentrator, in addition to that of the control devices, would amount to as much only as is absolutely necessary for the activation of the cross-points taking part in a single connection. This power requirement of a few watts only could then be supplied from the transit exchange over the controlling trunks.

In the telephone system of the future *the time division multiplex system* will in all likehood be prevalent. If, however, the copper weight values calculated earlier in this paper are submitted to a scrutiny once again it will become evident that the time division multiplex system will make headway only at a moderate pace. Of the minimum copper weight of $2 \cdot 2 \cdot 10^6$ kilograms calculated (for sixteen exchanges)

$1 \cdot 7 \cdot 10^6$ kilograms, i. e. approximately 80 per cent

will have to be allocated to the trunks between transit exchanges, while the balance of *twenty per cent* only would have to be reserved for the cables between the line concentrators and the transit exchanges. One third of this twenty per cent would be absorbed by the subscriber lines, which, however, for the purpose of the time division multiplex system cannot enter into the picture. However, the time division multiplex system could be employed between line concentrator and transit exchange, yet with this system the circuitry would become rather complex, and there might be difficulties experienced also in satisfying the service requirements. In addition, savings in copper weight would be negligible, as the estimated savings are not likely to exceed *ten per cent.* A still further difficulty is presented by the fact that conventional subscriber's cables could be used only with intermediate repeaters [2]. Obviously, the results obtained on these trunks with the introduction of the time division multiplex system would be only illusory.

On the other hand, as far as the trunks between the transit exchanges are concerned, the situation is an altogether different one. In addition to the circumstance that about eighty per cent of the copper weight of the network is invested in inter-exchange trunks, there are no limitations encountered here as far as the subscribers and the line concentrators are concerned. It would therefore be worth while to introduce the time division multiplex system (or for that matter any other system implying the multipled utilization of the wires) on these trunk sections, as here substantial quantities of copper might be saved.

A *combined system* on this pattern would imply a number of advantages, *viz.*

(a) *the present type of subscriber's telephones of a fairly simple design could remain* (possibly in a modified design, *e. g.* equipped with a keying device instead of a dial);

(b) *the concentrator would remain simple in operation, requiring but little maintenance ;*

(c) all complex circuit equipment for the operation of the network could be *concentrated* in a moderate number of transit exchanges, another point redounding to the simplicity of maintenance.

Further, it has to be borne in mind that to-day large cities are fairly well provided with exchanges more or less suitable for conversion into transit exchanges. Exchanges actually in service could be extended by jettisoning *the line finder and final selector stages*, while in their stead equipment co-operating with the line concentrators could be installed. As dictated by requirements varieties of equipment of different capacities could be developed, while these varieties could then be employed for future extensions of the network.

As far as the accommodation of the line concentrators is concerned, there are certain points deserving careful attention, *viz.*:

(a) no air-conditioned rooms can be provided for the line concentrators;

(b) if the line concentrators are not built up of electronic elements, then the contact field will have to operate in as noiseless a manner as possible;

(c) at installation only the load-carrying capacities of conventional apartment house floors can be reckoned with.

The want of air conditioning facilities has to be taken into account in the same way as nowadays with PABX. s. Since conventional living rooms are concerned here, with a central heating plant temperature may be kept between *18 and 35° C.* If the concentrators are built up of purely electronic elements dusting problems become a matter of secondary consideration. For crossbar type switches dustproof cabinets have to be used, even if, as is known, these cabinets do not afford perfect safety. The power consumption of a line concentrator amounts to a *few watts* only, consequently the equipment does not generate heat, the temperature will be uniform in the inside, so that no circulation of air conveying dust into the cabine has to be feared.

As for convenience of maintenance, all assemblies of the line concentrator should preferably be of the *plug-in type.* In this case maintenance work would boil down to *preventive tests* to be carried out at regular intervals, on severe conditions. Crossbar equipment actually in current use is not of the plug-in type, although a design of a crossbar switch of a capacity of 10×10 with *three* contacts only at the cross points is fairly well imaginable.

Anyhow the idea suggests itself to design a crossbar switch operating on the principle of electromagnetism which would be capable of being locked in its activated condition without current. Owing to the relatively low capacity of the line concentrators there would remain *ample time for operation*, which means that

(a) windings of high resistance values could be used;

(b) locking would be secured by means of the *operating sequence* of the magnets, while permanent holding magnets, or special windings could be dispensed with.

With these two conditions satisfied, and with the wires A and B of the trunks for signal transmission connected in parallel and provided with earth return, an output of *5* to *6* watts could be secured for the line concentrator, which would on the whole be quite sufficient.

As far as equipment weight is concerned, in general in a Rotary automatic exchange the average weight per subscriber is *10 to 12* kilograms. Consequently, a line concentrator equipped for *250* subscribers would weigh as much as 2500 to 3000 kilograms. However, in reality this weight is substantially lower as the rack system of the line concentrator is of a far simpler design. Besides, there are no message registers installed in the line concentrator, its functions being confined to through-connection only. Further cuts could be made in the weight with the increasing use of electronics. From the literature[8] it appears that with the introduction of electronic switching elements savings in the order of magnitude of 5 to 1 may be achieved in the overall weight of the equipment. On the assumption of crossbar techniques the weight of a line concentrator of this type would then be in the neighbourhood of *1000 to 1500* kilograms, *i. e.* the line concentrator may safely be accommodated in a living room with floors of the conventional load carrying capacity of *150 kilograms per sq. metre.*

V. Conclusion

With the replacement of Rotary type *main and satellite exchanges* by *transit exchanges and line concentrators* the copper weight of the network may be reduced. In the *200 000-line* theoretical network investigated in this paper the average copper weight for each subscriber's loop has been calculated as being *18.5 kilograms*, while with the introduction of line concentrators this weight could be reduced to *11 kilograms*, the rate of savings being approximately *forty per cent.* For the total service the savings may amount to about *23 per cent.* The surplus costs of assemblies are not critical, as the switching system of the line concentrator consists only of the line finder and final selector stages removed from the main exchange. Consequently, it is only the control system that might come to mean additional costs of investment. However, these additional costs could be redeemed by a better exploitation of the trunks adequately guaranteed by the adoption of the marker principle. (If *e. g.* the trunks handling incoming and outgoing traffic would be segregated then instead of *37* trunks $2 \times 22 = 44$ trunks would be needed.)

The cost items to be amortized and tabulated in the Introduction could then be modified as follows:

Subscriber's apparatus	6 per cent.
Exchange equipment	32 per cent.
Network	42 per cent.
Maintenance, general running expenses .	20 per cent.
Total:	100 per cent.

The network continues to remain a substantial item, and a further reduction of its costs is conceivable only with *the multiple exploitation of the transit trunks, i. e. with the time division multiplex system.* With the reduction of the percentage share of the network in the overall costs of investment that of the other items will naturally tend to increase. Consequently, the costs of exchanges and maintenance will constitute major items and, as for these, the introduction of electronics in telephony forecasts chances of development still on a large scale.

It appears to be worth while to investigate the possibilities offered by electronically controlled line concentrators yet equipped with electromagnetic contact fields. A concentrator of this type may easily be *assimilated into existing networks*, it certainly favours the *development of the network on a higher grade of economy*, it opens the path for the *experimental exploitation of electronic control circuits*, and finally this type of concentrator may be helpful *in accumulating experience and in training a maintenance staff.* In addition network requirements may be cut down, a circumstance particularly welcome if with the introduction of line concentrators of this type *the extension of the existing cable network could be deferred to a later term.*

In spite of considerable efforts, the realization of purely electronic exchanges is still lagging behind. Obviously, there will still much time be wanted until some sort of a definitive point of view could be formed in this matter. On the other hand, the circuitry for *electronic control* is already available, and is suitable for the activation of any type of crossbar switch operating on electromagnetic principles [8]. For this reason the opinion may be considered correct that the telephone networks of the future should preferably be developed with a trend towards a compromise, *i. e.* on the line evolved in this paper.

Summary

The introduction of crossbar type switches and electronic switching features into telephone technics has opened the way for cutting down the amount of wire material absorbed by the networks of present multi-office city areas. For and by itself savings achieved in wire material may in the last end redound effectively to a lowering of the tariff rates. The subject-matter of this paper is to investigate the conditions to be satisfied in order to cut down the weight of the wire material invested in any given telephone network.

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