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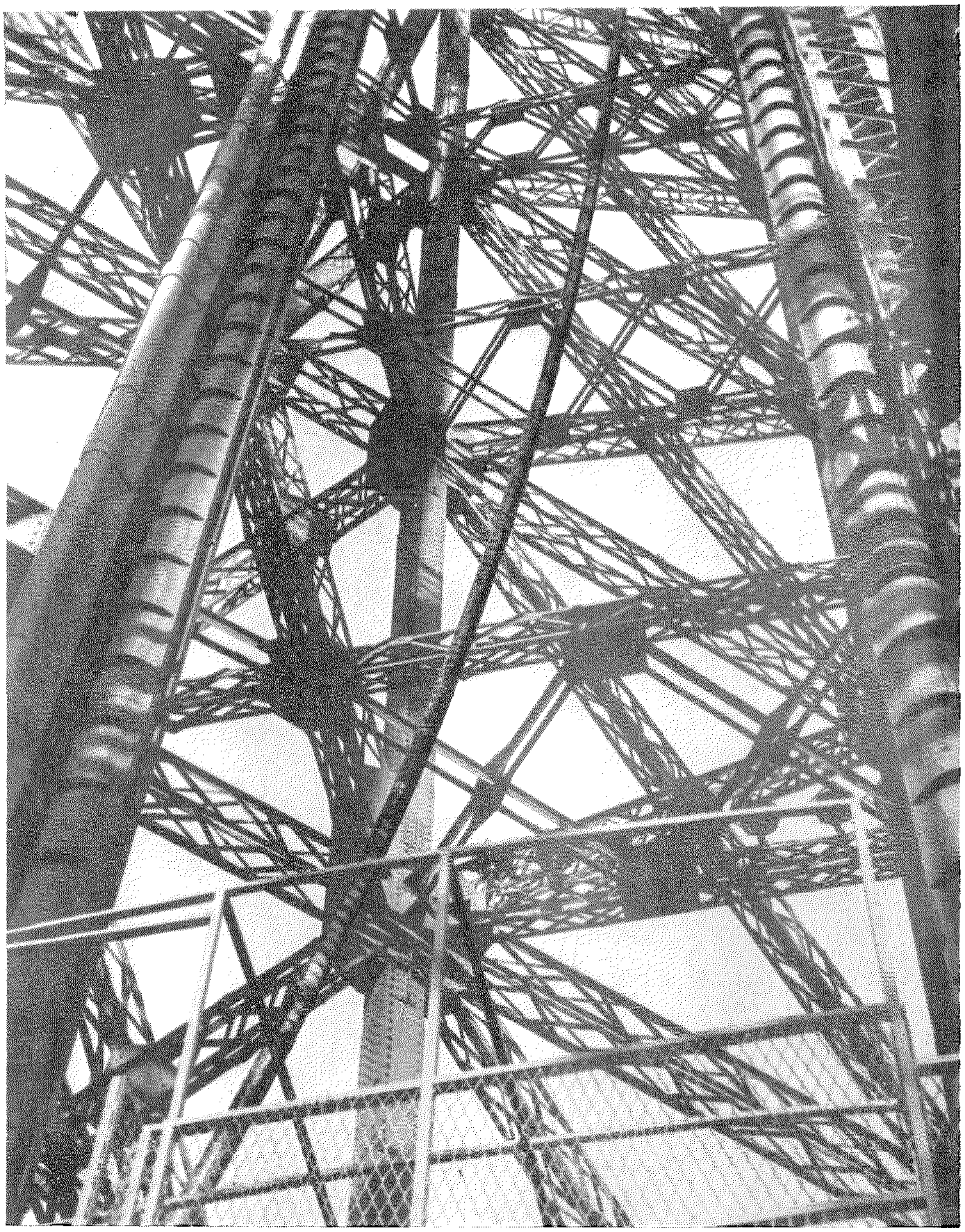


Photo: Jasz, Paris

The French P.T.T. recently ordered from Le Matériel Téléphonique, Paris, a 30 kW Television Transmitter to be installed at the base of the Eiffel Tower. The view shows a Section of the 12-ton Transmission Cable being hoisted into position to connect the Transmitter and the Antenna located at the top of the Tower.

The Coronation

London, May 12, 1937

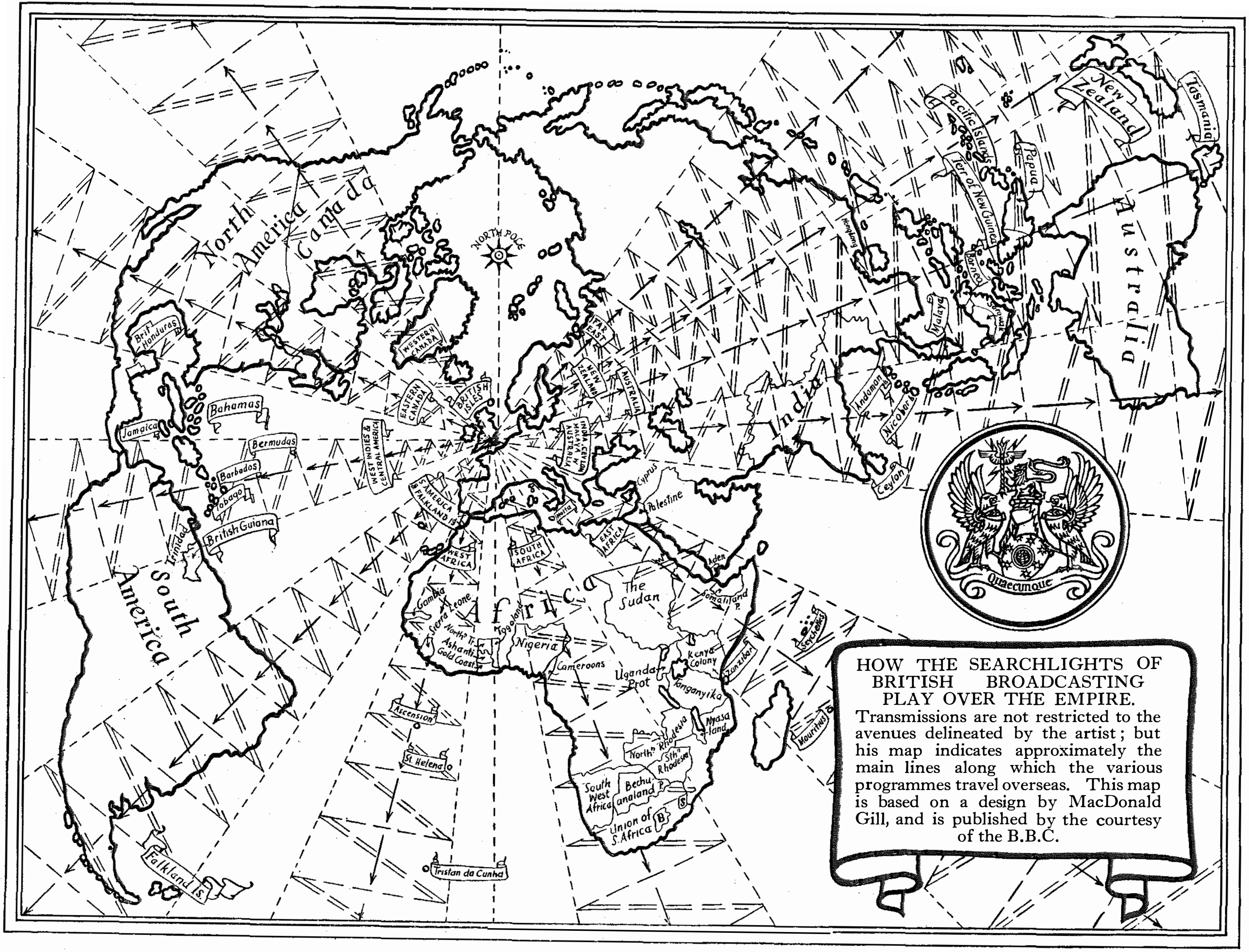
By F. GILL,

Vice-President, International Standard Electric Corporation

A MOVING Ceremony, which stirred the feelings and imagination of the British Empire and evoked world-wide interest, took place in London on the 12th of May, 1937, in the Coronation of Their Majesties King George VI and Queen Elizabeth. It is not the present purpose to describe the ceremony, but rather to convey an impression of how the broadcast went out to the Empire and other interested Nations. Prior to recent years, participation in such an event would of necessity have been confined to a very small number of persons who could hear and see the actual ceremony and to a larger, but comparatively small, number who could be accommodated within Westminster Abbey. Today, however, the situation is vastly different. Thanks to advances in electrical communication, millions were as well placed for hearing as if they had been among the few who had their places in the Chancel of the Abbey. Though separated by distances up to thousands of kilometres, they were able to hear as if present, and thousands, by simultaneous television broadcasts, were able to see something of the procession. Whereas, formerly, to announce the moment of the Coronation to the people " at a signal given, the great guns at the Tower are shot off ; " this time the people heard the actual words of the Service, including the voice of the King. This particular Coronation, too, was of great political significance : Representatives of the free and equal Nations composing the British Commonwealth of Nations, for the first time, were physically present when the King was Presented to and Recognised by them as their undoubted King and also at the actual Crowning ; similarly, untold numbers of these Nations, for the first time, were able to hear this impressive ceremony and thus, in a personal manner, participate in the recognition of the Crown, the vital link in this British Empire.

How the Programmes Were Sent Out

The heart of the ceremony was Westminster Abbey and it may be of interest to describe briefly the arrangements made by The British Broadcasting Corporation to broadcast the Coronation Ceremony from the Abbey, the commentaries on the Procession, and the sound effects which were collected by the microphones distributed along the route, all of which were mixed together to form a continuous sound picture of the pageant. In the Abbey, there were 38 microphones which were connected to a number of four-channel mixing units in the Abbey Control Room, the outputs of these mixers being connected to the first amplifiers. Twenty more microphones outside the Abbey were connected to a number of subsidiary control points, each equipped with mixers, amplifiers and control telephones. The outputs from the four-channel mixers and the incoming lines from the subsidiary control points were connected at the Abbey Control Room to an eight-channel "mixer-amplifier." Its output was used to feed the programme through further amplifiers to Broadcasting House, to the loud-speakers in the Abbey and along the route, to the film- and disc-recording equipment, and to the Foreign Control Room. From Broadcasting House the programme was sent to the B.B.C.'s Empire Short Wave Transmitters and to the



HOW THE SEARCHLIGHTS OF BRITISH BROADCASTING PLAY OVER THE EMPIRE.

Transmissions are not restricted to the avenues delineated by the artist; but his map indicates approximately the main lines along which the various programmes travel overseas. This map is based on a design by MacDonald Gill, and is published by the courtesy of the B.B.C.

Long and Medium Wave Transmitters used for its home service.

From the Empire Station the programmes were broadcast to the whole world, and reports of favourable reception were received from Fiji, N. Borneo, Hong Kong, Malaya, Malta, India, Ceylon, S. Rhodesia, Kenya, Nigeria, Gold Coast, Sierra Leone, Ascension, Newfoundland and the Falkland Islands, as well as China, Egypt, Iceland and Poland. Many of these countries rebroadcast them from their own stations. To supplement direct reception from the B.B.C.'s Short Wave Station, there were also transmissions to Australia, Canada, South Africa and New Zealand, as well as Argentina, Brazil, Japan and the United States, via the General Post Office radio-telephone transmitting station at Rugby.

The transmissions from the Empire Station were made on wavelengths and directions which were chosen to give the best service to each zone, according to the time of reception and the

Night View of Westminster Abbey, Showing Coronation Floodlighting. In the Foreground is the Temporary Annexe Erected for the Coronation.

expected conditions of propagation. Recordings of the events of the day were reproduced in subsequent transmissions for the benefit of those who were unable to listen during the original broadcasts.

At the Foreign Control Room ten commentators' boxes, each giving a view of the Procession as it entered and left the Abbey Annexe, were available for foreign observers. The speech from these observers was superimposed on the sound-picture of the Procession by means of mixing units, the output from which, after amplification, was sent direct to the international trunk exchange of the General Post Office for transmission overseas by line and radio services. Altogether commentaries in twelve different languages, in addition to the ceremony itself, were given. Special composite programmes were arranged for the relays to America, which included commentaries by observers stationed at two different points and excerpts from the B.B.C. programme.

High-quality sea and land telephone circuits were used to send the programmes to Austria, Belgium, Czechoslovakia, Denmark, Finland, France, Germany, Holland, Hungary, Norway, Sweden, Switzerland and Yugoslavia.

Thus the transmissions were sent over the regular telephone service routes of the world to more than 20 destinations overseas, and were widely broadcast there and, in some cases, redistributed to other countries. Very many ships also are known to have received these programmes, and much work was done by the Telegraph Companies on messages relating to the event.

*The Electrician** refers to this broadcast as "an achievement which has cemented the Empire in a way that nothing else could have done."

International System Contribution

To indicate more than generally the contributions of International System Companies and of Companies associated with the International System to this unique achievement, would be tedious. The apparatus and equipment included the following of Standard type: the microphones used for picking-up the Abbey service and the cheers of the vast crowds; four of the B.B.C. Empire broadcast transmitters (two of these were the new high power stations, the installation of which was specially expedited for this purpose, and two were older, lower power stations); the international telephone exchange toll test racks through which all the telephone circuits were set up; the radio transmitters used on several of the radio telephone circuits; radio telephone and switching facilities in Argentina, Brazil and other countries; and radio telephone equipment in hundreds of ships including liners such as the Cunard White Star *Queen Mary* and *Berengaria.* The wire telephone circuits to the 13 European countries included much Standard type apparatus in the form of Cable, Loading Coils, Repeaters, Carrier Equipment, Toll Switchboards, etc. Over half a million Standard type broadcast receiving sets probably were in actual use during the ceremony, and Standard type broadcasters in numerous countries were involved in retransmissions of the programmes.

In the organisation of British broadcasting, International Standard Companies, with others, played a part both on the original Committee and in the Company which operated for some years before the advent of the British Broadcasting Corporation. They have also actively supported the International Consultative Committee for Radiocommunications (C.C.I.R.) and the International Telephone Consultative Committee (C.C.I.F.), to which the World is largely indebted for the spectacular improvement in international telephony.

Acknowledgment

That this difficult and admirable broadcast was carried out by The British Broadcasting Corporation with remarkable success is a matter of public record. For furnishing facts relating to the dissemination of the programmes, the author gratefully acknowledges his indebtedness to The British Broadcasting Corporation and to the British Post Office.

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* Issue of May 21st, 1937.

General Problems Before the C.C.I.F. for 1937-1938

By BRUCE H. McCURDY

THE growing public demand for better and more extensive international telephone service, together with the rapid development of methods and equipment for providing this service, have brought before the C.C.I.F. a multiplicity of new problems. New technique, such as carrier-on-cable and toll dialling, have raised many technical problems which must be studied internationally if the economic possibilities of such systems are to be taken advantage of fully. The present-day requirements of providing a faster, easier and more extensive service involving the connection of any subscriber with any other subscriber, regardless of where located, is necessitating the expansion and in certain cases the revision of existing overall recommendations of performance in order that this universal interconnection of subscribers may be taken care of adequately, economically, and in a manner fair to all parties concerned.

The work of the C.C.I.F., therefore, despite great progress already made, is fully as important as in the past, and the amount of co-operative work and study necessary to answer the questions before the various commissions is constantly increasing. The gradual shift from considerations of a strictly laboratory nature to questions of coordinated application is necessitating a new method of attack in which special sub-committees, such as the one on the European Toll Plan, are set up to study specific problems. Whereas, in the past, it has been possible to confine the meetings of the technical commission to one each year and to exchange supplementary information by mail, it is now necessary to discuss jointly and step-by-step many of the investigations and to follow them much more closely than formerly. The smaller sub-committees set up to study these special subjects can, and are, now meeting at more frequent intervals, and it is hoped that such meetings will allow the work of the C.C.I.F. to keep pace with the ever increasing extent and complexity of the international telephone problem.

An attempt is made herein to summarise the inter-relation of the problems which the C.C.I.F. is now studying in order to meet these new conditions.

I. PROBLEMS OF NEW TECHNIQUE

(A) Multi-Channel Carrier-on-Cable

The introduction of multi-channel carrier-on-cable technique raises numerous problems of coordination which must be solved if the economies of the new systems are to be taken advantage of fully in the international network.

In building up international circuits over voice-frequency circuits, each individual circuit can be treated very much as a separate entity. The international agreements necessary could therefore be kept very broad. Carrier systems, however, involve groups of circuits which cannot easily be modified individually. Furthermore, in order to derive the greatest advantage from these systems in the international network, breaking down such circuits to voice-frequency at the frontier must be eliminated. Thus international agreement is necessary on many factors which, in the older technique, were primarily only of national interest.

Agreement on most of the essential requirements for single-channel carrier systems has been reached, and a start made on the standardisation of essential characteristics for three- and four-channel systems. More study is necessary on the matter of standardising the performance of these latter systems, however, and the list of new questions covers such items as :

(*a*) Allowable values of relative level at frontier stations ;

(*b*) Admissible values for near-end crosstalk between the pairs or quads used for single-channel and for 3- or 4-channel carrier systems ;

(*c*) Capacity and inductive unbalances for loaded cable pairs or quads used for carrier ;

(*d*) Characteristics of loading coils used on pairs or quads which are to be utilised for carrier ;

(*e*) Voice-frequency input limitations on single and 3-or 4- channel carrier-on-cable.

The subject of multi-channel carrier on non-loaded pairs or quads and on coaxial systems must be attacked from the very beginning, and among the subjects scheduled for discussion in 1937–38 are :

(*a*) Choice of carrier frequencies ;

(*b*) Essential characteristics for the cables or coaxial structures ;

(*c*) Conditions to be imposed on such systems from the standpoint of non-linearity, especially in connection with the effects of non-linear crosstalk.

Of these, the question of choice of carrier frequencies is perhaps the most important since it will most vitally affect the basic development now being carried out ; it will have a very important bearing on overall performance of the international network, and will be the most difficult to change in the future. In selecting the frequencies to be used, full weight must be given to the question of band width which is to be required in the future on international circuits. The effect of the newer subsets, which give a much flatter and broader band width than the older sets, will undoubtedly result in greater emphasis being placed upon long-distance or inter-urban circuit band width than is the case at present ; and, unless the long-distance technique takes this factor into account, much of the advantage to be gained from the new subsets may be lost. This question is tied up with the rating study, as will be noted below under Section III.

As in the case of recommendations adopted by the C.C.I.F. for voice frequency systems, the C.C.I.F. will endeavour to keep the recommendations for carrier systems as broad as possible in order to permit the greatest freedom in development and exploitation in individual countries ; but, at the same time, guard against non-coordinated or divergent growth such as would result in inflexibility and increased costs when the systems are applied to the international network.

(B) Toll Dialling

Here again the problem arises of a compromise between two courses : on the one hand, rigid specifications restricting national development and the catering for specific national requirements ; on the other hand, too liberal recommendations with resultant possible growth of systems which could not interwork or which would give rise to false signalling from one international system into another. There seems to be no doubt that international toll dialling in some form or other will be required in the immediate future, and it is essential that agreement be reached on certain fundamental requirements by all the nations concerned in order that *national* systems now being evolved will be adaptable to international working without fundamental revision or great modification.

II. THE EUROPEAN TOLL FUNDAMENTAL PLAN AND ITS ALLIED PROBLEMS

The need for, and the general points to be considered in, the preparation of a general toll plan for Europe have been indicated in a previous paper.[1] In accordance with the decision of the Copenhagen Plenary Meeting, the consideration of this problem as a whole has been made the subject of a specific question ; and a sub-committee comprising members of both the technical and the exploitation Commissions des Rapporteurs has been appointed. The work of this sub-committee is being carried out along the following lines :

(A) Study of the Form and Make-up of the "Standard International Connection"

In order that a universal interconnection of subscribers throughout Europe may be achieved practically and economically and in a way that will be fair to all parties concerned, it will be necessary to break down existing overall transmission limits to a series of limits applicable to the individual links which may make up any

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[1] "Some Considerations Regarding a Toll Fundamental Plan for Europe," by Bruce H. McCurdy, *Electrical Communication*, October, 1935.

overall connection. Before this can be done, however, it will be necessary to determine the form of what may be termed the "standard international connection." The theoretical determination of an "ideal" switching arrangement would present a very interesting study; and it is possible that, before the work of the sub-committee on the European Toll Plan is complete, the preparation of such an "ideal" plan may be undertaken as a possible guide for long-term planning. In attacking the problem from the viewpoint of practical accomplishment in the immediate future, however, it will be necessary to take into consideration two main factors:

(*a*) The fact that each nation in Europe has built up a toll distribution network to meet its own national needs; and, although this national network is used to distribute throughout its territory the international calls received from or directed to the outside, national distribution is still of primary importance so that no major re-arrangement of the existing form of the national networks should be called for if it can be avoided.

(*b*) Not only is the form of the national portion of the "Standard international circuit" more or less fixed by the considerations noted above, but also the electrical characteristics. Certain minor modifications can be expected to be introduced gradually if studies indicate that they are necessary, especially when new plant is laid down, as is continually being done. The existing characteristics must, however, be taken as a starting point.

As a result of the above considerations the sub-committee on the European Toll Plan has started by making a survey of just what does exist today and, consequently, has asked all Administrations to present in detail their national switching plans in so far as they affect the question of international service. It is hoped that a joint study of all the plans presented will result in a certain amount of standardisation in form and performance characteristics, which will serve as a starting point.

Having determined what may be termed the "inherent" characteristics of the national networks, the committee will proceed to study:

(*a*) The characteristics necessary for the international network proper which, with the existing "inherent" national characteristics, will be necessary to provide a satisfactory grade of service on all international connections; and

(*b*) Whether these characteristics can be met practically and economically, or whether, from the outset, certain changes in the national systems will be required.

The ultimate plan probably will involve several steps and take the form of:

(*a*) A provisional "standard connection" which, although perhaps not meeting fully the requirements of a completely satisfactory universal interconnection, nevertheless will allow a much more efficient use of the existing network than at present.

(*b*) An "ideal" future network, perhaps arrived at in several steps, to serve as a guide, both nationally and internationally, for all future construction, re-arrangements and changes.

(B) Re-allocation and Revision of Existing Overall Technical Recommendations Regarding Performance, to Apply to Individual Links in the "Standard International Connection"

The study of the existing characteristics of the national and international networks now going on will serve a two-fold purpose: (1) It will give the C.C.I.F. a basic point from which to work in allocating performance requirements to the individual links of the overall international connection in a way both practicable and fair to all parties concerned; and (2) it will provide data for use in connection with another very important phase of the interconnection problems—the rating study. Local conditions vary so much from country to country that any attempt to standardise performance requirements for any specific type of circuit or connection is extremely difficult. A series of limits which might be economically satisfactory in one country might be too severe for another country, and vice versa. The various factors which affect overall performance are numerous, and their inter-relation so complex that, until recently, it has been necessary to work on the basis of individual and somewhat arbitrary limits for each of them.

The extensive research which has been carried out by individual Administrations and operating companies, and by the SFERT laboratory are bringing out the fact that, within limited ranges, certain inter-relationships exist between these various factors which can all be reduced, for practicable engineering purposes, to a common denominator. Thus, for instance, noise, within certain limits and for certain limits of overall volume loss, may be treated not as a specific limit (not to be exceeded) but as introducing a certain "noise transmission impairment," expressible in db and subject to compensation by a variation in some other factor such as attenuation. If, as a result of the surveys of the "inherent characteristics" of the various national and international networks now under way, it can be stated that certain factors will vary only between specified limits, the commissions dealing with the rating study proper will be able to equate, for purposes of specific application, the effect of these various transmission factors much more accurately than has heretofore been possible despite the fact that the present-day problem of interconnection requires a much more definite series of limits than has been the case in the past.

The advantage of such a method of treating transmission characteristics is that the possibility of treating the various factors in terms of a common denominator rather than as specific and individual limits will, it is hoped, actually allow a greater freedom in individual design than even the present general requirements permit. Thus, meeting the new and more exacting overall performance requirements in an economical manner will be facilitated.

(C) Minimum Net Loss Study

Although it probably will be possible to treat the majority of the transmission factors in the way mentioned above, certain other factors, namely, echo, singing margin and crosstalk, must still be subject to specific and individual limitations. As explained in a previous paper[2] these three factors are, for given types of design, dependent upon the volume loss of the overall toll circuit and can best be controlled by specifying, for each type of circuit, the "minimum net equivalent" at which a circuit of given length can be worked. The subcommittee on the European Fundamental Plan has been examining this question exhaustively and it is hoped that, before the next meeting, an acceptable method of determining the "minimum net" and the "minimum net working" loss for the most common types of circuits in Europe will be arrived at. The studies already carried out have resulted in a general acceptance of the echo net loss curves for circuits not equipped with echo suppressors. In the determination of net loss curves for circuits equipped with echo suppressors, the rather difficult question arises as to whether the three factors mentioned should be engineered on the basis of eliminating troublesome effects for the average case, the majority of cases, or for *all* cases. This is especially true regarding the acceptable limit for echo. Two general echo curves have been produced: one curve represents a condition in which it is safe to say that no troublesome echo effects will be noticed except perhaps under very exceptional conditions and then only by critical subscribers; the other curve represents a condition in which the echo effect, if increased at all, is likely to cause annoyance to the average subscriber. Unfortunately, there is a wide divergence between the curves representing these two limits. It is possible that curves based on both of these limits will have to be presented to a Plenary Meeting for a decision as to which of the two values should be adopted, or whether a compromise between the two, acceptable to all, can be effected.

(D) Echo Suppressors

The effects of echo suppressor characteristics upon the ultimate shape and position of the net loss curves is such as to require a considerable amount of coordinated study of this item of equipment. In order that such studies shall be comparable and in order that their results may be stated in terms generally understandable, it has been necessary to revise the existing definitions regarding operating characteristics and to call for specific data regarding the characteristics

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[2] "Application of Minimum Net Loss Theory to the Design of International Toll Circuits," by Bruce H. McCurdy, *Electrical Communication*, January, 1936.

of all types of echo suppressors now in general use or contemplated for the future. Whether this study will result in a more rigid specification of operating characteristics, or whether they will be expressed in the form of different net loss curves for circuits equipped with different types remains to be seen.

(E) Traffic Features of the European Toll Plan

In considering the form of the " Standard International Circuit," it will be necessary to take into account factors of traffic flow and operating methods, both in the national and the international network. For this reason members of the Traffic and Exploitation C.R.'s are represented in the joint committee on the European Toll Plan.

The objective of the joint study of the European Toll Plan is not only to guarantee a satisfactory grade of service from a transmission point of view, but to aid in coordinating the traffic and the transmission problem in such a way as to speed up service by a more efficient use of all facilities.

III. RATING STUDY

The inadequacy of the present volume method of rating telephone performance has generally been recognised. New methods are now being studied in an attempt to find one which will suitably express performance in terms of the reaction of subscribers under normal operating conditions, but still be practicable from the standpoint of the amount of work necessary for obtaining the answer for all possible conditions and combinations.

The problem involved is two-fold : (1) the general acceptance of a basic criterion of performance ; and (2) the method to be employed in applying this criterion in overall systems design.

With regard to the first, it has generally been accepted that the criterion to be used must take into account subscriber reaction under actual service conditions. In other words it must be based, in its ultimate analysis, upon actual field observations of subscribers' reaction, the type of field observation to be made being dependent upon the criterion of performance ultimately adopted. This, of course, necessitates a large amount of field testing and exchange of information and data in order to ensure that the methods adopted either are universally applicable or capable of being correlated.

With regard to the second problem, the ideal rating scheme would be one which would allow expressing in terms of some common denominator the contribution made by any piece of equipment or section of line to the overall performance of a given connection. The advantages of such a method have been touched upon in the preceding section and, as has been noted, some progress has already been made in determining the effects of such factors as noise, frequency distortion, etc., on the overall performance when the remaining factors are kept within certain limits. These studies are far from complete, however, and a very considerable amount of investigation must be carried out by the C.C.I.F., the SFERT laboratory, and the various Administrations and operating companies concerned before a workable method can be evolved.

The development and acceptance of a complete rating method cannot be expected for some years. Certain trends, however, can be determined and present concepts of required performance modified accordingly, especially with respect to the effects of noise and of frequency-band transmitted. These two factors appear in the list of new questions.

As already mentioned, the question of the effect of the frequency-band to be transmitted may have a very material effect upon the question of carrier frequencies to be selected for the new technique of multi-channel carrier-on-cable. Coincident with recognition of the very marked effect of frequency distortion of the long-distance line on overall performance, there is the previously mentioned subset development which gives both a flatter and a broader frequency response. There is every reason to believe that, even before the final rating study is worked out, an allowance for the better frequency response of these new subsets with consequent revision of the tentative "distortion transmission impairment curve" can be made, thus achieving better overall performance and, possibly, greater economy.

IV. PERFORMANCE AND REQUIRED CHARACTERISTICS OF SUBSCRIBERS' SETS

The contribution of the subscribers' sets to the performance of the overall connection is of such importance that it has been found necessary for the various Administrations and operating units throughout the world to consider jointly, through the C.C.I.F. and in conjunction with the SFERT laboratory, all factors entering into the question of subset performance and the methods of determining and expressing the same. Among the points now under study are room noise (including methods of measuring and expressing it); the measurement of the reference equivalent of side tone ; and the effects due to non-linear distortion in subscribers' equipment.

Although related to the question of rating telephone performance, these studies deal more directly with the development of the subset itself as a specific problem.

V. OTHER TRANSMISSION PROBLEMS

Correlated with the above major problems there are still many detailed points of a transmission nature on which general agreement will be necessary, such as the technique involved in the interconnection of radio links and land lines, transmission requirements of broadcast circuits to facilitate the international exchange of broadcast programmes, methods of measuring and specifying limits for cross-talk, effect of line noise and the limits to be imposed when considering induced noises from power lines, etc., and the requirements necessary to facilitate the provision of telegraph circuits over telephone lines, etc.

VI. PROTECTION AGAINST INTERFERENCE AND CORROSION

With the exception of the studies involving the actual limits to be set down for induced voltages, the work of the Commission dealing with Protection is for the most part concerned with the exchange and correlation of information regarding methods to be used and recommended for guarding against interference and against corrosion. The limits to be imposed in connection with induced voltages concern both the quality of the telephone transmission and the danger to personnel and telephone plant. This latter work is being carried out in close conjunction with the other C.C.I.F. technical commissions and similar bodies representing the power companies, in an endeavour to arrive at limits which will be fair both to the telephone and the power interests ; and, also, to reach an agreement upon the measures which should be taken by both parties to attain these results.

Regulations with regard to corrosion of telephone cables are similarly being considered in co-operation with the power companies.

VII. EXPLOITATION AND TARIFF PROBLEM

Coincident with the demand for better and more extensive international telephone service is the demand for greater ease and greater speed in the handling of calls as viewed by the subscriber. In order to meet this demand the 6th and 7th C.R.'s, which deal with Tariffs and Exploitation, have on the Agenda for 1937–38 a number of questions which deal with the following problems :

(*a*) Operating methods to accomplish a more speedy switching of international calls ;

(*b*) A consideration of the method of presenting statistics of present service. This is far from being an academic point ; for, if an easier and speedier service is to be provided in the future, it is necessary to know what is actually being accomplished and where the weaknesses, in the form of delays, exist.

(*c*) The possibility of eliminating excessive peaks by the introduction of deferred calls which would be handled during the idle or low-load periods ;

(*d*) Methods and desirability of giving toll calls priority over local calls.

These two Commissions will also participate in the study of the European Toll Plan, particularly the switching plan to be adopted for the future. The objective is the coordination of traffic and transmission requirements with special reference to the establishment of suitable alternate routings which should allow a speeding-up of service and a more efficient utilisation of existing circuits.

Automatic Telephony in Country Districts of Great Britain

By E. P. G. WRIGHT, A.M.I.E.E.,

Standard Telephones and Cables, Limited, London, England

Introduction

THE installation of rural exchanges in Great Britain is now proceeding along a general plan which envisages the replacement of all the manually operated country exchanges during the next few years. The rural exchanges are of three standard sizes and cater for all equipments up to an ultimate of 800 lines. From 1929 until recently, small boards of a very simple type had been installed widely in unattended and unheated buildings. Although the old type provided 24-hour operation and eliminated the difficulty of maintaining accurate service in country districts, a change in design was introduced because the former did not permit realization of maximum economy inasmuch as the local traffic seldom exceeded 25 per cent. and all the remaining connections had to be established by an operator located in the nearest large town. As the general plan includes automatization of the country exchanges, the operator will tend to become more remote from the rural boards and it will become more important in the future that as much rural traffic as possible be completed automatically.

The requirements for the new type of rural boards were largely controlled by the ultimate switching plan of the country as a whole and, in order to appreciate these conditions, it is desirable to describe in general terms the principle of the fundamental switching plan of the country.

Exchange Networks

The country can be divided up into three main classes :

(*a*) Large cities, such as London, Birmingham, Manchester, Liverpool and Glasgow ;

(*b*) Smaller cities and towns varying from cities such as Newcastle, Edinburgh and Bristol to isolated towns, such as Chippenham ;

(*c*) Small towns and villages.

In the first class, a step-by-step translating system is used, and approximately 150 exchanges have already been installed in three cities. Subscribers in these areas have automatic access to all subscribers situated within either a 10 or 7½ mile circle, with the addition of certain types of calls not exceeding 5 miles, but which terminate outside the circle.

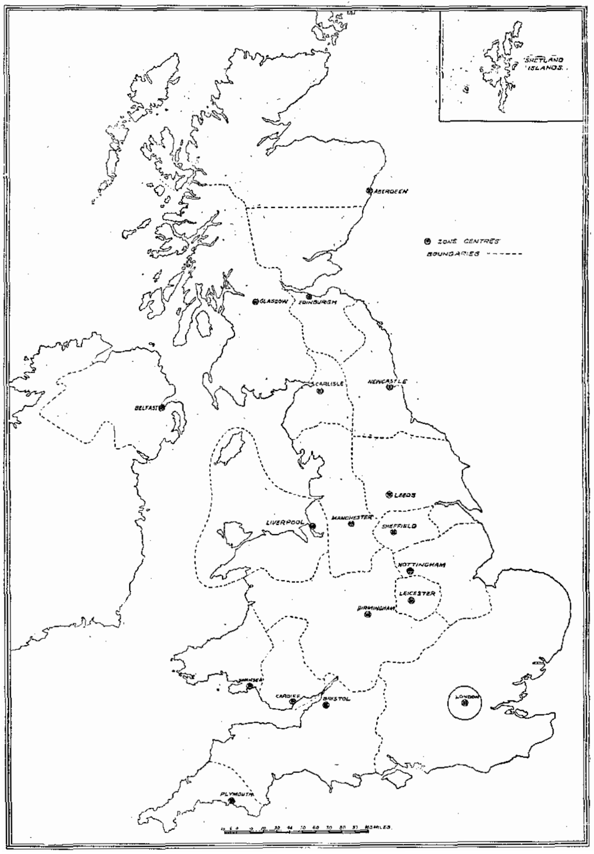

Fig. 1—*Zone Centres of Great Britain.*

In the second class, non-translating step-by-step is employed and, in general, the area is restricted to a 5 mile circle. In many cases there is more than one exchange in the circle, the central exchange having an associated manual board, the remainder being of the satellite type.

In the third class, rural boards are utilized, unless geographical position dictates treatment as in one of the other two classes.

Fundamental Toll and Trunk Switching

For the purpose of interconnecting between exchange networks the country is divided up into a number of zones, each zone being composed of a number of groups and controlled from a zone centre, which has long distance circuits to the other zone centres as well as circuits to all the group centres of its own and, when necessary, direct circuits to adjacent group centres in other zones. Repeatered 4-wire circuits are used between zones working at zero transmission loss. The zone to group circuits are generally amplified and have a maximum loss of 3 db. When the number of circuits does not exceed 10, junction circuits are generally operated on a bothway basis. Quantities from 6 to 10 sometimes use a combination of single and bothway, the latter being of adequate gauge for any traffic.

Table I gives the 18 zone centres with the distribution of the 171 dependent group centres; Fig. 1 shows the zone centres and Fig. 2, a typical zone with its dependent group centres.

TABLE I

Aberdeen ..	5	Leicester ..	4
Belfast	4	Liverpool ..	9
Birmingham ..	16	London	44
Bristol	15	Manchester ..	15
Cardiff ..	5	Newcastle ..	5
Carlisle ..	4	Nottingham ..	9
Edinburgh ..	5	Plymouth ..	5
Glasgow ..	9	Sheffield	4
Leeds	9	Swansea	4

In certain cases several groups have been incorporated into a single toll area. The toll calls are handled on a no-delay basis, the control being frequently with an operator in the originating exchange. The subscriber waits on the line until the connection is established. The toll calls of less than 15 miles are not timed, even when established by an operator.

More distant calls, known as "Trunk Calls," are handled on a demand basis. The subscriber normally waits on the line, but the call is controlled at an exchange suitably equipped for time measurement, which is applied on all trunk calls.

Each group includes minor exchanges, directly connected to the group centre. In addition, there are dependent exchanges not directly connected to the group centre.

Fig. 3 illustrates a rural exchange belonging to network classification (*c*) (see section "EXCHANGE NETWORKS" above) with 5 and 15 mile circles surrounding it. Inside the 15 mile circle are three towns of network classification (*b*). All the exchanges in the 5 mile circle round these towns operate on a common numbering basis.

It will be seen that certain exchanges fall in two different 5 mile areas; dialling between such areas is made possible by the use of a prefix. The typical rural exchange shown has access

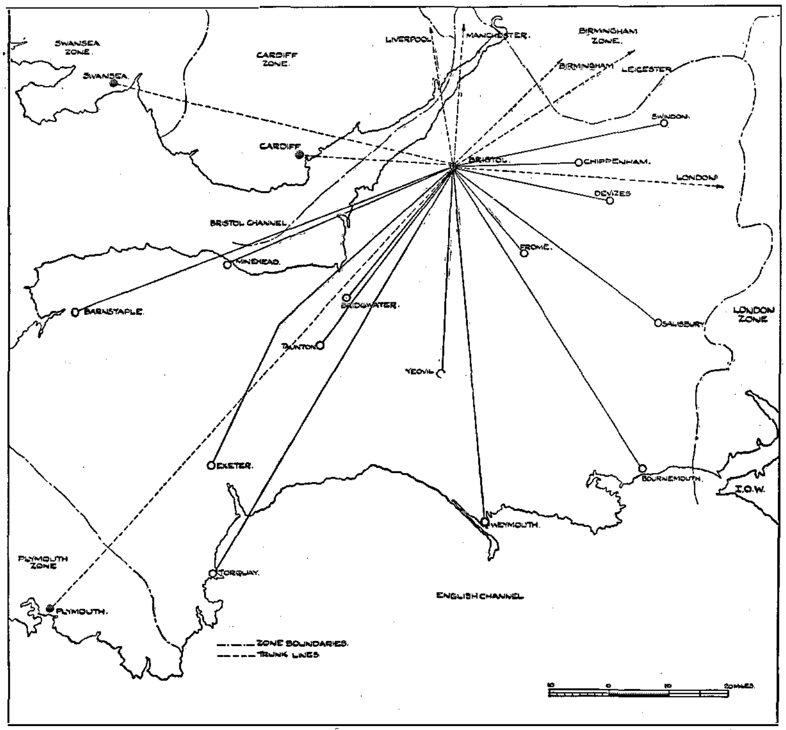

Fig. 2—Bristol Zone Showing Connections to Group Centres.

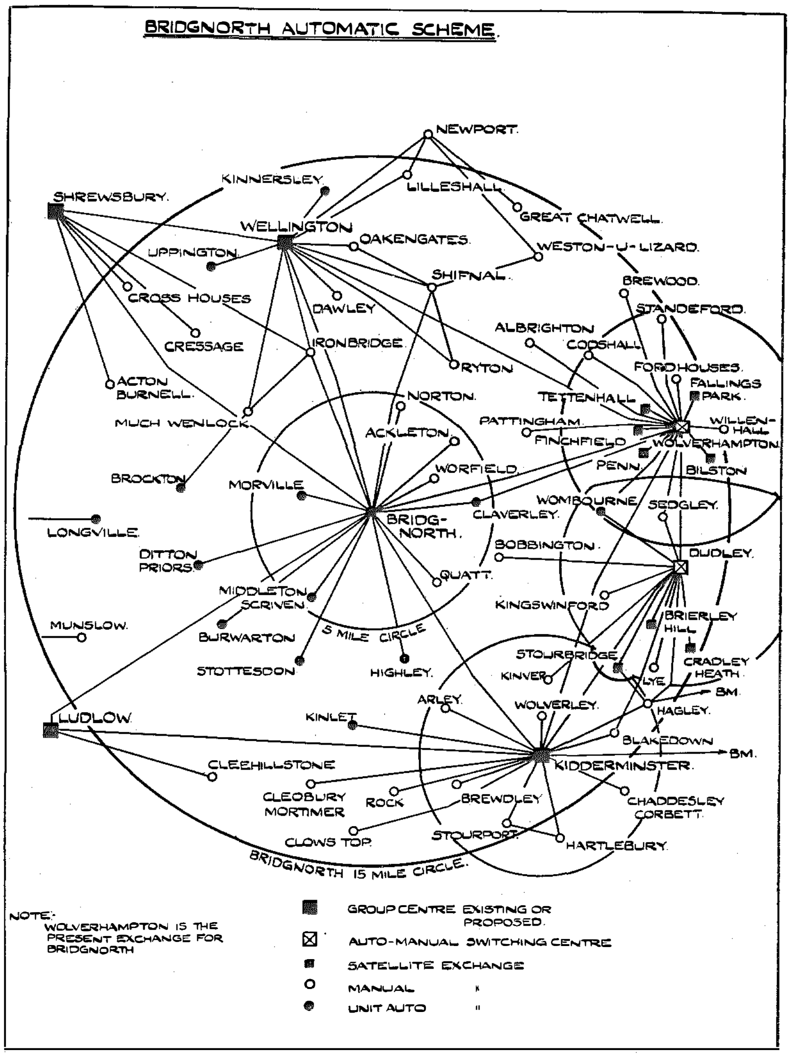

Fig. 3—Typical Connections of Rural Network to Group Centres.

to a number of different areas; calls up to 5 miles are single fee, but all the exchanges in the 5 mile area round a rural board do not operate on a single numbering scheme.

Fig. 4 indicates a typical switching diagram showing toll switches available to operators for connection to distant exchanges which are normally beyond the range of subscriber dialling. Although this illustration only shows a small section of the country, it will be understood that, in conjunction with the group and zone circuits, a connection can be built up from any operator to any subscriber.

The rapid increase in the volume of long distance traffic which has followed the introduction of the flat rate one shilling night service has resulted in a demand for an ever increasing quantity of long distance circuits. Recent developments calculated to assist in handling this traffic are being investigated and subjected to extensive trials.

V.F. dialling circuits have been developed to permit zone and group centre operators to dial long distance calls direct to subscribers. When this conversion is complete, it is considered that not more than one operator should be necessary to connect any two subscribers together.

All national long distance calls are connected on a demand basis, a percentage being reversed for various reasons. All the subscribers are charged on a message rate basis and it has been the practice to supply, with the account, details of all long distance calls. During the last five years, multi-metering has been adopted and has been installed on the latest type of rural board for calls which may be completed automatically up to a maximum of 15 miles. In the large multi-exchange areas the 5 mile circle is considered as a point so that, in certain circumstances, calls beyond 15 miles are permitted.

The present plans make no provision for the introduction of subscriber national dialling by means of closed numbering schemes for large rural districts. The more important arguments in favour of subscriber national dialling in Great Britain are:

(1) Increased speed in establishing a conversation. It is assumed that the probability of loss on long distance circuits is not greater than on local circuits. The prospect of an immediate connection should result in valuable increase in toll traffic. Apart from any consideration of cost, the public is more hesitant in making long distance calls

because of the possibility that it will be necessary to wait about for the call to mature.

(2) Greater uniformity of operation. The subscriber would no longer have to discriminate between local, toll and trunk procedure.

(3) Saving in operating expense.

The major objections to national dialling in Great Britain are:

(1) The existing undertaking to give the subscriber a detailed account of long distance calls.

(2) The absence of operator assistance on expensive calls and the hesitancy of granting subscribers control of valuable circuits.

(3) The complexity of the numbers to be dialled.

The recent development of the automatic ticketer may offer a solution to the first problem. The satisfactory result which has been obtained with national dialling in Switzerland is a matter of reassurance on the reaction of subscribers on long distance circuits, and it is possible to imagine some operator calling system similar to that used on P.A.B.X. equipments to cause, when necessary, the intervention of an operator on a long distance call which has been set up automatically. The problem of the numbers to be dialled is more difficult.

Numbering Arrangements for National Dialling

It is interesting to compare the conditions in Great Britain with those existing in other countries. Statistics are published periodically as to the number of telephones in each country and the ratio of population to telephones. In considering national dialling, the more important statistics are the number of telephones and the number per square mile. Table II shows the largest telephone countries with details of the number of telephones and the number per square mile.

Switzerland has already adopted a national dialling plan and Holland has prepared switching plans in such a way that the adoption of national dialling will cause very little modification. It is understood that both Belgium and Denmark have also laid preliminary plans for national dialling. These four countries have the greatest absolute telephone density. Although Great Britain has approximately the same density, the number of telephones in London alone is approximately equal to the number in Switzerland, Holland and Belgium added together. To interwork with the open numbering arrangements in Great Britain, it is estimated that 11 or 12 digits would be necessary in extreme cases. Considering England alone, the absolute density is very high, but the number of telephones would still necessitate 11 or 12 digits.

TABLE II

Country	Sq. miles	Telephones	Telephones per sq. mile
England & Wales	58 000	2 134 140	36.8
Netherlands	12 760	352 741	29.0
Belgium	11 400	323 423	28.0
Denmark	15 000	377 565	25.0
Gt. Britain and N. Ireland	95 030	2 366 311	24.0
Switzerland	16 000	383 289	22.0
Germany	180 800	3 134 103	17.0
Austria	32 180	258 748	8.0
France	213 000	1 399 869	6.5
U.S.A.	3 738 395	16 868 955	4.5
Italy	120 000	516 075	4.3
Japan	260 800	1 068 244	4.1
Sweden	173 000	616 947	3.5
Czechoslovakia	55 000	171 646	3.1
Latvia	25 000	65 345	2.6
Norway	125 000	199 684	1.6
Poland	150 000	211 334	1.4
New Zealand	105 005	159 170	1.4
Portugal	35 500	49 466	1.4
Irish Free State	26 600	34 799	1.3
Spain	200 000	312 719	1.1
Finland	150 000	141 067	0.94
Greece	50 000	26 712	0.53
Jugoslavia	94 000	49 846	0.52
Bulgaria	45 000	20 646	0.458
Roumania	123 000	56 797	0.45
Hungary	360 180	121 802	0.33
Canada	3 547 230	1 193 729	0.33
Australia	3 000 000	501 402	0.16
Russia	8 241 673	739 381	0.08
China	3 870 000	164 000	0.04

The difficulties mentioned would scarcely apply to subscribers dialling between adjacent towns such as London and Birmingham, or Manchester and Liverpool; and it is possible that subscribers in Chatham, Canterbury, Watford, Maidstone, Brighton, etc., may dial into London in the future.

Rural Equipments

A general re-arrangement of the rural districts has taken place with the object of providing

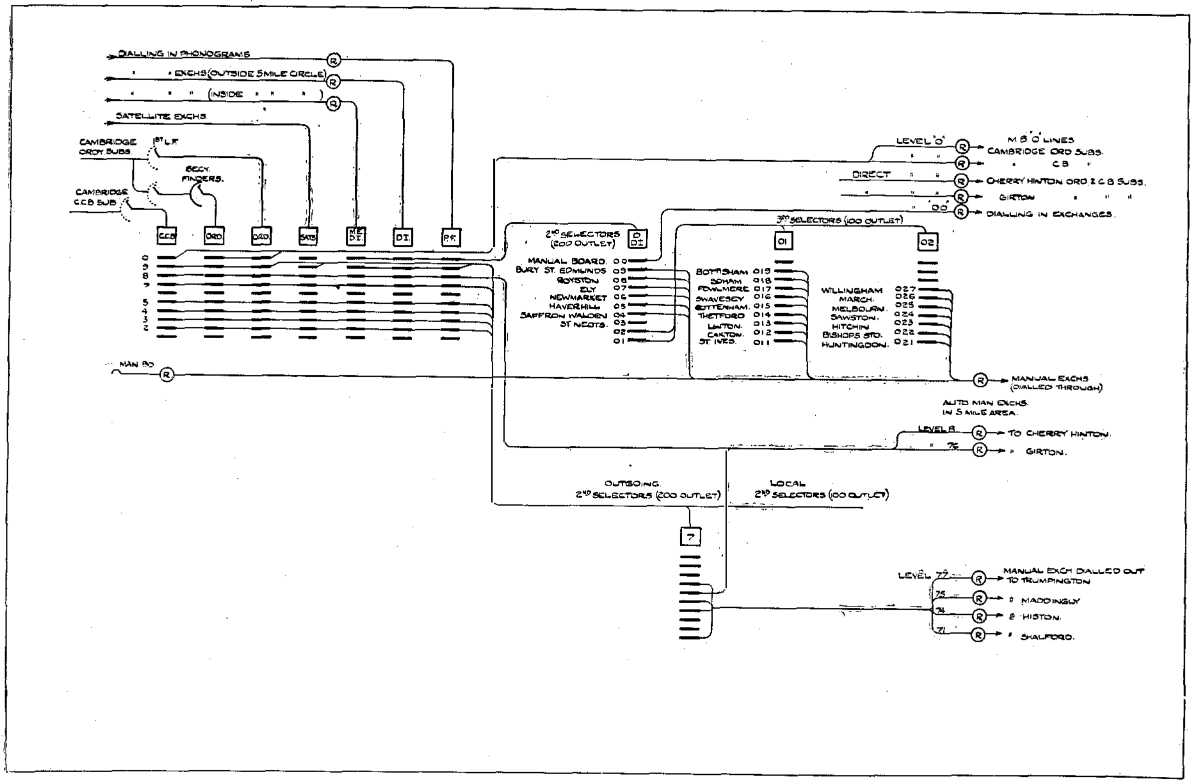

Fig. 4—Cambridge Switching Diagram Showing Toll Switches.

subscribers situated in such localities with the best possible service, which will be able to interwork smoothly and rapidly with subscribers in the cities and towns.

The standard rural boards, which have been developed to fit in the general plan of conversion to automatic, provide a number of facilities which are common to all three types. A few more elaborate facilities are restricted to the larger types only.

The U.A.X. No. 12 has an ultimate capacity of approximately 90 lines and is housed in a building with internal dimensions :

Width	7 ft. 7 in.
Length	14 ft. 0 in.
Clear Height	8 ft. 9 in.

These buildings are either of brick or stone. A slightly modified type is used in areas liable to floods and has the floor raised 2 feet above the ground level. The U.A.X. No. 12 comprises three different units. The first unit has a capacity for 25 subscribers' lines, 4 local links and 4 junction circuits. The second unit is an extension unit, catering for 20 subscribers' lines, 2 local links and 2 junction circuits. The normal procedure as the board grows is to start with one 25 line unit, to add a 20 line unit, then a 25 line unit and, finally, another 20 line unit. It is not possible to commence with a 20 line unit. The third unit accommodates the main frame, testing equipment and relay sets for common services.

The link circuit is maintained operated throughout junction calls and is accessible to the subscribers and to junctions by means of 50 point homing line finders. The junctions appear as early choices on the line finder banks and, although second dial tone is given, it is not considered necessary for operators to wait for this tone. If, on account of congestion, dialling starts before the link is available, busy tone is connected. With the earliest supplies of the U.A.X. No. 12 the old type of Strowger mechanism has been employed, but it is expected that supplies with the new type of switch will become available before very long.

It is the practice to order the initial type units with three link circuits and extension units with a single link circuit. Junction circuits are ordered separately and drawn from stock to suit the conditions of the particular installation. The junctions between the rural exchange and its parent are normally operated on a bothway basis. Because of the complexity of these circuits, there is no automatic extension of alarms. The parent exchange makes periodical calls to a test number, on which a reversed ringing tone is heard if there are no alarms operated. Absence of tone indicates failure.

The U.A.X. No. 13 is made up of 50 line units and has an ultimate capacity of 200 lines. It is housed in a building having internal dimensions as follows :

Width	10 ft. 6 in.
Length	19 ft.
Clear Height ..	8 ft. 11 in.

There are three types of units : the first carries 50 subscribers' lines, 2 finder control circuits, 8 line finder circuits, 8 selector circuits and 5 final selector circuits. The second unit carries jack-in type junction circuits. The third unit accommodates the M.D.F., testing equipment and relay sets for common services.

The U.A.X. No. 14 equipments are extensible to a capacity of 800 lines and contain the following :

A. 100 line units including 10 First Line Finders and 10 Final Selectors. Arrangements are provided for connecting 3 First Choice Finders direct to First Selectors and the remaining 7 through Secondary Uniselectors, which are mounted on this unit.

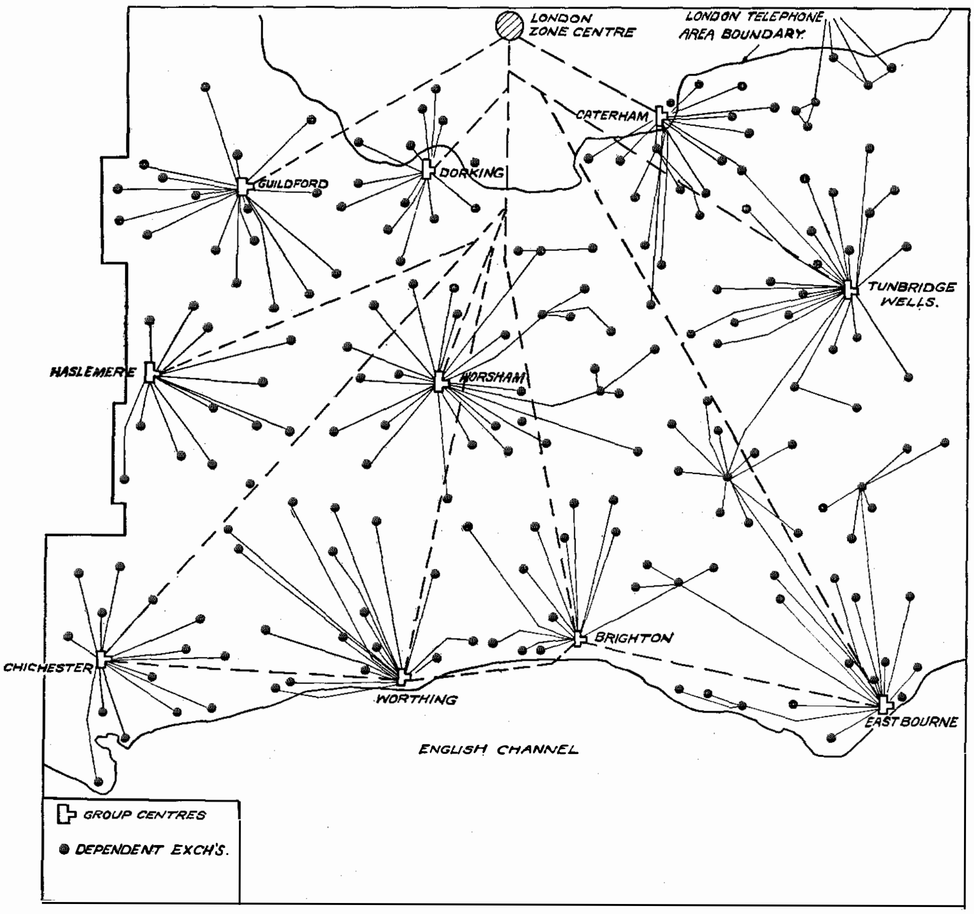

Fig. 5—Portion of the London Zone Showing all Exchanges and Typical Method of Connection to Zone Centre.

B. Selector Unit, capacity 50 First or Second Selectors.
C. Junction Apparatus Unit including multi-metering circuit for equipments in provincial areas.
D. Miscellaneous and Auxiliary Equipment Rack.
E. Route Discriminating Equipment Rack, provided only when interworking automatically with director areas.
F. Meter Rack.
G. Meter Machine and Distribution Rack.
H. Test Rack.
I. Traffic Recorder Rack.

Incoming parent exchange junctions terminate on First Selectors; other junctions terminate direct through secondary uniselectors, depending upon traffic occupancy.

Alarms are extended automatically to the parent exchange; the circuits cater for P.B.X.'s up to 20 exchange lines and service observation equipment is provided.

Both the U.A.X. Nos. 13 and 14 incorporate the new type of two-motion selector.

Traffic Facilities on Rural Boards

The U.A.X. No. 12 may not be used for tandeming traffic and is, therefore, only fitted as a terminal exchange. If a small exchange requires tandem facilities, the U.A.X. No. 13 is installed. The U.A.X.'s Nos. 12 and 13 have a 3-digit numbering scheme for local subscribers. The U.A.X. No. 14 needs 4 digits.

The district operator can be obtained by dialling the single digit "O," even if such a call has to be set up over two junctions in series. Adjacent automatic and manual exchanges are obtained by dialling a series of prefixes. As a matter of general practice, inter-exchange junctions are of two classes, with different gauge copper. The former are available for short distance calls, whereas the latter must be used for all toll and trunk connections.

To obtain long distance calls, the subscriber dials "O" and, in these circumstances, the link circuit provides the necessary facilities, such as re-ringing. If the parent operator is not the long distance operator for the area, the call is extended in such a way as to give suitable supervisory signals from the subscriber's switchhook to the controlling operator. "Manual Hold" and "Re-ring" facilities are provided at the parent exchange. On non-parent manual boards there is either "Manual Hold" or "Metering" but not both. The circuits are designed for trunk offering and completing over any parent junction. If a subscriber's line is busy, the operator receives busy tone and flash, the call is offered and the line is subsequently rung by the use of the operator's ringing key. Supervision is provided to indicate when both parties have released before ringing is connected. There is no breakdown facility and, if the call is accepted but the calling party does not clear, a toll call cannot be connected because experience has shown that the amount of malicious interference does not justify the provision of such a facility. The trunk offering circuits are also used extensively for assistance purposes, such as monitoring. The boards are designed to incorporate automatic multi-metering equipment; the prefix dialled determines the fee charged, the maximum being fourpence.

Owing to the open numbering arrangement, it is often possible to dial a much longer call, and the multiple metering equipment is used to restrict the subscriber to a fourpenny call over the prescribed channels only. By the addition of further relays, the multi-fee can be recorded every three minutes, but at the present time this fee is not collected. Coin box lines obtain single fee calls automatically, but for all multiple fee calls it is necessary to dial the operator, who supervises the connection and the class of the fee. The complete functions of the multi-metering equipment are:

(1) To connect the appropriate fee circuit for message registration.
(2) To connect N.U. Tone on a spare code, or on a call not permissible to a coin box subscriber.
(3) To connect N.U. Tone on a spare code, or on a call not permissible to an ordinary subscriber.
(4) To bring about circuit changes on a call to a non-parent manual board, introducing manual hold to an automatic subscriber but N.U. Tone to a coin box subscriber.
(5) To introduce manual hold conditions on calls from either a coin box or an ordinary subscriber.

On the U.A.X. No. 13 equipments, certain of the junction circuits are fitted with an additional uniselector, which is caused to rotate and find a free circuit to the parent operator, so that the subscriber on an indirectly connected U.A.X. can obtain access to an operator by dialling "O" once only.

On the U.A.X. No. 13 a further requirement is imposed on the multi-metering equipment, preventing unauthorized dialling on calls originated locally but permitting an operator to dial through without restriction.

With rural switching up to 15 miles, the number of repetitions becomes, in certain cases, beyond the scope of the apparatus, unless the adjustment of impulsing relays is matched to the associated junctions or other relatively close limits are imposed. It is the aim of the British Post Office to maintain impulsing relays on a mechanical adjustment basis only and, to avoid impulse repetition difficulties, it is proposed to make extensive use of regenerative impulse repeaters. These circuits can be arranged to accept impulses already slightly distorted and to re-transmit them as accurate impulses.

Fig. 5 shows a typical arrangement of rural exchanges with interconnecting circuits, and gives some idea of the future distribution of manual boards serving the rural exchanges.

The author wishes to express thanks to the Engineer-in-Chief of the British Post Office for permission to publish this article and the accompanying diagrams.

BIBLIOGRAPHY

(1) J. STRATTON and W. G. LUXTON : "Modern Developments in Telephone Transmission over Lines," *Inst. P.O.E.E. Paper No.* 153, October, 1933.
(2) S. BIRCH : "The London Trunk Centre," *P.O.E.E. Journal*, October, 1934.
(3) T. S. SKILLMAN : "Developments in Long Distance Switching," *I.E.E. Journal*, November, 1934.
(4) C. G. GRANT and E. M. COOKE : "Unit Automatic Exchange No. 12," *P.O.E.E. Journal*, July, 1935.
(5) H. S. SMITH, T. H. FLOWERS and B. M. HADFIELD : "Signalling on Trunk Circuits—Introduction of Two Frequency Working," *P.O.E.E. Journal*, April, 1936.
(6) C. G. GRANT and A. J. C. HENK : "Unit Automatic Exchange No. 13," *P.O.E.E Journal*, July, 1936.
(7) "Telephone Statistics," *Europäischer Fernsprechdienst*, October, 1936.
(8) LESLIE B. HAIGH : "Automatic Ticketing of Telephone Toll Calls," *Electrical Communication*, April, 1937.
(9) L. DEVAUX : "Automatic Printing Register for Telephone Call Recording," *Electrical Communication*, April, 1937.

The Selenium Rectifier

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DRY rectifiers operate on the same principle as crystal detectors, but their effective rectifying surface can be so increased in area that kilowatts can be handled by rectifiers as compared with milliwatts rectified by detectors. Fundamentally, all dry rectifiers are constructed on the same principles, differing only in the electrode and semi-conducting layer materials used. In this article, the dry rectifier using selenium as the semi-conducting layer is described.

CONSTRUCTION AND OPERATION OF A SELENIUM RECTIFIER DISC

The semi-conducting layer of this rectifier, as its name suggests, consists of selenium. In order to keep the internal losses of the rectifier small, the selenium is applied as the thinnest possible coating (approximately 0.05 mm). This coating is applied to one side of a roughened iron disc called the back electrode ; it is then converted by heat treatment into a metallic form and, finally, covered by a soft metal layer, which forms the front electrode (Fig. 1).

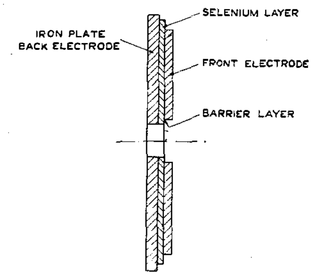


Fig. 1—*Schematic Showing Construction of Selenium Rectifier Disc.*

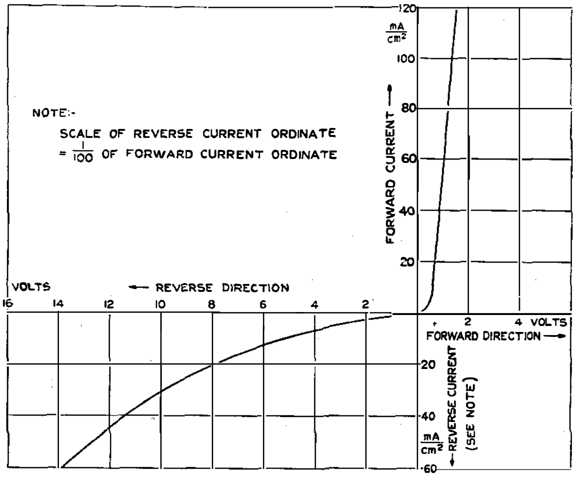


Fig. 2—*Static Characteristic of a Selenium Rectifier Disc having Effective Surface area of* 1 *cm* ².

The resistance of the rectifier is different when the selenium is positive with respect to the front electrode from that obtained when the selenium is negative, and in subsequent processes a layer between the surface of the selenium and the soft metal layer increases this difference between the resistances in the two directions. Capacity tests and the direct removal of this layer have shown its thickness to be approximately 10^{-5} cm. If the front electrode is a metal which is a good conductor and is made the cathode, an observable current flows from the

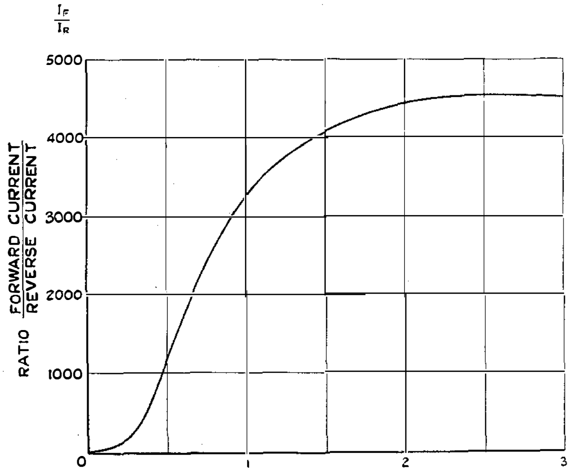


Fig. 3—*Rectification Ratio.*

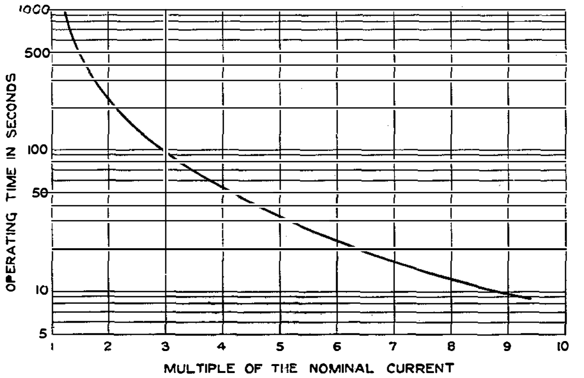


Fig. 4—Short Period Current Overload Capacity of a Selenium Rectifier.

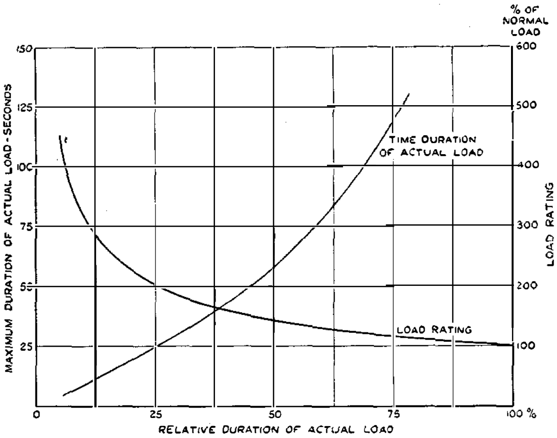


Fig. 5—Overload Rating and Operating Time for a Selenium Rectifier on Intermittent Operation.

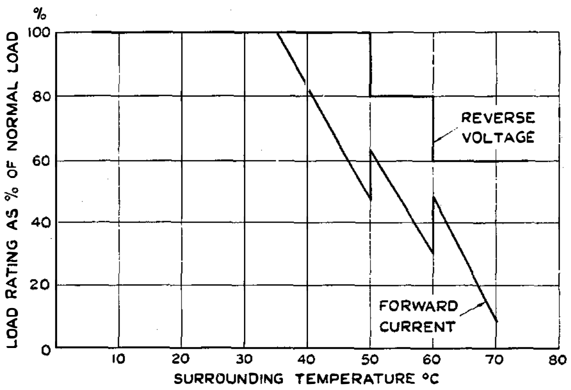


Fig. 6—Load Rating and Surrounding Temperature.

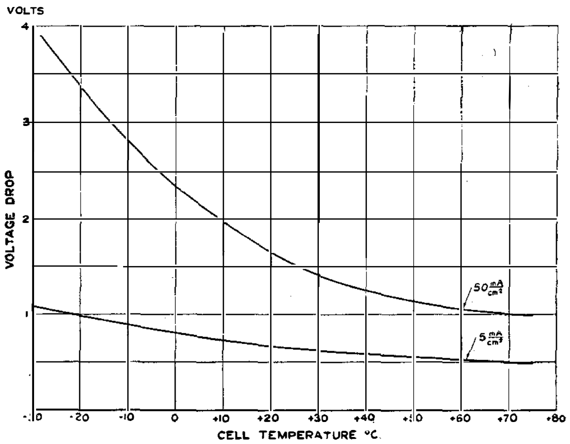


Fig. 7—Forward Voltage Drop and Cell Temperature (for full load and one-tenth full load).

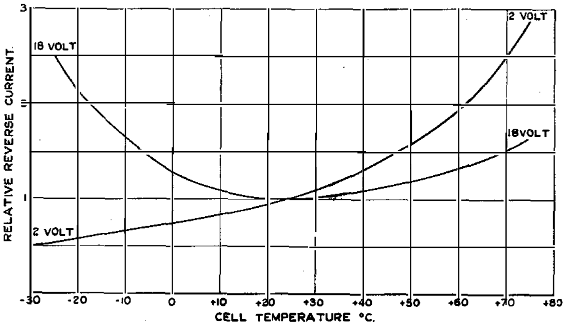


Fig. 8—Reverse Current and Cell Temperature (for normal voltage and fraction of normal voltage).

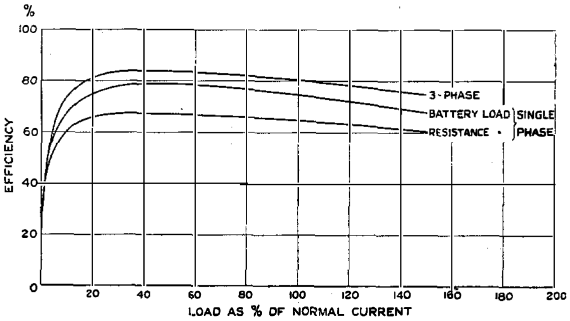


Fig. 9—Efficiency of Selenium Rectifier Operating at Full Load Voltage.

selenium to the front electrode even at fractions of a volt (forward direction), whilst in the case of reversed polarity a considerably smaller (reverse) current flows. Contrary to the case of a thermionic rectifier, in which electron emission is produced by heat, it is not necessary to allow any heating-up time for the selenium rectifier, the d.c. output being available immediately the alternating voltage is applied. There is no deterioration of the electrodes during operation, so that the life of a selenium rectifier is practically unlimited. The only change is a slight increase in the forward resistance during the first 10 000 hours of use, thus reducing the rectified d.c. voltage. This reduction may be compensated for by increasing the alternating voltage by 5%.

ELECTRICAL CHARACTERISTICS OF RECTIFIER DISCS

The Characteristic Curve

The static characteristic of a selenium rectifier disc is given in Fig. 2, in which the current values are based on an effective disc surface area of 1 cm ^{2}.

The characteristic always passes through zero, the current increasing rapidly at a forward voltage of approximately 0.3 and finally becoming almost linear. The reverse current is extremely small at corresponding voltages in the reverse direction, and it is only by employing a decreased scale that it is possible to plot the reversed current on the same sheet.

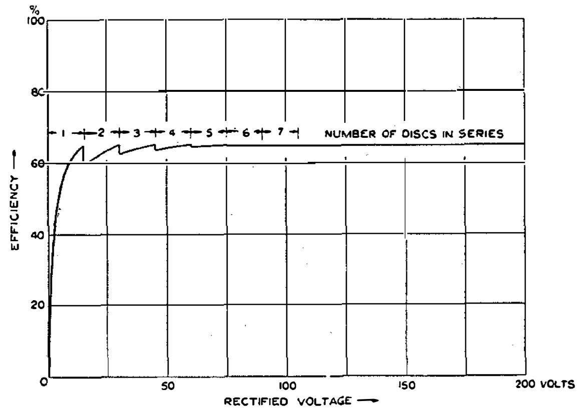
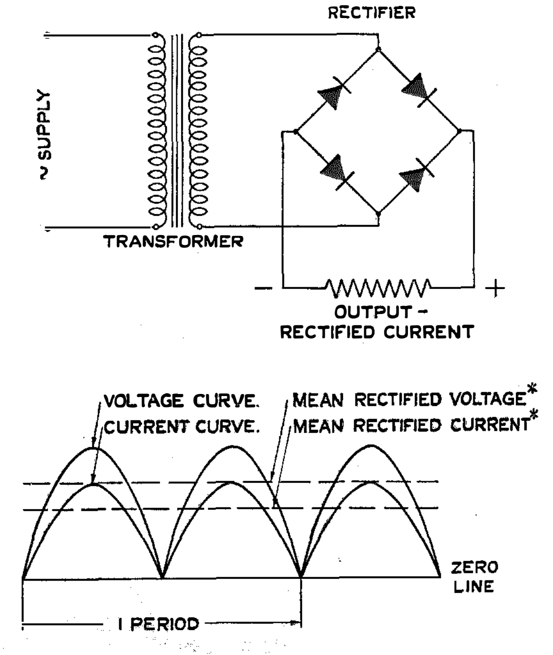


Fig. 10—*Efficiency of Selenium Rectifier as a Function of Rectified Voltage.*

The ratio of forward to reverse current for a



*MEASURED WITH MOVING COIL INSTRUMENT.

Fig. 11—*Single-Phase Bridge Circuit. Current and Voltage with Resistance Load.*

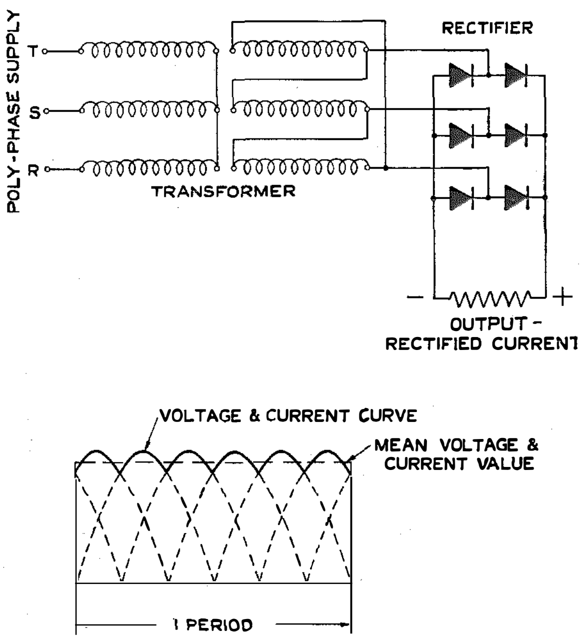


Fig. 12—*Three-Phase Bridge Circuit. Current and Voltage for all Types of Loads.*

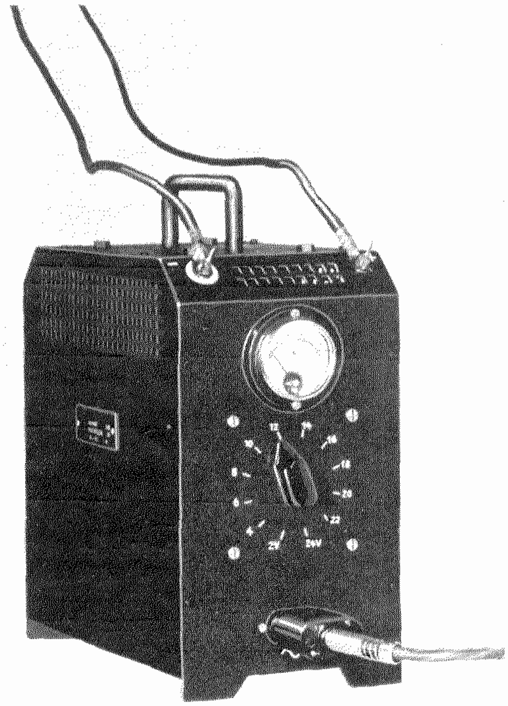


Fig. 13—*Portable Charging Equipment for Car Batteries,* 2–24 *Volts in Steps of* 2 *Volts.*

rectifier at low voltages is shown in Fig. 3. In actual operation, however, there is a large difference between the voltages across the rectifier in the forward and reverse directions, due to the voltage drop at the load. The maximum voltage in the reverse direction which may be applied to a single selenium rectifier disc is as a rule 18 volts. A current density of approximately 50 mA per cm ^{2} is allowed continuously in the forward direction, corresponding to a voltage drop of approximately 1.0 V (Fig. 2). From the same figure, the reverse current produced by a reverse voltage of 18 will be seen to be of the order of 1 mA, giving an effective ratio of 50 : 1 for the forward to reverse current under full reverse voltage and full load current conditions. At very low voltages the rectification ratio approaches unity, resulting in very inefficient operation of the rectifier.

Rating of the Selenium Rectifier

The amount of power which may be handled by a selenium rectifier disc is determined by the following factors :

Temperature rise and voltage breakdown: Limitation is imposed by the heating of the rectifier caused by its internal losses, and the final temperature produced by these losses should not exceed 75° C. The load specified for a typical rectifier is such that the temperature rise does not exceed 40° C. and normal rectifiers, therefore, are suitable for continuous operation in an ambient temperature up to 35° C. For this load, self-cooling of the rectifier elements is sufficient. The relationship of the disc spacing to the disc diameter in a rectifier assembly is such that, for the spacing used, optimum cooling is obtained. The current which may be carried by a rectifier disc is only limited by its maximum temperature. This current may be considerably increased by the provision of better cooling, such as the use of ventilation or by the addition of cooling fins or by increased spacing between discs. As the internal losses of an overloaded rectifier are considerably increased, such operation is only

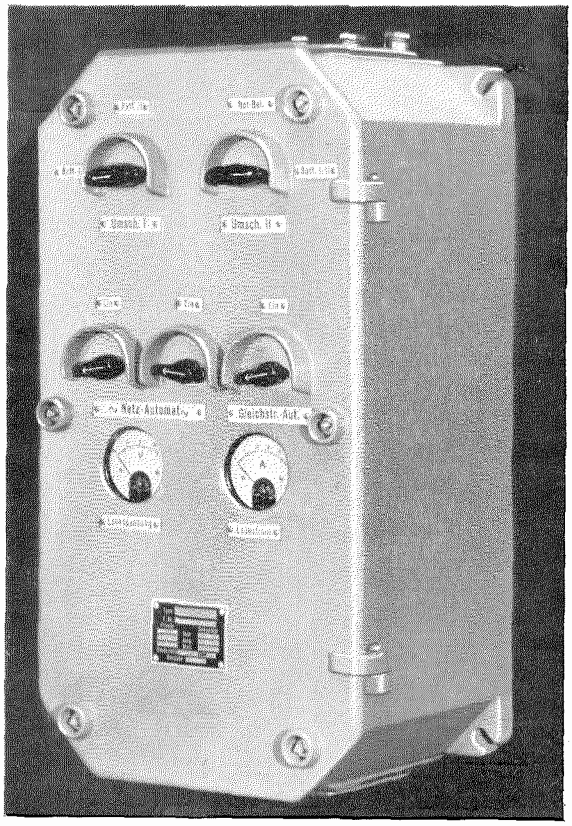


Fig. 14—*Battery Charging Equipment in Water-tight Container. Direct Current Output* 28 *V,* 15 *A.*

advantageous if low price, reduced space and weight can compensate for increased operating costs.

The voltage which may be applied to a selenium rectifier disc is limited by: the breakdown strength of the blocking layer, and the heating produced by the reverse current.

The breakdown strength is constant for every type of disc, and it is not permissible to apply any considerable excess voltage even for a time interval so short that no appreciable heating (due to increased reverse current) takes place. The test voltage applied to the discs is sufficiently above the normal operating voltage to take care of supply voltage variations.

Intermittent Operation and Overloads

Since the current output from a selenium rectifier is not limited by emissive power but only by maximum temperature, a rectifier which is initally cold can be loaded to many times its normal carrying current for a short time. It is only necessary that the load, when the maximum temperature is reached, should be decreased to the normal value. Fig. 4 shows the relation between the operating time and load rating for a temperature rise of 40° C.

The current overload capacity indicated in Fig. 4 as a function of the operating time applies only to cases where the interval (at least half an hour) between each operation is sufficient to allow for the cooling of the rectifier. For short cooling periods, the curves of Fig. 5 apply. One curve shows the relation between percentage operating time and permissible overload of the rectifier ; the other, the corresponding maximum operating time in seconds.

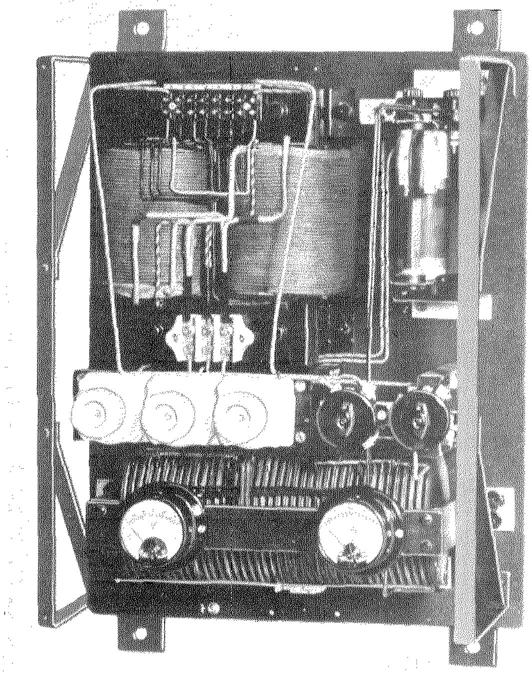


Fig. 16—*Equipment for Charging or Floating a* 20-*Cell Lead Battery. Adjustable from* 4.5 *to* 7 *A, Open.*

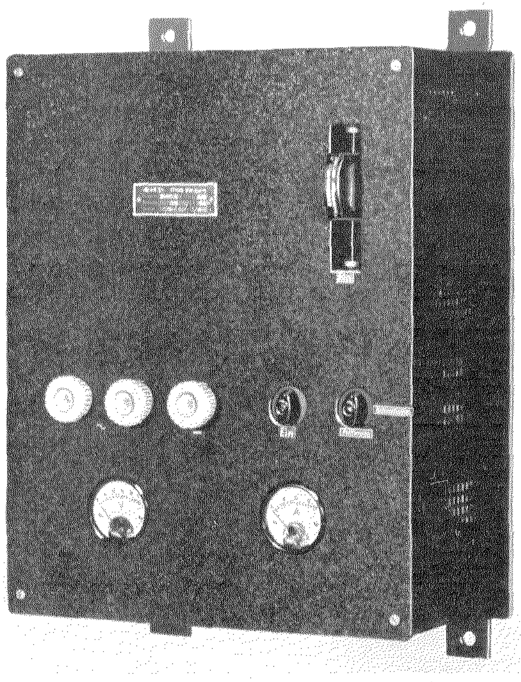


Fig. 15—*Equipment for Charging or Floating a* 20-*Cell Lead Battery. Adjustable from* 4.5 *to* 7 *A.*

Ratings for Increased Room Temperature

The high operating temperature of the selenium rectifier enables it to be used in any surroundings with temperatures below 75° C. In room temperatures above 35° C., the power handled by the rectifier must be reduced so as to decrease internal losses to a value such that the temperature rise of the rectifier does not exceed the difference between 75° C. and room temperature. Since the rectifier losses comprise forward and reverse current losses, both the current and voltage requirements of the rectifier should be decreased in accordance with Fig. 6.

Temperature Coefficient of the Rectifier Resistance

The forward resistance of a selenium rectifier falls with increasing temperature. Fig. 7 shows the shape of the forward voltage drop for the range of −30° C. to +75° C. When a calculation is made from this curve, it should be noted that the rectifier resistance is only about 10 per cent. of the total resistance in the circuit; and, therefore, the change in the rectifier voltage drop is only a negligible percentage of the value of the direct voltage. Further, the negative temperature coefficient of the rectifier resistance is largely balanced by the positive temperature coefficient of the transformer resistance. The variation of the reverse resistance for the same range of temperature is given in Fig. 8. In order to show this more clearly, the values of the reverse current at the different reverse voltages have been taken as equal to unity at a rectifier temperature of 25° C. The actual values of the reverse current may be calculated from Fig. 2.

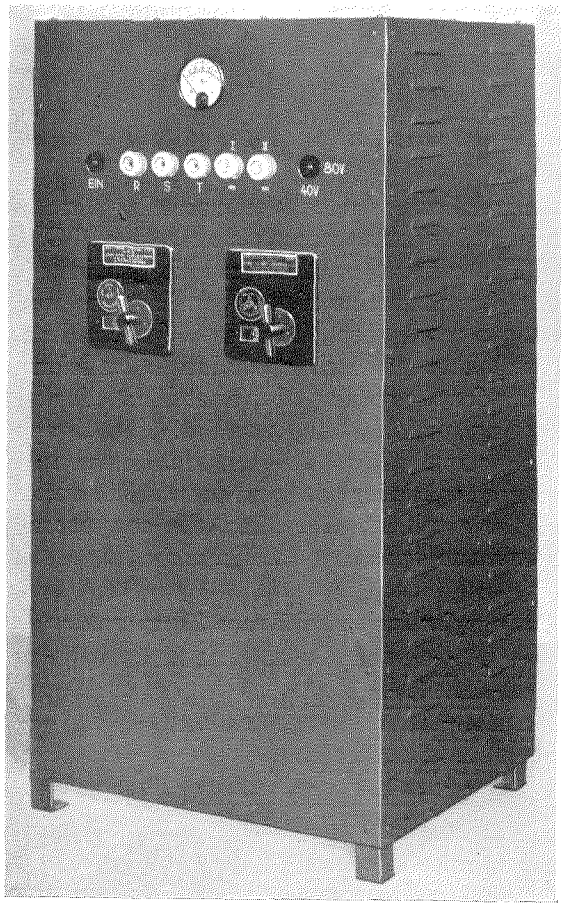


Fig. 17—Charging Equipment for 2 Batteries which can be Switched over from 40 V, 48 A to 80 V, 24 A.

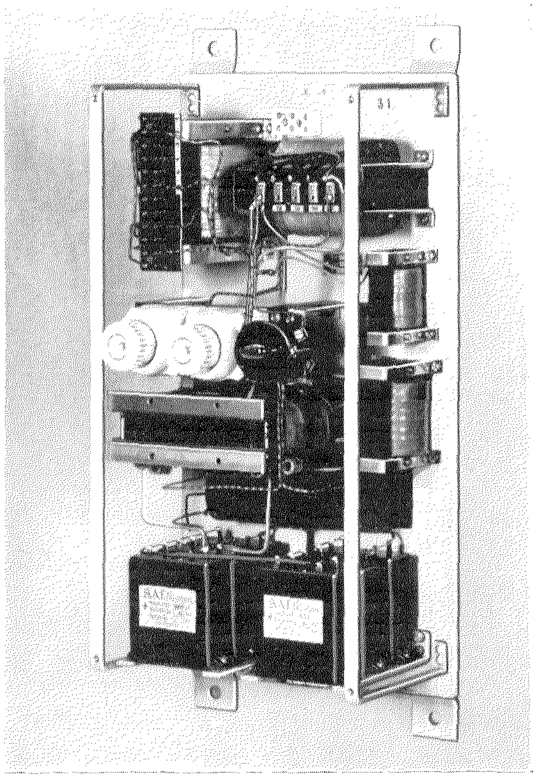


Fig. 18—Equipment for Direct Operation of a Telephone Exchange (open). Direct Current Output 24 V, 2.4 A. Equipped with Filter Network and Voltage Compensation Choke.

These curves show that, even at low temperatures, the selenium rectifier continues to be effective although its efficiency decreases.

Efficiency of a Complete Rectifier

The efficiency of a rectifier can be defined in various ways. One way is to consider the efficiency as the ratio of the output of the rectifier in watts to the input in watts, or about 85% for a fully loaded rectifier. This value applies for all sizes of discs, types of loads and rectifier circuit arrangements; it follows from the fact that the cooling factor for all sizes of discs is the same, and the permissible loads for the different circuit arrangements are fixed so that the same final temperature is reached.

With constant reverse voltage, the efficiency remains constant from full load down to about 20% of the rated load, further reductions in the load current resulting in a rapid drop in efficiency.

The definition of efficiency given above is one of general application, but is not usually applied in the case of rectifiers. The use of a wattmeter on the direct current side of a rectifier does not indicate the actual d.c. voltage ; furthermore, in the case of rectified current, it is usually the arithmetical mean value of the output which is of interest and not the R.M.S. value. Accordingly, the definition of rectifier efficiency usually given is : the relationship between the product of the d.c. voltage and d.c. current, measured with moving coil instruments, and the power consumed on the alternating current side, measured with a wattmeter.

In this definition, the efficiency also depends on the waveform of the direct current and voltage, and therefore at full load the efficiency will vary with the type of circuit and load. Fig. 9 shows the efficiency (defined in this way) as a function of the current consumption for a rectifier operating at full load voltage. Fig. 10, in contrast thereto, shows the efficiency as a function of the rectified voltage at full load current for a single-phase bridge with a resistance load. Under conditions of continuously increasing operating voltages with irregular additions of discs (and consequently greater internal losses), the efficiency curve tends to fluctuate, especially at low voltages. At higher voltages the addition of an extra disc does not make any appreciable change in the resistance already present, so that the efficiency remains practically constant. Thus the efficiency of a selenium rectifier at normal operating voltages is independent of its size, since the number of discs, and in consequence the loss in the rectifier, are proportional to the output.

Element Design

Having determined the direct current output required, a suitable rectifier circuit arrangement must first be chosen. Figs. 11 and 12 show a single-phase full wave bridge circuit and a corresponding three-phase circuit. The three-phase circuit has the advantages of balance load on the supply network, higher efficiency and smaller ripple component in the output, as compared with the single-phase rectifier. A disadvantage in the case of the three-phase rectifier is the higher cost of the additional switchgear required.

When the circuit arrangement has been decided on, then the disc area necessary to obtain the required direct current must be determined. It is chosen so that the current density in the individual branches of the rectifier approaches as nearly as possible a value of 50 mA, effective per cm ^{2}. For this purpose, discs are available in areas ranging from 1 mm ^{2} to 80 cm ^{2}.

After the area of the rectifier discs has been

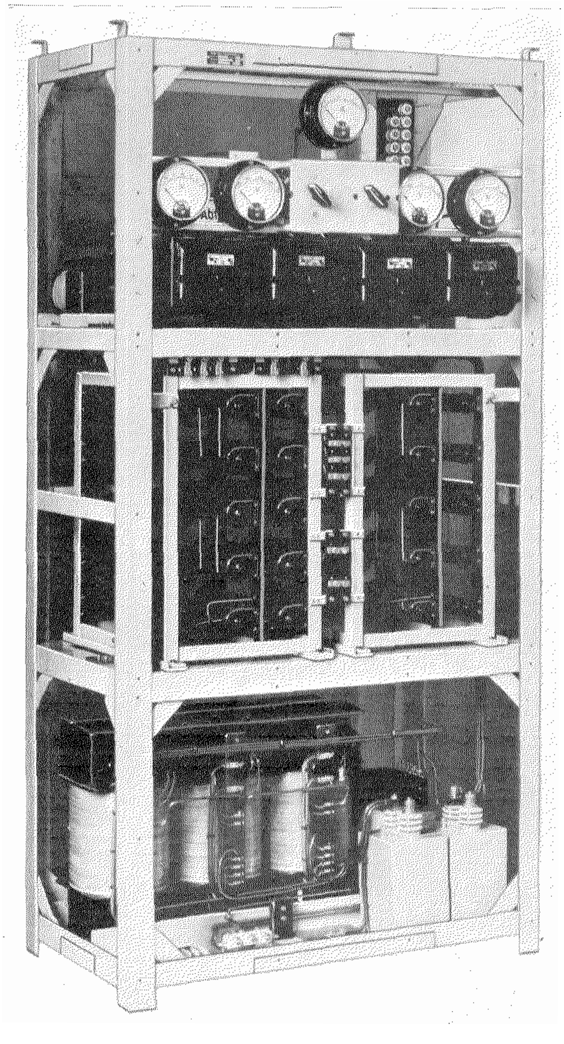


Fig. 19—Radio Transmitter Supply Equipment (open) for Direct Current Output of 3 000 *V,* 1 *A ;* 50 *V,* 0.5 *A ;* 80 *V,* 35 *A.*

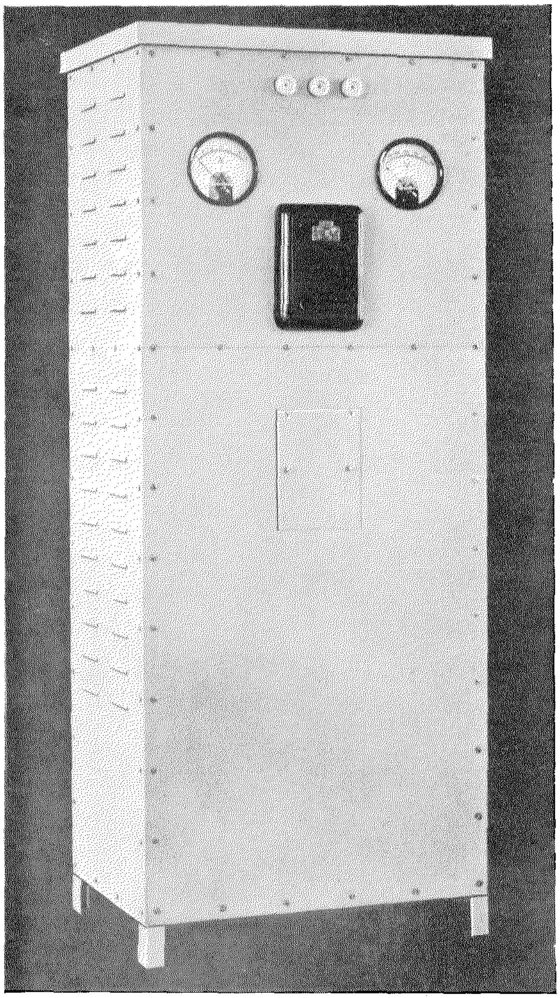


Fig. 20—Radio Transmitter Supply Equipment for Direct Current Output of 1 200 *V,* 1.5 A. *Damp-proof, for* 50° C. *Room Temperature.*

obtained in accordance with the desired current density, the alternating voltage required to produce the direct voltage can be determined. Assuming a rectifier which is free from loss, also a sinusoidal voltage, the ratio between the arithmetical mean value of the rectified voltage and the R.M.S. value of the same voltage prior to rectification is calculated. The voltage is corrected for the actual rectifier drop to be expected. When the alternating voltage actually required is known, the number of discs to be connected in series in each branch of the rectifier can readily be determined.

If the rectifier operates with either a battery or a condenser load (in which a reverse e.m.f. is produced), it must be remembered that the voltage at the d.c. output terminals of the ideal rectifier is no longer of pulsating sinusoidal form, but rises to a value approximately equal to the peak value of the alternating voltage, depending on the amount of smoothing. With constant effective current, the peak value of the forward current which flows through the rectifier and also the voltage drop in the rectifier are greater.

The necessary corrections resulting from high room temperature, unfavourable mounting, short time operation, etc., are now applied to the rectifier design data.

FIELD OF APPLICATION OF SELENIUM RECTIFIERS

Selenium rectifiers were first used for charging accumulators. In charging equipment of this kind, with a suitable size of series load resistance (or preferably a choke in the case of larger outputs), it is possible to secure automatic tapering of the charging current to any desired final value. After charging has been completed, the battery and charging equipment can be separated by means of switches or the apparatus can be automatically switched over to a second battery (Figs. 13–17). If a voltage compensation choke, which is saturated by the direct current, is connected in the alternating current side of a floating battery equipment, an automatic charging current control is produced, thus giving a minimum amount of fluctuation in the battery voltage.

The next field of application of the selenium rectifier was the supply of direct current from a.c. mains without the intermediate connection of a battery. In many cases, special smoothing for the voltage when supplied to equipments including electric motors, inductive loads of many kinds, such as lifting magnets, magnetic brakes, relay operation and switching systems, is not required.

Where the rectifier is used to supply voltages to any electro-acoustic system, it is necessary to reduce the residual ripple of the direct voltage to a low value by means of filters in order to avoid the production of interfering humming noises. Fields of this type of selenium rectifier application are direct feed to telephone exchanges, the supply of filament and anode current to radio transmitting and receiving equipment, public address amplifiers, etc. (Figs. 18–20). Where constant voltage is required with fluctuating load, a voltage compensating choke may be introduced as previously described.

Dry rectifiers to a large extent furnish the current supply to electro-plating systems. Their application in this field affords the great advantage of operating at constant efficiency down to a fraction of their nominal output current.

When welding with rectified current, the advantages of the welding transformer are added to the superiority of a direct current weld.

In addition to the normal alternating current uses, selenium rectifiers are employed in numerous ways as unilateral elements in order to prevent current flowing with reversed polarity in direct current circuits.

Selenium rectifiers in high frequency technique are used not only as detectors, but also in circuits where a resistance-voltage characteristic is required. They may also be used as spark quenchers for inductive circuits. The selenium instrument rectifier, in conjunction with moving coil instruments, permits the measurement of alternating current energy up to the highest frequencies.

The selenium rectifier as a converter has penetrated into practically every field of application of d.c. voltages. Moreover, its use has not been confined to those fields in which its cost, or efficiency, gives it an advantage over other direct current producers. Other considerations often have been controlling. Advantages, such as unlimited life, constant readiness for operation, mechanical strength, quietness and the lack of any need of maintenance, on close examination, have shown that the selenium rectifier is economically applicable for many purposes.

Dry Rectifiers for Repeater Station Power Supply

By **H. JACOT**, Ing. Dipl. E.P.F.,
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and
M. FREY, Ing. Dipl. E.P.F.,
Bell Telephone Manufacturing Company, Berne

AS A RESULT of the growth of Swiss repeater stations, the consumption of filament current has increased very considerably. By replacing a large number of the 1 ampere triodes by low consumption triodes ($\frac{1}{4}$ ampere), the Swiss Telegraph and Telephone Administration in some cases was able to avoid the extension of batteries or their replacement by batteries of larger capacities. In a great many other cases the Administration finally adopted a scheme whereby the power supply can be taken directly from the mains, a solution which yields the maximum number of advantages.

The simple extension or the replacement of an existing battery by an increased capacity installation would have given rise to difficulties because of lack of space. Moreover, even with the continued use of batteries, the introduction of $\frac{1}{4}$ ampere valves and the stricter stipulations of the C.C.I.F. relative to gain constancy of repeaters would have required closer regulation of the voltage at the filament busbars. As in Switzerland the filament battery used for the repeater station is nearly always the same as that which supplies the automatic and toll central exchanges where strict regulation of the voltage is superfluous, it was found

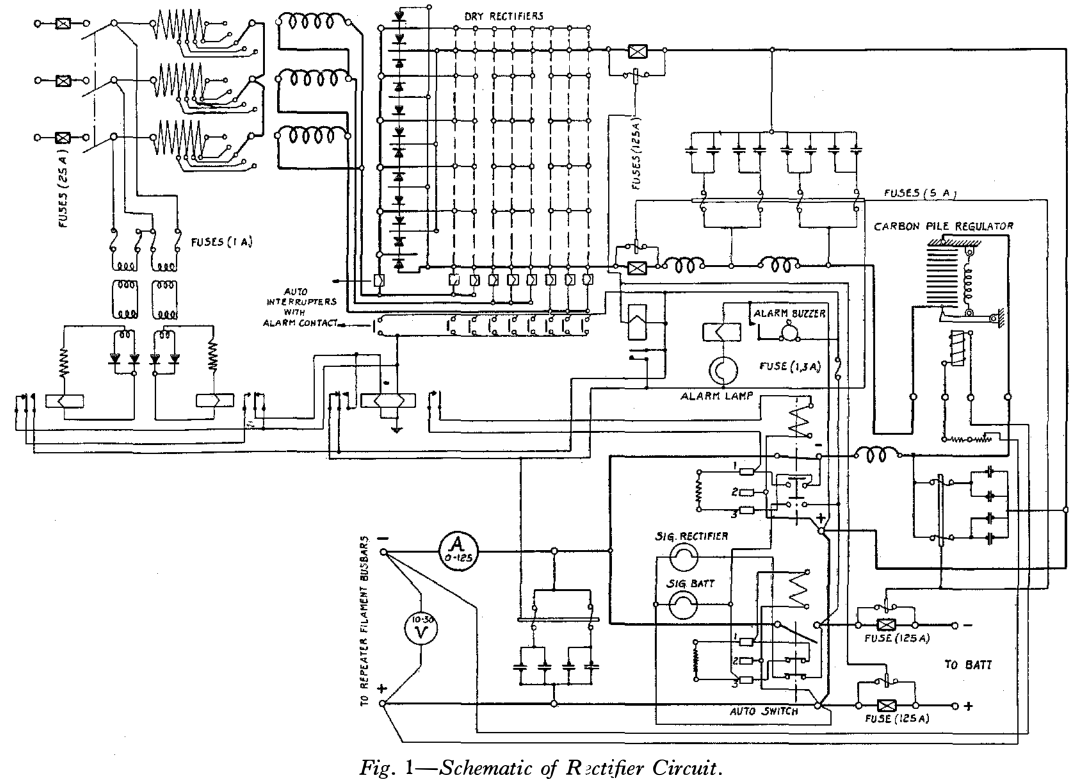

Fig. 1—Schematic of Rectifier Circuit.

preferable to use these batteries for repeaters only in case of emergency.

The Administration has adopted a flexible solution enabling the direct supply to the repeaters from a.c. mains through a rectifier supplied with a voltage regulator. In the event of a breakdown in the system, an automatic device transfers the repeaters to the toll battery.

The solution adopted for the anode voltage is similar. The battery which originally supplied the anodes is kept as a reserve to provide for breakdowns in the network.

The many advantages of this solution are evident: the supply equipment is of small dimensions and relatively light; and, since it does not include any movable member which might give rise to vibrations, it may be placed in the repeater room itself. Thus cabling is reduced to a minimum and supervision greatly facilitated. The carbon pile regulator used enables the regulation of the voltage between very narrow limits, whilst permitting of an efficiency which is satisfactory for this type of work. Finally, maintenance is reduced to an almost negligible quantity so that very great economy is achieved in comparison with battery operation.

FILAMENT RECTIFIERS

Conditions to be Fulfilled

The rectifier must function entirely automatically and without requiring any routine maintenance. The supply to the repeater station must be made direct from the mains by the rectifier and associated equipment, whilst fulfilling the following important conditions: voltage variation not more than ± 0.2 V for mains voltage fluctuations of ± 10 per cent. and for load fluctuations of ¼ to full load. If the a.c. power supply breaks down, the load of the station should be immediately and automatically transferred to a reserve battery. (The toll or automatic exchange battery can be used as the reserve battery.) The interfering voltage at the output of the rectifier must be maintained within such limits that the psophometric potential tested at the output of a repeater will not exceed 200 microvolts, irrespective of the type of repeater.* Cross-talk emanating from the feed circuit should not exceed the values previously obtained with battery supply.

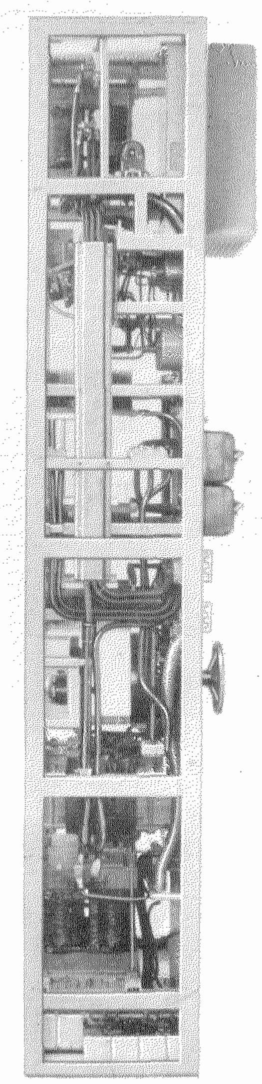

Fig. 2—100 *Ampere Filament Rectifier Bay—Side View.*

Fundamental Circuit Arrangement

The Graetz three-phase arrangement is used for the rectifier elements. Compared with a single-phase arrangement, it presents the advantage that the higher frequency of the

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* " Noise Limits in Long International Circuits," by John Collard, *Electrical Communication,* October, 1934.

residual voltage ripple at the output of the rectifier elements (300 p : s) makes filtering easier. Further, the industrial network at a reduced tariff is three-phase.

The fundamental circuit diagram (Fig. 1) shows clearly how the rectifier functions.

The different rectifier elements are protected by individual cut-outs. These cut-outs have automatically retarded thermal releases and instantaneous magnetic releases. They protect the rectifier against any sustained small excess load or breakdown of an element. The fuses are connected to the general alarm circuit in a manner such that the attendant is immediately informed of any breakdown which might arise. The primary of the transformer connected to the alternating three-phase network has five taps, which can be selected by means of a manual switch, in order to compensate for any increase in internal resistance of the rectifier elements due to ageing. Adjustment is made from time to time, as required. Immediately following the rectifier, a filter serves to reduce the ripple voltage below the maximum permissible value. The electrolytic condensers of the filter are protected by fuses. A voltage regulator of the compressed carbon ring type is inserted in the filter circuit.

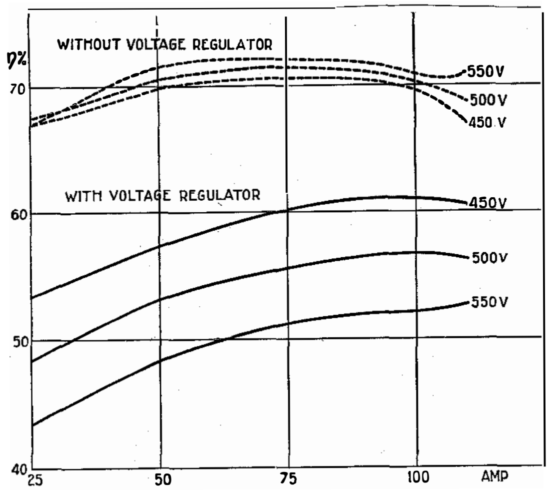

Fig. 3—Efficiency of Rectifiers, 500 *V* Δ 23 *V,* 100 *A.*

An automatic change-over switch immediately connects the discharge circuit to the reserve battery in the event of a mains breakdown.

All the principal fuses are supplied with alarm devices. Further, a special alarm is arranged on each phase of the three-phase network in a manner such that when only one fuse breaks down, the discharge circuit is automatically connected to the reserve battery. Thus the rectifier is prevented from functioning on only two phases.

A voltmeter and an ammeter complete the circuit. There are three indicator lamps : the first indicates that the rectifier is properly in circuit ; the second, that the mains are disconnected and that the discharge circuit is connected to the reserve battery ; and the third, that a fuse has blown.

EQUIPMENT

Two types of rectifiers, employing selenium rectifier elements, have been produced, one for large stations and the other for medium stations. The first is for a maximum load current of 100 amperes ; the second, for a maximum load current of 50 amperes. Since these rectifiers are intended for direct feeding of the repeater stations, the equipment has been mounted in cubicles having the width and height (540 and 2 740 mm, respectively) of the standard repeater bays normally used in Switzerland. When the depth (450 mm) of the rectifier cubicles permits, they can be placed in line with the repeaters beside the fuse bays, thus making connections between the rectifiers and fuses of minimum length. The weight of the 100 ampere type is approximately 900 kg and that of the 50 ampere, approximately 530 kg.

Fig. 2 shows the arrangement of the apparatus in a 100 A rectifier unit. The electrolytic condensers are placed at the bottom away from the heat generated by the rectifiers ; immediately above them are two of the choke coils of the filter, also the transformer. The groups of rectifier elements are mounted so that they can be readily replaced. At the top of the unit is mounted the voltage regulator and the third choke coil of the filter ; adjacent thereto are the terminal strips to which the cables to the fuse bays and the reserve batteries are connected. The associated fuses, indicator lamps, voltmeter and ammeter are mounted on the front panel. The automatic change-over switch panel is mounted directly above the rectifiers.

RESULTS OF TESTS

Very accurate tests were made on the rectifiers. The output of the rectifier was determined, with and without the voltage regulator, for various mains voltages and loads. From Fig. 3 it will be seen that, in the case of the rectifier complete with regulator, the efficiency lies between 43.5 per cent. and 60 per cent. according to the mains voltage and the load current. It is natural that for a mains voltage of + 10 per cent. the efficiency is lowest, the voltage regulator coverting the superfluous power into heat. By way of comparison, the efficiency measured in two repeater stations supplied by batteries varied between 44 per cent. and 55 per cent. The first figure relates to a battery operating essentially on a charge-discharge routine, whilst the second figure relates to a floating battery. Due to the voltage regulator associated with the rectifier, the voltage variation at the busbars is limited to ±0.2 V. In old installations, making use of batteries, the voltage was constant only within about ±0.5 V.

With the rectifier and regulator, the ripple voltage measured directly at the terminal bars with a maximum load current was 0.02 mV. The psophometric voltage at the output of a two-wire test repeater supplied by the rectifier was found to be very small. Preliminary tests enabled the determination of the psophometric voltage at the output of the different types of repeater to be measured as a function of the ripple voltage for every harmonic of the supply frequency. These curves show that the psophometric voltage at the output of the two-wire repeater was 0.3 microvolts.

The above results were obtained on repeaters in the laboratory. In a repeater station conditions are slightly different since other factors intervene. By way of information, the psophometric voltages tested at the Zurich Repeater Station with rectifier supply are given :

	Supply through Rectifier
Broadcasting Amplifiers	0.04 mV
4-wire Repeaters . .	0.10 mV

In this particular case the rectifier was found to give better results from the point of view of noise than the old battery installation. The latter, however, also supplied the toll and automatic systems. These results are confirmed by tests made in other repeater stations under similar conditions.

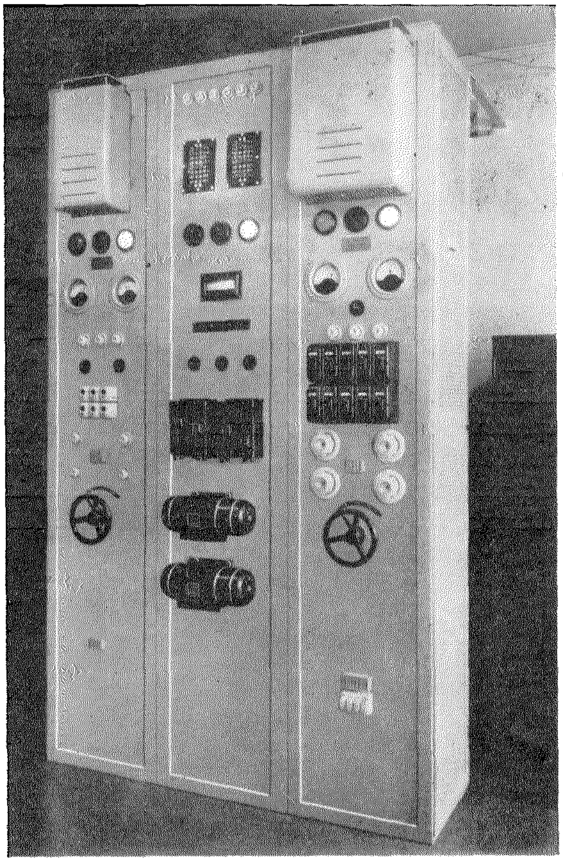

Fig. 4—Rectifier Equipment—Zurich Repeater Station.

As regards crosstalk : it was found from tests made on repeaters of the same type (4-wire repeaters) in various repeater stations, supplied by a battery or by a rectifier, that the crosstalk values obtained in stations supplied by a rectifier are not greater than those in stations with battery supply.

RESULTS OF FIELD OPERATION

For more than a year, six 23 V, 100 A rectifiers have been in operation day and night in four of the Swiss T.T. Administration's repeater stations without any breakdown or maintenance. The station voltage can be regulated to the desired value and is quite constant due to the carbon pile regulator. The C.C.I.F. recommendations regarding sources of power supply for repeaters on long international circuits are entirely fulfilled.

In all the Swiss repeater stations where a rectifier for the supply of the filament circuits has thus far been installed, the transmission testing apparatus (type 74006-N, etc.) is also similarly supplied. No special precautionary measures have been taken, but entirely satisfactory operating results have been obtained. The plate circuits, however, are still fed from batteries.

ANODE CURRENT RECTIFIER

This rectifier is identical in principle to the filament current rectifier. Its circuit arrangement is similar and it is also arranged in a cubicle which can be placed in line with the repeater bays. A carbon pile regulator keeps the voltage constant at 130 V ±2 V for load fluctuations of $\frac{1}{4}$ full load to full load and mains voltage variations of ±10 per cent. The load is transferred automatically to a reserve battery in case of mains failure.

The psophometric voltage produced at the output of the repeaters is negligible. (The values shown above for the Zurich Station broadcasting amplifiers and four-wire repeaters were measured with both filament rectifiers and anode rectifiers in operation.)

The efficiency of the anode rectifier as a function of the load current and mains voltage is of the same order as the filament rectifier.

Fig. 4 shows the arrangement of the 23 V and 130 V rectifiers in the four-wire repeater room at Zurich: the bay on the left is the rectifier for the anode current and that on the right, the rectifier for the filament current; the middle bay serves for supplying the 500/20 p:s ringing current.

A number of these filament and anode current selenium rectifiers are already in service in Swiss repeater stations. They are being manufactured by Standard Telephon & Radio, S.A., Zurich, an associate Company of the Bell Telephone Manufacturing Company and of the International Standard Electric Corporation.

A Million-Cycle Telephone System*

By M. E. STRIEBY,

Bell Telephone Laboratories

ABOUT two years ago a new wide-band system for multi-channel telephone transmission over coaxial cables was described.[1] An experimental system has now been installed between New York and Philadelphia. The various tests and trials which are planned for this system have not been carried far enough to justify a formal technical paper. Meanwhile, the considerable interest that has been aroused in the system has led to this brief statement of its principal features and its general technical performance as so far measured.

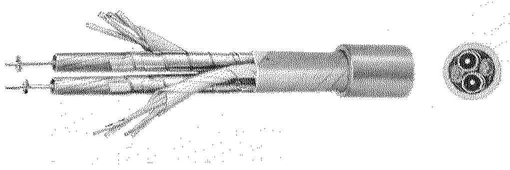

Fig. 1—View Showing Structure of Coaxial Cable.

The coaxial cable itself has been installed between the long distance telephone buildings in New York and Philadelphia, a distance of 94.5 miles. It has been equipped with repeaters, at intervals of about 10 miles, capable of handling a frequency band of about 1 000 000 cycles.

This million-cycle system is designed to handle 240 simultaneous two-way telephone conversations. Only a part of the terminal apparatus has been installed, sufficient in this case to enable adequate tests to be made of the performance of the entire system. A general view of the New York terminal is shown in Fig. 2. Some preliminary test conversations have been held over the system, both in its normal arrangement for providing New York-Philadelphia circuits, and with certain special arrangements whereby the circuit is looped back and forth many times to provide an approximate equivalent of a very long cable circuit. The performance has been up to expectations, and no important technical difficulties have arisen to cast doubt upon the future usefulness of such systems. Much work remains to be done, however, before coaxial systems suitable for general commercial service can be produced.

The Coaxial Cable

Figure 1 shows a photograph of the particular cable used in this installation. It contains two coaxial units, each having a 0.265-inch inside diameter, together with four pairs of 19-gauge paper insulated wires, the whole enclosed in a lead sheath of $\frac{7}{8}$ inch outside diameter. The

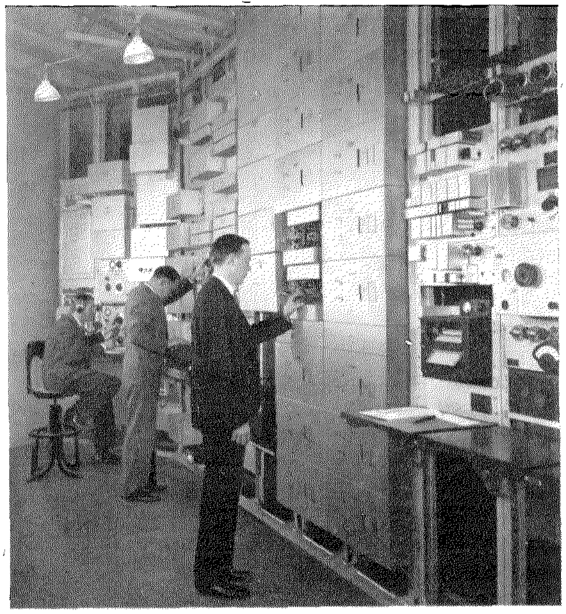

Fig. 2—The New York Terminal of the Coaxial System.

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* Republished by permission from *Electrical Engineering*, January, 1937, and *Bell System Technical Journal*, January, 1937.

[1] "Systems for Wide-Band Transmission Over Coaxial Lines," by L. Espenschied and M. E. Strieby, *Bell Sys. Tech. Jour.*, October, 1934; *Elec. Engg.* (*A. I. E. E. Transactions*), Vol. 53, 1934, pages 1371–80.

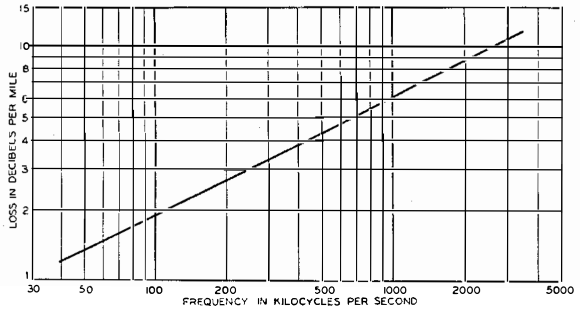

Fig. 3—Attenuation of the Coaxial Conductor.

central conductor of the coaxial units is a 13-gauge copper wire insulated with hard rubber discs at intervals of $\frac{3}{4}$ inch. The outer conductor is made up of nine overlapping copper tapes which form a tube 0.02-inch thick; this is held together with a double wrapping of iron tape.

The transmission losses of this coaxial conductor at various frequencies are shown in Fig. 3. This attenuation is about 4 per cent. higher than is calculated for a solid tube of the same dimensions and material. Another matter of importance is the shielding obtained from one conductor to the other or to outside interference. Inasmuch as the most severe requirement is that of crosstalk from one coaxial unit to another, this has been used as a criterion of design. Figure 4 shows the average measured high-frequency crosstalk in this particular cable on a 10-mile length without repeaters, both near-end and far-end.

Repeaters

The amplifiers used in this system were designed for a 10.5 mile spacing and a frequency range of 60 to 1 024 kc. A total of 10 complete two-way repeaters has been provided including those at the terminals. Two of the intermediate repeaters are at existing repeater stations along the route, the other six being at unattended locations along the line. Four of these are in existing manholes, while the other two are placed above ground for a test of such operation. Figure 5 shows a manhole repeater with the cover removed for routine replacement of vacuum tubes. Figure 6 shows one of the installations above ground.

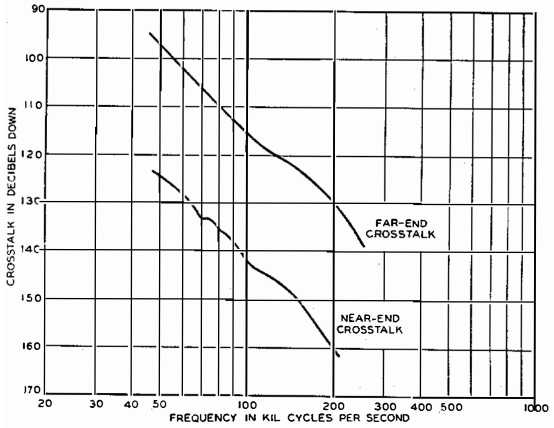

Fig. 4—Crosstalk between the Two Coaxial Conductors in the New Cable.

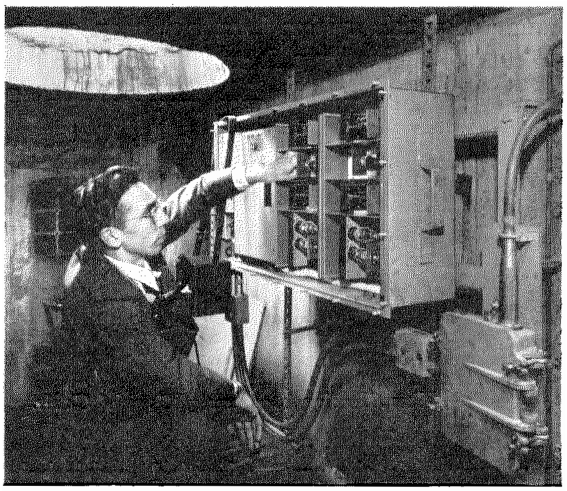

Fig. 5—Million-cycle Repeater Mounted in a Manhole.

The measured gain of a typical repeater is shown by the points on the curve of Fig. 7. The curve itself is the line loss that the repeater is designed to compensate. Three stages of pentodes are used with negative feedback[2] around the last two stages. Attenuation changes due to temperature of the line are compensated automatically by a pilot channel device which has been installed at every second or third repeater. The regulating mechanism uses four small tubes and is added to the normal repeater when desired. The amplifiers shown in Figs. 5 and 6 are regulating. As the cable is underground, the temperature changes are very slow and but meagre data on the accuracy of compensation are yet available.

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[2] "Stabilised Feedback Amplifiers," by H. S. Black, *Bell Sys. Tech. Jour.*, January, 1934.

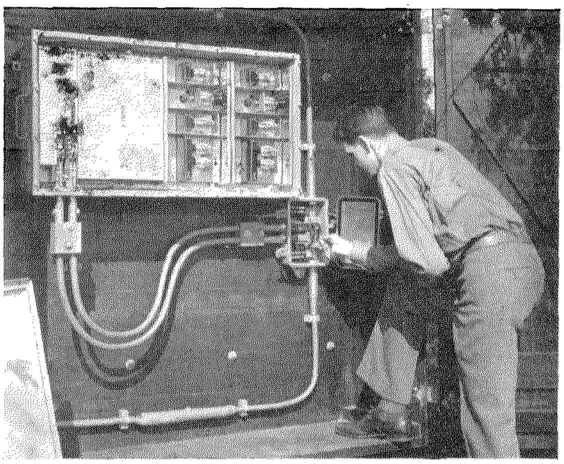

Fig. 6—Installation of Coaxial Repeater above Ground.

Terminals

A schematic diagram of the terminal arrangements for a 240-channel million-cycle system is shown on Fig. 9. In this installation the New York and Philadelphia terminals have each been equipped to handle only 36 two-way telephone conversations. As has been pointed out, the scheme employed involves two steps of modulation, the first of which is used to set up a 12-channel group in the frequency range from 60 to 108 kc. Three such groups have been provided in this installation. In order to transmit at the higher frequencies, a second step of modulation is used in which an entire 12-channel group is moved to the desired frequency location by a "group" modulator. Six such group modulators have been provided at various frequencies throughout the range, including both the top and bottom. Patching facilities have been provided so that any 12-channel group may be transmitted over any one of the high-frequency paths. A typical frequency characteristic of one of the channels is shown in Fig. 8. It may be observed that relatively high quality has been obtained, due largely to the use of quartz crystal electric wave filters, even though the channels are spaced throughout the frequency range at 4 000-cycle intervals.

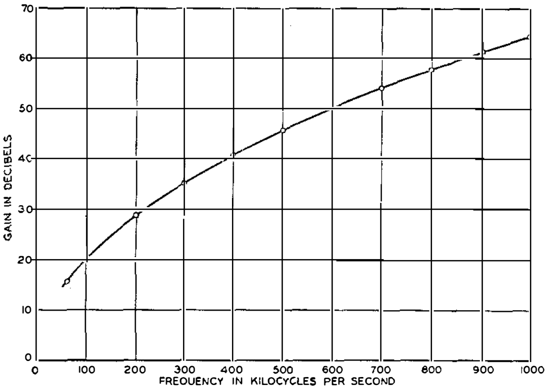

Fig. 7—Gain-frequency Characteristic of Coaxial Repeater.

Preliminary Tests

As already noted, various long circuits have been built up by looping back and forth through the coaxial system. One set-up over which conversations were successfully carried out consisted of five voice-frequency links in tandem, each link being 760 miles long, giving a total circuit length of 3 800 miles. This set-up included, in each direction, seventy stages of modulation and the equivalent of 400 line amplifiers, the transmission passing twenty times through each one of the twenty one-way line amplifiers constituting the ten two-way repeaters.

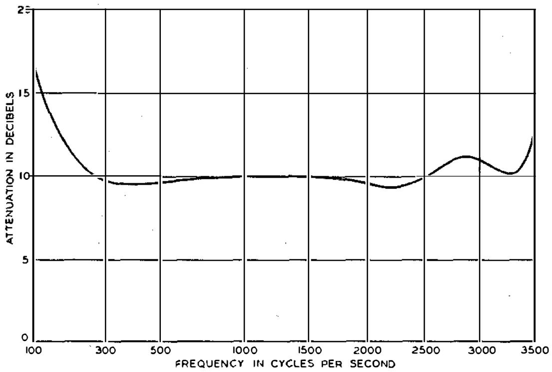

Fig. 8—Schematic Diagram of a Coaxial Million-cycle System showing Frequencies Assigned to the Different Channels.

This demonstrated that the complete assemblage of parts, including filters which divide the frequency range into the required bands, modulators which produce the necessary frequency transformations, and amplifiers which counteract the line attenuation, introduced very little distortion. Many problems require further consideration, however, before these systems will be ready for design and production for general use. The final systems must have such refinement that they are suitable for transcontinental distances; the tremendous amplifications needed for such distances must have very precisely designed regulation systems, particularly where aerial construction is involved; noise and crosstalk must not accumulate over the long distances; the repeaters must have such stability and reliability that continuity of service will be assured with hundreds of repeaters operating in series and each repeater handling several hundred different communications simultaneously.

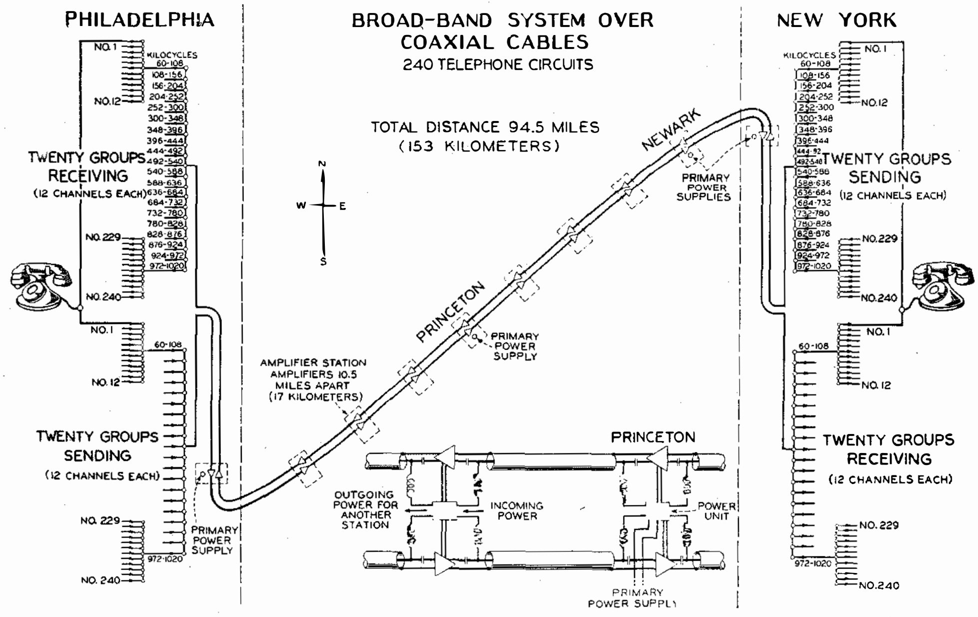

Fig. 9—Frequency Characteristic Allocation Assignments of a Typical Speech Channel. Broad-band System over Coaxial Cables (240 *Telephone Circuits*).

Crosstalk Between Coaxial Transmission Lines*

By S. A. SCHELKUNOFF, and T. M. ODARENKO,

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The general theory of coaxial pairs was dealt with in an article on " The Electromagnetic Theory of Coaxial Transmission Lines and Cylindrical Shields," by S. A. Schelkunoff (B.S.T.J., Oct., 1934). *The present paper considers a specific aspect of the general theory, namely, crosstalk.*

Formulæ for the crosstalk are developed in terms of the distributed mutual impedance, the constants of the transmission lines and the terminal impedances. Some limiting cases are given special consideration. The theory is then applied to a few special types of coaxial structures studied experimentally and a close agreement is shown between the results of calculations and of laboratory measurements.

If the outer members of coaxial pairs are complicated structures rather than solid cylindrical shells, the crosstalk formulæ still apply but the mutual impedances and the transmission constants which are involved in these formulæ must be determined experimentally since these quantities cannot always be calculated with sufficient accuracy.

The crosstalk between coaxial pairs with solid outer conductors rapidly decreases with increasing frequency while the crosstalk between unshielded balanced pairs increases. In the low frequency range there is less crosstalk between such balanced pairs than between coaxial pairs, but at high frequencies the reverse is true. The diminution of crosstalk between coaxial pairs with increasing frequency is caused by an ever increasing shielding action furnished by the outer conductors of the pairs.

Finally, crosstalk in long lines using coaxial conductors is discussed and the conclusion is reached that, unlike the case of the balanced structure, the far-end crosstalk imposes a more severe condition than the near-end crosstalk in two-way systems which involve more than two coaxial conductors.

A COAXIAL line consists of an outer conducting tube which envelops a centrally disposed inner conductor. The circuit is formed between the inner surface of the outer conductor and the outer surface of the inner conductor. Since any kind of high-frequency external interference tends to concentrate on the outer surface of the outer conductor and the transmitted current on the inner surface of the outer circuit, the outer conductor serves also as a shield, the shielding effect being more effective the higher the frequency.

Due to this very substantial shielding at high frequencies, this type of circuit has been a matter of increased interest for use as a connector between radio transmitting or receiving apparatus and antennæ, as well as a wide frequency band transmitting medium for long distance multiplex telephony or television. It has been a subject of discussion in several articles published in this country and abroad.*

The purpose of this paper is to dwell at some length on the shielding characteristics of a structure exposed to interference from a similar structure placed in close proximity. Such interference is usually referred to as crosstalk between two adjacent circuits, so that the purpose of this paper is a study of crosstalk between two coaxial circuits. In what follows we shall give an account of the theory of crosstalk, the results of experimental studies, and application of these to long lines employing coaxial conductors.

General Considerations

Let us consider a simple case of two transmission lines (Fig. 1) and let us assume that both lines are terminated in their characteristic impedances Z_1 and Z_2, and that their pro-

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* For references see end of paper.

pagation constants per unit length are γ_1 and γ_2 respectively. If the disturbing voltage E is applied to the left end of line (1) and the induced voltage V_n is measured at the corresponding end of line (2), the ratio V_n/E is called the near-end crosstalk ratio from circuit (1) into circuit (2). Similarly, if V_f is the induced voltage as measured at the right end of line (2), when the disturbing voltage E is applied to the left end of circuit (1), we define the ratio $V_f/Ee^{-\gamma_1 l}$ as the far-end crosstalk ratio from circuit (1) into circuit (2). For convenience, we shall speak of the near-end crosstalk and the far-end crosstalk whenever the voltage crosstalk ratios are actually involved. Thus, the magnitude of crosstalk will be given by the absolute value of the corresponding crosstalk ratio. It might be expressed either in decibels as is done in this paper or it might be given in terms of crosstalk units, if the absolute value of the crosstalk ratio is multiplied by a factor 10^6.

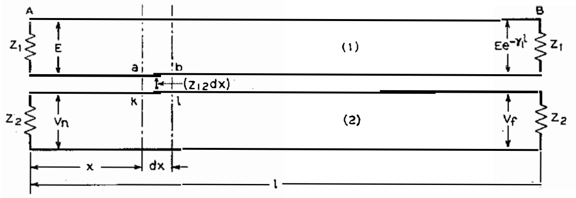

Fig. 1—Direct Crosstalk Between Coaxial Pairs.

It is well to observe at this point that, depending upon special conditions, the *significant* crosstalk ratio may be either the voltage ratio or the current ratio or the power ratio. The power ratio, or more commonly the square root of it, is usually the most important, but if the outputs are impressed on the grids of vacuum tubes then the voltage ratio becomes the significant measure of crosstalk. However, if one crosstalk ratio is known, any other crosstalk ratio can be readily determined provided that the characteristics of both circuits are known. Thus for the conditions of Fig. 1 the value of far-end crosstalk as given by the ratio $V_f/Ee^{-\gamma_1 l}$ in the voltage ratio system will become $(V_f/Ee^{-\gamma_1 l})$ (Z_1/Z_2) in the current ratio system.

In general, the crosstalk between any two transmission lines depends upon the existence of mutual impedances and mutual admittances between the lines. Generally, then, one can differentiate between two types of crosstalk. The first is produced by an electromotive force in series with the disturbed line in consequence of mutual impedances between the lines, and can be appropriately designated as the " impedance crosstalk." The other is due to an electromotive force in shunt with the disturbed line, induced by virtue of mutual admittances, and can be designated as the "admittance crosstalk." The two types of crosstalk are frequently referred to either as " electromagnetic crosstalk " and " electrostatic crosstalk " or as "magnetic crosstalk" and "electric crosstalk"; the latter terminology is the better of the two.

The Mutual Impedance

Consider the simplest crosstalking system consisting of two circuits only, such as shown schematically in Fig. 1. The mutual impedance between two corresponding short sections of the two lines, between the disturbing section *ab* and the disturbed section *kl*, for instance, will be defined as the ratio of the electromotive force induced in the disturbed section to the current in the disturbing section. In what follows we shall assume that the coupling between the two transmission lines is uniformly distributed ; that is, that the mutual impedance between two infinitely small sections, each of length dx is $Z_{12}dx$, where Z_{12} is independent of x. The constant Z_{12} is the mutual impedance *per unit length.*

The mutual impedance between coaxial pairs will be dealt with in a later section. For the present we need only assume that this impedance can be either calculated or measured. We shall find that the crosstalk is proportional to the mutual impedance, the remaining factors depending upon the length of transmission lines and the character of their terminations.

Direct and Indirect Crosstalk

Let us now return to the circuits shown in Fig. 1. Because of the mutual impedance between the two circuits a certain amount of the disturbing energy is transferred from line (1) to line (2), producing voltages at both ends. The voltage at the end A determines the near-end crosstalk. The type of crosstalk present in a simple system of two circuits only in consequence of the direct transmission of energy from one circuit into another we shall call the direct crosstalk. Later on we shall discuss the case where three circuits are involved in such a way that the energy transfer takes place via an intermediate circuit, causing the crosstalk which we call the indirect crosstalk. Both direct and indirect types of crosstalk have a close correspondence to the types of crosstalk used in connection with work on the open-wire lines or the balanced pairs as discussed in the paper on open-wire crosstalk.[1] The direct crosstalk of the present paper is the direct transverse crosstalk; our indirect crosstalk is the total crosstalk due to the presence of the third circuit and as such is the resultant of the indirect transverse crosstalk and the interaction crosstalk of the above paper. Following the general method outlined in the present paper one can easily subdivide the indirect crosstalk into its components. Since only simple crosstalk systems consisting of two coaxial conductors are considered in our paper, the work has not been carried through.

Direct Near-End Crosstalk

We proceed now to develop the formula for the direct near-end crosstalk. The line (1) being terminated in its characteristic impedance Z_1 the current through the generator is E/Z_1 and therefore the current in the section *ab* is

$$i_{ab} = \frac{Ee^{-\gamma_1 x}}{Z_1}. \tag{1}$$

Hence, by definition of the mutual impedance, the electromotive force induced in the section *kl* is

$$e_{kl} = i_{ab} Z_{12} dx = \frac{Ee^{-\gamma_1 x}}{Z_1} Z_{12} dx, \tag{2}$$

and the current in the section *kl*

$$i_{kl} = \frac{e_{kl}}{2Z_2} = \frac{Ee^{-\gamma_1 x}}{2Z_1 Z_2} Z_{12} dx. \tag{3}$$

Therefore the current at the left end of line (2) due to the electromotive force e_{kl} is given by the expression

$$(i_{kl})_n = i_{kl} e^{-\gamma_2 x} = \frac{EZ_{12}}{2Z_1 Z_2} e^{-(\gamma_1+\gamma_2)x} dx. \tag{4}$$

The contribution dV_n to the potential across the left end of line (2) due to crosstalk in the section dx, x cm away from the left end of the line, is

$$dV_n = (i_{kl})_n Z_2 = \frac{E}{2Z_1} Z_{12} e^{-(\gamma_1+\gamma_2)x} dx. \tag{5}$$

Hence the total induced voltage at the near end is

$$V_n = \int_0^l dV_n = \int_0^l \frac{E}{2Z_1} Z_{12} e^{-(\gamma_1+\gamma_2)x} dx. \tag{6}$$

Integrating, we obtain

$$V_n = E \frac{Z_{12}}{2Z_1} \frac{1 - e^{-(\gamma_1+\gamma_2)l}}{\gamma_1+\gamma_2}. \tag{7}$$

The near-end crosstalk is thus given by the expression

$$N_{12} = \left(\frac{V_n}{E}\right)_{12} = \frac{Z_{12}}{2Z_1} \frac{1 - e^{-(\gamma_1+\gamma_2)l}}{\gamma_1+\gamma_2}. \tag{8}$$

If we reversed the procedure and considered the crosstalk from circuit (2) into circuit (1), we would similarly obtain

$$N_{21} = \left(\frac{V_n}{E}\right)_{21} = \frac{Z_{21}}{2Z_2} \frac{1 - e^{-(\gamma_1+\gamma_2)l}}{\gamma_1+\gamma_2}. \tag{9}$$

By the reciprocity theorem, $Z_{21} = Z_{12}$. Incidentally, if instead of adopting as the definition of crosstalk the ratio of two voltages we regarded it as the ratio of the induced voltage to the current through the disturbing generator, we should have obtained $N_{21} = N_{12}$.

Finally, if the circuits are alike $Z_1 = Z_2 = Z_0$, $\gamma_1 = \gamma_2 = \gamma$ and the near-end crosstalk is given by the expression

$$N = \frac{V_n}{E} = \frac{Z_{12}}{2Z_0} \frac{1 - e^{-2\gamma l}}{2\gamma}. \tag{10}$$

We observe that the near-end crosstalk depends on length l. Two limiting cases are of importance here. For a length l so small, that for a given frequency $2\gamma^2 l^2$ is negligible when compared with $2\gamma l$, we have

$$\begin{aligned} e^{-2\gamma l} &= 1 - 2\gamma l + 2\gamma^2 l^2 \\ &= 1 - 2\gamma l, \end{aligned} \tag{11}$$

and the expression (10) becomes

$$N = \frac{V_n}{E} = \frac{Z_{12}}{2Z_0} l. \tag{12}$$

The near-end crosstalk is therefore proportional to l.

For very large values of γl, that is, a very high frequency or extreme length or both, where the exponential expression is negligible as compared to unity, the expression (10) becomes

$$N = \frac{V_n}{E} = \frac{Z_{12}}{2Z_0} \frac{1}{2\gamma}, \tag{13}$$

which is independent of length.

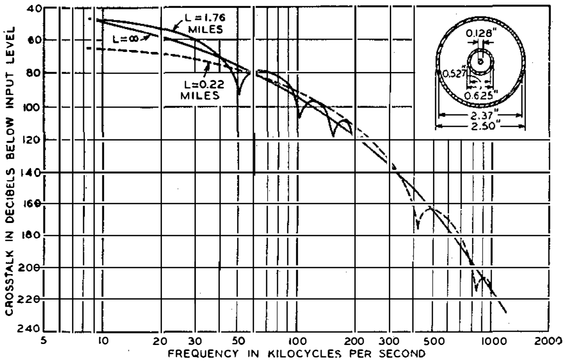

Fig. 2—Direct Near-end Crosstalk in a System of Three Coaxial Conductors.

The variation of the near-end crosstalk with length for intermediate values of γl can be best followed if instead of the expression (10) we use its absolute value

$$|N_{12}| = \left|\frac{V_n}{E}\right| = \frac{|Z_{12}|}{2|Z_1|} \frac{\sqrt{1 - 2\,e^{-2\alpha l}\cos(2\beta l) + e^{-4\alpha l}}}{\sqrt{\alpha^2 + \beta^2}}. \tag{14}$$

Here

$$\gamma = \alpha + i\beta, \tag{15}$$

α is the attenuation constant in nepers per unit length and β is the phase constant in radians per unit length.

We observe that for a given value of l one of the factors in (14) is oscillating with frequency. Thus, if we plot the crosstalk against frequency, the resulting curve is a wavy line superimposed upon a smooth curve, with the successive minimum points corresponding to the frequencies for which the given line is practically a multiple of half wave-lengths. The smooth curve is, of course, given by the magnitude of the expression (13). The curves on Fig. 2 illustrate the change of the near-end crosstalk with frequency for different lengths of a triple coaxial line made of copper conductors.

Direct Far-End Crosstalk

In order to determine the far-end crosstalk, we have to compute the induced voltage arriving at the far end of the system. Proceeding in a way similar to the derivation of the near-end crosstalk, we obtain the contribution dV_f to the potential across the right end of circuit (2), due to the electromotive force in the section ***kl***, to be given by the expression

$$dV_f = \frac{E}{2Z_1} Z_{12} e^{-\gamma_2 l} e^{(\gamma_2 - \gamma_1)x} dx. \tag{16}$$

Integrating this over the total length l we obtain the total voltage induced at the far end

$$V_f = E \frac{Z_{12}}{2Z_1} \frac{e^{-\gamma_2 l} - e^{-\gamma_1 l}}{\gamma_1 - \gamma_2}, \tag{17}$$

and the far-end crosstalk from circuit (1) into circuit (2) is

$$F_{12} = \frac{V_f}{Ee^{-\gamma_1 l}} = \frac{Z_{12}}{2Z_1} \frac{1 - e^{(\gamma_1 - \gamma_2)l}}{\gamma_2 - \gamma_1}. \tag{18}$$

If two similar lines are considered, with equal propagation constants and the characteristic impedances, equation (18) becomes

$$F = \frac{V_f}{Ee^{-\gamma l}} = \frac{Z_{12}}{2Z_0} l. \tag{19}$$

The far-end crosstalk is proportional to the length of the line at all frequencies.

Inasmuch as we have ignored the reaction of the induced currents upon the disturbing line, the foregoing equations must be regarded as approximations. Under practical conditions these approximations are very good. Only equation (19) must not be pushed to its absurd implication, that for long enough transmission lines most energy will eventually travel via the disturbed line. The true limiting condition is that the energy will ultimately be divided equally between the two lines.

Crosstalk via an Intermediate Circuit

The simplest case of the coaxial conductor system where the only crosstalk present is of the direct crosstalk type, as considered in the previous section, is the triple coaxial conductor. The mutual coupling in this case is due only to the transfer impedance between two circuits, as there are no other physical circuits involved. The case of two single coaxial conductors, the outer shells of which are in continuous electrical contact or strapped at frequent intervals, approximates the condition for the direct crosstalk if the system is sufficiently removed from any conducting matter. When two single parallel conductors in free space do not touch, an extra transmission line, an "intermediate circuit," is present consisting of the two outer shells of the coaxial conductors. Even two conductors, the shells of which are electrically connected, will form an intermediate circuit consisting of the outer shells and the other parallel conductors.

The voltage impressed on the disturbing coaxial circuit induces currents and voltages in the intermediate circuit, which now acts as a disturbing circuit for the second coaxial circuit, thus causing crosstalk. We shall now consider the near-end and far-end components of this indirect type of crosstalk.

Indirect Near-End Crosstalk

Let us consider a system shown in Fig. 3. The circuit (3) is the intermediate circuit with an impedance Z_3 and propagation constant per unit length γ_3. Let the disturbing voltage E be applied at the A end of circuit (1). Then the current in the section kl is given by the expression similar to (3)

$$i_{kl} = \frac{EZ_{13}}{2Z_1Z_3} e^{-\gamma_1 x} dx. \tag{20}$$

The current in the section pq is

$$i_{pq} = i_{kl} e^{-\gamma_3 s}, \tag{21}$$

where

$$s = |y - x|. \tag{22}$$

The total current in the generic element of the intermediate transmission line due to coupling with circuit (1) is, then,

$$I_y = \int_0^l i_{pq} = \frac{EZ_{13}}{2Z_1Z_3} \int_0^l e^{-\gamma_3 s} e^{-\gamma_1 x} dx. \tag{23}$$

In carrying out the process of integration, we must keep in mind that from 0 to y, $s = y - x$ and from y to l, $s = x - y$.

Hence, we have

$$\int_0^l e^{-\gamma_3 s} e^{-\gamma_1 x} dx = e^{-\gamma_3 y} \int_0^y e^{(\gamma_3 - \gamma_1)x} dx + e^{\gamma_3 y} \int_y^l e^{-(\gamma_3 + \gamma_1)x} dx,$$

and

$$I_y = \frac{EZ_{13}}{2Z_1Z_3} \left[\frac{e^{-\gamma_1 y} - e^{-\gamma_3 y}}{\gamma_3 - \gamma_1} + \frac{e^{-\gamma_1 y} - e^{\gamma_3 y} e^{-(\gamma_3 + \gamma_1)l}}{\gamma_3 + \gamma_1} \right]. \tag{24}$$

The elementary electromotive force induced in the second coaxial conductor by the current I_y is

$$E_y = Z_{32} I_y dy. \tag{25}$$

The contribution of this electromotive force to the voltage across the near-end of the second coaxial pair will be then

$$dV_n = \frac{1}{2} E_y e^{-\gamma_2 y} = \frac{Z_{32}}{2} I_y e^{-\gamma_2 y} dy. \tag{26}$$

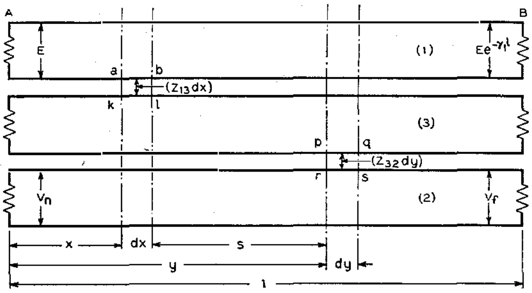

Fig. 3—Indirect Crosstalk Between Two Coaxial Pairs.

The total induced near-end voltage will be given by the expression

$$V_n = \frac{1}{2} \int_0^l Z_{32} I_y e^{-\gamma_2 y} dy. \tag{27}$$

Using the expressions (23) and (24), we obtain

$$V_n = E \frac{Z_{13} Z_{32}}{4Z_1Z_3} S_n, \tag{28}$$

where

$$S_n = \int_0^l e^{-\gamma_2 y} \left[\frac{e^{-\gamma_1 y} - e^{-\gamma_3 y}}{\gamma_3 - \gamma_1} + \frac{e^{-\gamma_1 y} - e^{\gamma_3 y} e^{-(\gamma_3 + \gamma_1)l}}{\gamma_3 + \gamma_1} \right] dy. \tag{29}$$

Integrating (29) we have

$$S_n = \frac{2\gamma_3}{\gamma_1 + \gamma_2} \frac{1 - e^{-(\gamma_2 + \gamma_1)l}}{\gamma_3^2 - \gamma_1^2} - \frac{1 - e^{-(\gamma_3 + \gamma_2)l}}{(\gamma_3 - \gamma_1)(\gamma_3 + \gamma_2)} + \frac{1 - e^{(\gamma_3 - \gamma_2)l}}{(\gamma_3 + \gamma_1)(\gamma_3 - \gamma_2)} e^{-(\gamma_3 + \gamma_1)l}. \tag{30}$$

Thus, the near-end crosstalk from circuit (1) into circuit (2) via the intermediate circuit (3) is given by the expression

$$N_{12}' = \frac{V_n}{E} = \frac{Z_{13}Z_{23}}{4Z_1Z_3}S_n. \qquad (31a)$$

In a similar manner we can derive the following expression for the near-end crosstalk from circuit (2) into circuit (1) via the intermediate circuit (3):

$$N_{21}' = \frac{Z_{13}Z_{23}}{4Z_2Z_3}S_n. \qquad (31b)$$

The factor S_n present in (31*b*) is the same as in (31*a*), being symmetrical with respect to the subscripts 1 and 2 as a close inspection of the formula (30) would prove. $Z_{13} = Z_{31}$ and $Z_{23} = Z_{32}$ by the reciprocity theorem.

For the case of two similar coaxial pairs with equal characteristic impedances Z_0 and propagation constants γ, and symmetrically placed with respect to the intermediate line, so that $Z_{13} = Z_{32}$, we have

$$N' = \frac{(Z_{13})^2}{4Z_0Z_3}\left[\frac{\gamma_3}{\gamma}\frac{1-e^{-2\gamma l}}{\gamma_3^2-\gamma^2} - \frac{1-2e^{-(\gamma_3+\gamma)l}+e^{-2\gamma l}}{\gamma_3^2-\gamma^2}\right]. \qquad (32)$$

Now for short lengths we may use again the approximation

$$e^{-a} = 1 - a + \tfrac{1}{2}a^2. \qquad (33)$$

The expression in the brackets of (32) then becomes equal to l^2 and the near-end crosstalk is given by the expression

$$N' = \frac{(Z_{13})^2}{4Z_0Z_3}l^2, \qquad (34)$$

which is proportional to the second power of length.

For γl very large we can rewrite expression (32) as follows:

$$N' = \frac{(Z_{13})^2}{4Z_0Z_3}\frac{1}{\gamma(\gamma_3+\gamma)}. \qquad (35)$$

Thus, for a system sufficiently long the near-end crosstalk via an intermediate line is independent of length.

If the intermediate transmission line is short-circuited a large number of times per wavelength, its propagation constant γ_3 becomes very large on the average and we have approximately

$$S_n = \frac{2[1-e^{-(\gamma_2+\gamma_1)l}]}{(\gamma_1+\gamma_2)\gamma_3}, \qquad (36)$$

and

$$N_{12}' = \frac{V_n}{E} = \frac{Z_{13}Z_{23}}{2Z_1Z_3\gamma_3}\,\frac{1-e^{-(\gamma_1+\gamma_2)l}}{\gamma_1+\gamma_2}. \qquad (37)$$

But $Z_3\gamma_3 = Z$, the distributed series impedance of the intermediate transmission line. Hence the "indirect" crosstalk becomes direct with the mutual impedance given by

$$Z_{12} = \frac{Z_{13}Z_{23}}{Z}.$$

Indirect Far-End Crosstalk

Using the method outlined in the previous section we arrive at the following expression for the far-end crosstalk from circuit (1) into circuit (2) via the intermediate circuit (3); see Fig. 3.

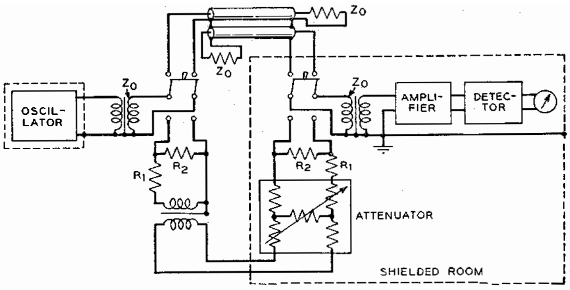

Fig. 4—Crosstalk Measuring Circuit Arranged for Far-end Measurements.

$$F_{12}' = \frac{V_f}{Ee^{-\gamma_1 l}} = \frac{Z_{13}Z_{32}}{4Z_1Z_3}S_f. \qquad (38a)$$

The crosstalk from circuit (2) into circuit (1) will be given by a similar expression with Z_2 replacing Z_1 in the denominator, namely

$$F_{21}' = \frac{Z_{13}Z_{32}}{4Z_2Z_3}S_f. \qquad (38b)$$

The factor S_f used in the above formulae is given by the expression

$$S_f = e^{-(\gamma_2-\gamma_1)l}\left[\frac{2\gamma_3}{\gamma_1-\gamma_2}\,\frac{1-e^{-(\gamma_1-\gamma_2)l}}{\gamma_3^2-\gamma_1^2} - \frac{1-e^{-(\gamma_3-\gamma_2)l}}{(\gamma_3-\gamma_1)(\gamma_3-\gamma_2)} + \frac{1-e^{(\gamma_3+\gamma_2)l}}{(\gamma_3+\gamma_1)(\gamma_3+\gamma_2)}e^{-(\gamma_3+\gamma_1)l}\right] \qquad (39)$$

When both coaxial pairs are similar and placed symmetrically with respect to the intermediate conductors we obtain the following expression for the far-end crosstalk between two coaxial conductors via an intermediate circuit:

$$F' = \frac{(Z_{13})^2}{4Z_0Z_3}\left[\frac{2\gamma_3 l}{\gamma_3^2 - \gamma^2} - \frac{1 - e^{-(\gamma_3-\gamma)l}}{(\gamma_3 - \gamma)^2} - \frac{1 - e^{-(\gamma_3+\gamma)l}}{(\gamma_3 + \gamma)^2}\right]. \quad (40)$$

For small l the expression for the far-end crosstalk becomes

$$F' = \frac{(Z_{13})^2}{4Z_0Z_3}\, l^2, \quad (41)$$

which is the same as (34) for the near-end crosstalk.

For large l and provided the attenuation of the intermediate circuit is greater than that of the coaxial circuit we have

$$F' = \frac{(Z_{13})^2}{4Z_0Z_3}\left[\frac{2\gamma_3 l}{\gamma_3^2 - \gamma^2} - \frac{2(\gamma_3^2 + \gamma^2)}{(\gamma_3^2 - \gamma^2)^2}\right]. \quad (42)$$

Finally, letting γ_3 approach γ and considering a limiting case when attenuation of the intermediate circuit is equal to attenuation of either of the coaxial conductors we obtain

$$F' = \frac{(Z_{13})^2}{4Z_0Z_3}\left[\frac{l}{2\gamma} + \frac{1}{2}l^2 - \frac{1 - e^{-2\gamma l}}{4\gamma^2}\right]. \quad (43)$$

If the intermediate transmission line is short-circuited a large number of times per wavelength its propagation constant γ_3 becomes very large on the average. The equation (37) becomes, then,

$$S_f = \frac{2[1 - e^{-(\gamma_2-\gamma_1)l}]}{(\gamma_2 - \gamma_1)\gamma_3}, \quad (44)$$

and

$$F_{12}' = \frac{Z_{13}Z_{32}}{2Z_1Z_3\gamma_3}\,\frac{1 - e^{(\gamma_1-\gamma_2)l}}{\gamma_2 - \gamma_1}. \quad (45)$$

The indirect crosstalk becomes direct with the mutual impedance given by the expression

$$Z_{12} = \frac{Z_{13}Z_{23}}{Z_3\gamma_3} = \frac{Z_{13}Z_{23}}{Z}, \quad (46)$$

where $Z = Z_3\gamma_3$ is the distributed series impedance of the intermediate transmission line.

Comparison between Direct Crosstalk and Crosstalk via Intermediate Circuit for Two Parallel Coaxial Conductors

We have already seen that two parallel coaxial conductors in free space form actually three transmission circuits, the third circuit being formed by two outer shells of the coaxial conductors. When this third line is shorted by direct electrical contact or by frequent straps only direct crosstalk is present. When the third circuit is terminated in its characteristic impedance we have crosstalk via the third circuit. In this last case, however, the crosstalk via the third circuit is also the total crosstalk, since the only available path for the transfer of interfering energy is via the third circuit. Thus, we can directly compare the values of crosstalk for the system for both conditions.

We have shown that for sufficiently short lengths of the crosstalk exposure the direct type of crosstalk is given by (12) or (19), namely,

$$F = N = \frac{Z_{12}}{2Z_0}\, l. \quad (47)$$

We have also found that the crosstalk via an intermediate circuit is given by (34) or (41) provided that the length of conductors is small enough. Thus

$$F' = N' = \frac{Z_{13}^2}{4Z_0Z_3}\, l^2. \quad (48)$$

Consequently

$$\frac{F'}{F} = \frac{N'}{N} = \frac{Z_{13}^2}{2Z_{12}Z_3}\, l. \quad (49)$$

In seeking an experimental verification of equation (49) a series of measurements were taken on a pair of coaxial conductors of varying lengths, separations, and different terminating conditions of the third circuit. The results agreed fully with the theory.

Mutual Impedance

Like the other constants of transmission lines the distributed mutual impedance can be measured. In certain cases, however, it is possible to obtain simple formulae for this impedance. For details of such calculations the reader is referred to a paper by one of the authors.[2]

In this paper the mutual impedance is expressed in terms of *surface transfer impedances.* Consider a coaxial pair whose outer conductor is either a homogeneous cylindrical shell or a shell consisting of coaxial homogeneous cylindrical layers of different conducting substances. The transfer impedance from the inner to the outer surface of the outer conductor is then defined as the voltage gradient on the outer surface per unit current in the conductor. In a triple coaxial conductor system this transfer impedance is evidently the mutual impedance between two transmission lines, one comprised of the two inner conductors and the other of the two outer conductors. On the other hand the mutual impedance has a quite different value if one line consists of the two inner conductors while the other is comprised of the innermost and the outermost conductors.

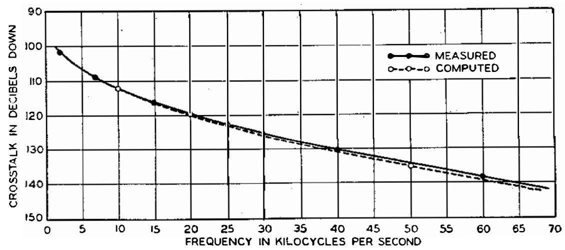

Fig. 5—*Crosstalk Between Two Coaxial Pairs* 20 *ft. Long Using Refrigerator Pipe* 0.032 *in. Thick for Outer Conductors. Both Coaxial Pairs Terminated in* 70 *Ohms. Outer Conductors in Contact.*

The surface transfer impedance of a homogeneous cylindrical shell is given by the following expression, good to a fraction of a per cent. for all frequencies up to the optical range if the thickness t is smaller than 20 per cent. of the average radius

$$Z_{ab} = \frac{\eta}{2\pi\sqrt{ab}} \operatorname{csch}(\sigma t). \qquad (50)$$

In this equation:

a is the inner radius of the middle shell in cm.

b is the outer radius of the middle shell in cm.

t is the thickness of the middle shell in cm.

$\sigma = \sqrt{2\pi g\mu f i}$ nepers per cm.

$$\eta = \frac{\sigma}{g} = \sqrt{\frac{2\pi\mu f i}{g}} \text{ ohms}$$

g is the conductivity in mhos per cm.*

μ is the permeability in henries per cm.*

f is the frequency in cycles per second.

If the ratio of the diameters of the shell is not greater than 4/3 the following formula correct to 1 per cent. at any frequency will hold for the absolute value of the transfer impedance.

$$|Z_{ab}| = R_{DC}\frac{u}{\sqrt{\cosh u - \cos u}}, \qquad (51)$$

where

R_{DC} = the dc resistance of the shell,

$u = t\sqrt{4\pi\mu g f}.$

The expression (51) is plotted in Fig. 3, p. 559 of Schelkunoff's paper.[2]

As it has been already mentioned, (50) and (51) represent the mutual impedance in a triple conductor *coaxial* system. One might anticipate that if the arrangement is not coaxial the mutual impedance has a different value. This is indeed the case if all three conductors have different axes. But if one transmission line is a strictly coaxial pair, then its own current remains substantially uniform around its axis and from equation (81) of Schelkunoff's paper we immediately conclude that the mutual impedance will be the same as if *all three* conductors were coaxial. *Both* transmission lines must be eccentric before their mutual impedance becomes affected by their eccentricities. Thus the mutual impedance Z_{13} between a coaxial circuit and the circuit consisting of its outer shell and a cylindrical shell parallel to it is given very accurately by (50) and (51).

The surface transfer impedance across a shell consisting of two coaxial homogenous layers is given by

$$Z_{12} = \frac{(Z_{ab})_1(Z_{ab})_2}{Z}, \qquad (52)$$

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* As in the previous paper by Schelkunoff we adhere throughout this article to the practical system of units based on the c.g.s. system. For copper of 100 per cent. conductivity

$g = 5.8005 \times 10^5$ mhos/cm and $\mu = 4\pi 10^{-9}$ henries/cm.

where Z_{ab} is the transfer impedance for each layer and Z is the series impedance per unit length of the circuit consisting of the two layers insulated from each other by an infinitely thin film, when one layer is used as the return conductor for the other.

The mutual impedance between two coaxial pairs the outer conductors of which are short-circuited at frequent intervals is also given by (52) provided Z is interpreted as the distributed series impedance of the intermediate transmission line comprised of the outer shells of the given coaxial pairs. This Z is the sum of the internal impedances of the two shells $(Z_{bb})_1$ and $(Z_{bb})_2$ and of the external inductive reactance ωL_e due to the magnetic flux between the shells. If the proximity effect is disregarded, the internal impedance of a single cylindrical shell is the same as that with a coaxial return and various expressions for it are given in equations (75) and (82) in the previous paper.[2] The inclusion of the proximity effect does not complicate the formulae if the separation between the shells is fairly large by comparison with their radii, but in this case the proximity effect is not very large either. The more accurate determination of Z leads to complicated formulae; for these the reader is referred to a paper by Mrs. S. P. Mead.[6] However, at high frequencies the important factors in the mutual impedance are the transfer impedances in the numerator of (52).

Under certain conditions it is easy to obtain approximate values of the denominator of (52) and use them for gauging the limits between which the mutual impedance must lie. If the frequency is so high that the proximity effect has almost reached its ultimate value the external inductance and the internal impedance of the intermediate line are approximately

$$\begin{aligned} L_e &= \frac{\mu}{2\pi}\cosh^{-1}\frac{l^2-b_1{}^2-b_2{}^2}{2b_1b_2}, \\ (Z_{bb})_1+(Z_{bb})_2 &= \frac{1}{2\pi}\sqrt{\frac{i\omega\mu}{g}} \\ &\quad \frac{\left(\frac{1}{b_1}+\frac{1}{b_2}\right)+\frac{b_1{}^2-b_2{}^2}{l^2}\left(\frac{1}{b_1}-\frac{1}{b_2}\right)}{\sqrt{\left[1-\frac{(b_1+b_2)^2}{l}\right]\left[1-\frac{(b_1-b_2)^2}{l}\right]}}, \end{aligned} \tag{53}$$

where b_1 and b_2 are the external radii and l is the interaxial separation. Usually $b_2 = b_1 = b$ and consequently

$$\begin{aligned} L_e &= \frac{\mu}{2\pi}\cosh^{-1}\left(\frac{l^2}{2b^2}-1\right), \\ (Z_{bb})_1+(Z_{bb})_2 &= \frac{1}{\pi b}\sqrt{\frac{i\omega\mu}{g}}\left[1-4\frac{b^2}{l^2}\right]^{-\frac{1}{2}}. \end{aligned} \tag{54}$$

If the proximity effect is disregarded then the external inductance is simply

$$L_e = \frac{\mu}{\pi}\log_e\frac{1}{\sqrt{b_1b_2}}. \tag{55}$$

For this case, then, the mutual impedance is given by the expression

$$Z_{12} = \frac{(Z_{ab})_1(Z_{ab})_2}{(Z_{bb})_1+(Z_{bb})_2+\frac{i\omega\mu}{\pi}\log_e\frac{l}{\sqrt{b_1b_2}}}. \tag{56}$$

For two identical coaxial conductors the expression is further simplified to

$$Z_{12} = \frac{(Z_{ab})^2}{2Z_{bb}+\frac{i\omega\mu}{\pi}\log_e\frac{l}{b}}. \tag{57}$$

Measuring Method

As defined above, crosstalk between two transmission lines terminated in their characteristic impedances is given by the ratios of the induced and disturbing voltages. Consequently, if the input voltage into the disturbing circuit is known and the induced voltage at one of the ends of the disturbed pair is measured, the far-end or near-end crosstalk values are obtained readily. In fact, the magnitude of the near-end crosstalk is given by the expression

$$|N| = \left|\frac{V_n}{E}\right| \tag{58}$$

and the magnitude of the far-end crosstalk is given by the expression

$$|F| = \frac{|V_f|}{|E|e^{-\alpha l}}. \tag{59}$$

Taking 20 $\log_{10}\frac{1}{|N|}$ and 20 $\log_{10}\frac{1}{|F|}$, we obtain an equivalent loss in db between the disturbing and disturbed levels of the two crosstalking circuits. This consideration determined the method of measurements used in our experimental studies.

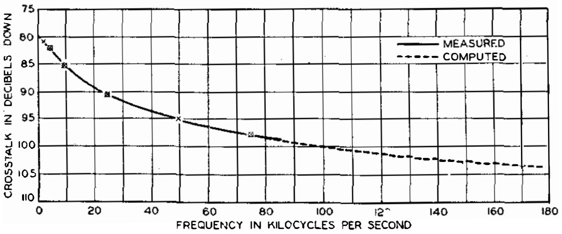

Fig. 6—*Crosstalk Between Two Coaxial Pairs* 25 *ft. Long. Outer Conductor made of Copper* 0.008 *in. Thick,* 0.232 *in. Inner Diameter. Both Coaxial Pairs Terminated in* 40 *Ohms. Outer Conductors in Contact.*

The circuit used is given in Fig. 4. The two branches of the measuring set are the comparison circuits, the upper containing the crosstalking system and the lower including adjustable attenuators. The input and output impedances of both branches are kept alike by adjusting the resistances R_1 and R_2. Thus, when the lower branch of the circuit is adjusted to produce the same input into the detector as through the crosstalking branch the loss in the calibrating branch gives an equivalent crosstalk loss in db. These values of crosstalk in db below the input level in the disturbing circuit are plotted on all our sketches.

Both coaxial circuits were terminated in resistances closely equal to the absolute values of their characteristic impedances. The terminations were carefully shielded to prevent any crosstalk at these points. Careful shielding and grounding were found necessary to reduce errors due to longitudinal currents, unbalances, and interference between different parts of the measuring circuit. The overall accuracy of the measuring circuit attained was better than 0.5 db when the difference in input to output levels amounted to 150 db.

Agreement between Theory and Experiments

The general agreement between the theory and the experiments is indicated by the curves in Fig. 5 and Fig. 6, which give the crosstalk values for cases of two small coaxial pairs with solid outer shells in continuous contact. The curves in Fig. 7 show a comparison between measured and computed values of near-end crosstalk for a system of three coaxial conductors 0.88 mile long as installed at Phoenixville, Pennsylvania.

Also, as was already stated above, full agreement between theory and experiments was established as to validity of equation (49).

Crosstalk in Long Lines Employing Coaxial Conductors

In a system consisting of two coaxial pairs, where two outer conductors are in contact, essentially only one kind of crosstalk is present depending on the direction of transmission on both pairs. It is near-end crosstalk when transmitting in opposite directions and far-end crosstalk for transmission in the same direction. Where more than two coaxial conductors are grouped together and transmission is in both directions both types of crosstalk are present.

Although for a sufficiently short length of crosstalk exposure near-end and far-end crosstalk are identical, in a sufficiently long system the transmission characteristics of the line and associated repeaters will make a marked difference between them. It has been a common experience that in a long system using unshielded balanced structures near-end crosstalk imposes more severe requirements on balance between crosstalking circuits than far-end crosstalk.

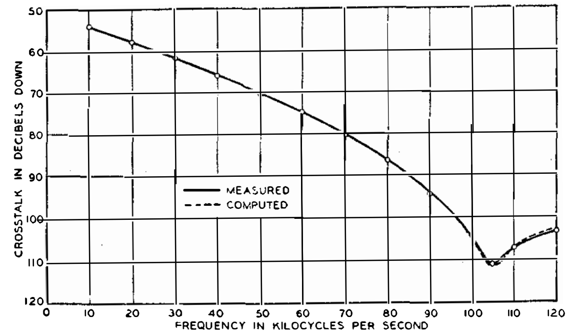

Fig. 7—*Near-end Crosstalk on a Triple Coaxial System of Conductors at Phoenixville, Pa. Outer to Inner Circuits. Length* 0.088 *mi.*

We shall now consider a coaxial pair. Here, the magnitude of the far-end crosstalk was found to be given by expression (19). The magnitude of the near-end crosstalk is given by expression (14), which for equal level points becomes

$$|N| = \left|\frac{Z_{12}}{2Z_0}\right| \frac{e^{\alpha l}\sqrt{1 - 2e^{-2\alpha l}\cos(2\beta l) + e^{-4\alpha l}}}{2\sqrt{\alpha^2 + \beta^2}}. \quad (60)$$

Thus, the ratio of the corrected near-end to the far-end crosstalk is obtained by combining equation (60) and (19):

$$\left|\frac{N}{F}\right| = \frac{e^{\alpha l}\sqrt{1 - 2e^{-2\alpha l}\cos(2\beta l) + e^{-4\alpha l}}}{2\sqrt{(\alpha l)^2 + (\beta l)^2}}. \quad (61)$$

The curve in Fig. 8 gives the db difference between near-end and far-end crosstalk for different frequencies on a 10-mile length of two parallel coaxial pairs with hard rubber disc insulation. Each pair consists of a copper outer conductor of 0.267 in. inner diameter and 0.020 in. thick, and a 0.072 in. solid copper inner conductor. It is evident that in a single repeater section far-end crosstalk is higher than near-end crosstalk up to about 900 kc.

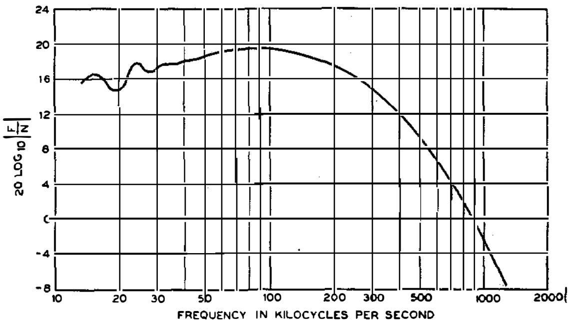

Fig. 8—Values of $20 \log_{10} |F/N|$ *for a* 10 *mi. Repeater Section of Two Parallel Coaxial Pairs in Continuous Contact. Coaxial Pairs consist of No.* 13 *AWG Solid Copper Wire,* 0.267 *in. Inner Diameter Copper Outer Conductor* 0.020 *in. Thick, and Rubber Disc Insulation.*

When a number of repeater sections are connected in tandem the near-end crosstalk contribution from a single repeater section will reach the terminal of the system modified both in magnitude and in phase due to transmission through intervening sections of crosstalking circuits. At the terminal the phase changes will distribute the crosstalk from all sections in a random manner, which, in accord with both the theory and experimental evidences, will result in a root-mean-square law of addition. Thus, the overall near-end crosstalk from m sections will be equal to the crosstalk from a single section multiplied by the square root of m.

On the contrary, in a system using similar coaxial pairs transmitting in the same direction and employing repeaters at the same points, the far-end crosstalk is affected mostly by the phase differences of the repeaters. If these do not vary from the average by more than a few degrees, the far-end crosstalk in a system involving even a comparatively large number of repeaters will change proportionally to the first power of the number of repeater sections m. Only with a very large number of repeater sections (perhaps 500 or more) and random phase differences of repeaters and line of perhaps 5°–10° will the far-end crosstalk from single sections tend to approach random distribution. In this case the root-mean-square law will hold reasonably well.

Thus, far-end crosstalk will grow faster than near-end crosstalk as the number of repeater sections increases. This, combined with the relationship between the far-end and the near-end crosstalk in a single repeater section as given by equation (61) and Fig. 8, leads us to conclude that in long systems with both near- and far-end crosstalk present the limiting factor will be the far-end crosstalk. This is contrary to the experience with balanced structures stated above.

REFERENCES

1. A. G. Chapman: "Open-Wire Crosstalk," *Bell System Technical Journal,* Vol. XIII, January, 1934, pp. 19–58, and April, 1934, pp. 195–236.
2. S. A. Schelkunoff: "The Electromagnetic Theory of Coaxial Transmission Lines and Cylindrical Shields," *Bell System Technical Journal,* Vol. XIII, October, 1934, pp. 532–579.
3. L. Espenschied and M. E. Strieby: "Systems for Wide-Band Transmission Over Coaxial Lines," *Bell System Technical Journal,* Vol. XIII, October, 1934, pp. 654–769.
4. E. J. Sterba and C. B. Feldman: "Transmission Lines for Short-Wave Radio Systems," *Bell System Technical Journal,* Vol. II, July, 1932, pp. 411–450.

5. H. F. Mayer and E. Fisher: " Breitband Kabel mit Neuartige Isolation," *E.T.Z.* No. 46, November, 14, 1935.
6. S. P. Mead: " Wave Propagation Over Parallel Tubular Conductors : The Alternating Current Resistance," *Bell System Technical Journal*, pp. 327–338, April, 1925.
7. John R. Carson and J. J. Gilbert: " Transmission Characteristics of the Submarine Cable," *Journal Franklin Institute*, December, 1921.
8. John R. Carson and Ray S. Hoyt: " Propagation of Periodic Currents over a System of Parallel Wires,"*Bell SystemTechnicalJournal*, July, 1927.
9. H. Kaden: " Das Nebensprechen Zwischen Parallelen Koaxialen Leitungen," *Electrische Nachrichten Technik*, Band 13, Heft 11 (1936), pp. 389–397.
10. M. E. Strieby: " A Million-Cycle Telephone System," *Electrical Engineering*, January, 1937 ; *Bell System Technical Journal*, January, 1937.

Stand of the Bell Telephone Manufacturing Company, Antwerp, May, 1937, *at the Brussels Aviation Exhibition, showing some of the latest aids to aircraft navigation, including the R.C.*5 *Automatic Radio Compass, Lorenz Blind Approach, Standard Adcock Ground Direction and Single-Seater Fighter Equipment.*

Superstyrex

The Use of Styrol as an Insulator

By T. R. SCOTT,

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THE present-day interest in Styrol prompts a review of the history and development of this high-grade insulating material. It would appear from an article by Hesse[1] that the material was developed about 1930, but such is not the case. As far back as 1839 Simon[2] described the preparation of the polymer (Polystyrol) from the monomer (Styrol).

One of the earliest references to the electrical characteristics of the solid polymer is contained in a patent by F. E. Matthews,[3] where the inventor proposes to replace hard rubber, celluloid, vulcanite, ebonite, glass, wood, etc., by polystyrol or polystyrol compounded with rubber. He states that the material " has excellent insulating properties."

Although several chemical references may be noted during the following fifteen or sixteen years (Ellis[4] referred to the earliest suggested process for making thread from this material), no further reference during this period has been noted regarding the insulating properties of the material. However, the I.T. and T. Laboratories in 1928 commenced to study in detail the properties of polystryrol with particular regard to its application to the insulation of cables. At that particular time two outstanding communication developments were commencing, namely, coaxial cables for wide frequency band carrier wave transmission systems, and long-distance submarine telephone cables. From this study, a series of patents originated, dating from 1929 down to the present, dealing first of all with combinations of polystyrol with rubber, balata, etc., of a thermoplastic nature suitable for extrusion but dealing later with other processes and applications.

The principle involved in the earlier work was the swelling of the rubber or balata by liquid monomeric styrol with subsequent polymerisation into a thermoplastic compound suitable for extrusion by well-known means. The development of thermoplastics of this nature directed the attention of the Laboratories to the liquid monomeric form of styrol which is a necessary starting point for the synthesis of such insulators.

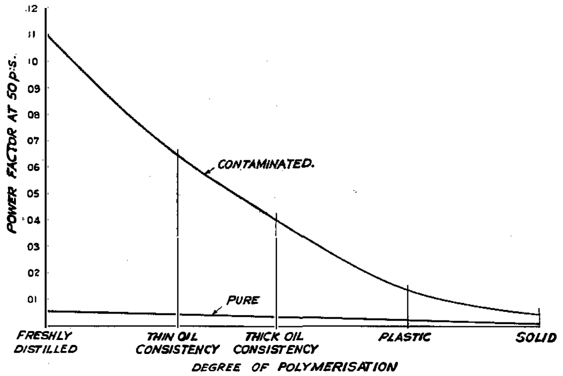

Fig. 1—Variation of Power Factor of Styrene with Degree of Polymerisation.

Sabatay[5] in 1929 described a method of preparing the monomer by the dehydration of beta phenyl ethyl alcohol and this process was adopted by the I.T. and T. Laboratories as the starting point of their developments referred to herein.

The liquid monomeric styrene is easily transformed into the solid polymeric form, for example, by the application of heat. This suggested applications to power cable fields and, as a result, a series of patents were taken out, the technical aspects of which have been described in papers by Scott and Webb. [6, 7, 8]

Here, the principle involved was the sub-

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[1] Hesse : *Telegraphen und Fernsprech Technik,* 1931, No. 5.

[2] Simon : *Annalen,* 1839, 31 267.

[3] F. E. Matthews : British Patent 16 278, 1911. French Patent 459 134, 1913.

[4] Ellis : *Synthetic Resins,* 1923.

[5] Sabatay : *Bull. Soc. Chim.,* 1929 (iv), 46, 69–75.

[6] Scott : *The Electrical Power Engineer,* Vol. 16, Nov./Dec., 1934.

[7] Webb : *Electrical Times,* July, 1934, 86 and 45.

[8] Scott and Webb : Conference International de Grand Reseaux Electriques, 1935.

stitution of oil or compound in the cable or joint by monomeric styrol which was subsequently polymerised and which thereby introduced into the cable or joint a solid barrier or plug of small dimensions but of high mechanical and electrical quality.

The study of the monomeric form, i.e., the liquid, also indicated approaches to other insulating problems.

Polystyrene, also known by the names polystyrol, metastyrol, metastyrene, etc., or by the trade names Rezoglaz, Victron, Trolitul and Superstyrex, is described variously as a resin, a glass, and a super-cooled rubber. Technical descriptions of the material, including tabulation of characteristics, also indicate wide variation of alleged mechanical and electrical characteristics. The reason for this is simple since the material varies considerably in its characteristics according to the process details of its manufacture.

As mentioned above, the monomeric form can be transformed into the polymeric form by the application of energy, e.g., heat. At atmospheric temperature the transformation may occupy several weeks ; at temperatures of the order of 200° C., the transformation will be substantially complete in less than an hour. The mechanical properties of the polymer vary very considerably according to the temperature of polymerisation employed.

The material, whether polymerised at atmospheric temperature or at an elevated temperature, is colourless (water white) and transparent, and in this respect is comparable to glass. It is hard and, when subjected to a sharp blow, will break with a conchoidal fracture. The ease of fracture is dependent upon the temperature of formation ; polystyrene formed at atmospheric temperature is tough, elastic, not readily fractured, and is very difficult to pulverise. Polystyrene is less tough the higher the temperature of formation and the hardness tends to increase, ease of fracture increases and the polymer formed at 250° C. can be readily disintegrated into a fine powder. In general, polystyrene formed at atmospheric temperature resembles a super-cooled rubber in its mechanical properties, but polystyrene formed at 250° C. tends more to resemble a natural resin. All degrees between these two extremes are possible.

On warming, polystyrene formed at atmospheric temperature, shows no melting point below its temperature of decomposition (300° C.) ; but, between 70° C. and 90° C., it commences to soften and assumes rubber-like properties, behaving similarly to raw rubber which has merely a lower "elasticity temperature." All the elastic phenomena exhibited by rubber are present with polystyrene of this type kept above its "elasticity temperature."

Polystyrene formed at an elevated temperature shows rubber-like properties to a less marked degree the higher the temperature of polymerisation. Polymers formed above 200° C., when examined at temperatures in excess of the softening temperature (70° C.–90° C.), tend to exhibit plasticity rather than the natural rubber properties. Actually they can be likened to heavily milled natural rubbers which have lost most of their "life."

Polystyrene formed at atmospheric temperature is not readily mouldable ; its close resemblance to unmilled natural rubber at moulding temperatures clearly describes the difficulties experienced. Mouldings can be satisfactorily completed but only when the mould is opened at temperatures below the elasticity temperature. This type of polystyrene may be classified as thermo-resilient but not thermoplastic. Prolonged milling at an elevated temperature appears to have no effect on the structure of any polystyrene polymers.

The permittivity of polystyrol is low, 2.2–2.6, and its conductance, under alternating or continuous voltages, is very low even at high temperatures (relative to industrial service) or under high humidity. The material retains its high-grade insulating properties even if immersed in water, and this fact, in 1929, led to the proposal of the I.T. and T. Laboratories for its use as an extruded submarine cable insulator in place of guttapercha. The material is, of course, infinitely superior to guttapercha.

Nevertheless, inclusion of chemical impurities in the material during manufacture do appreciably affect the conductance of the material so that the dielectric power factor is variously quoted as from 0.0001 to 0.0006. While dielectric losses of this order may from some points of view be considered as negligible, there are electrical insulation problems in which the doubling or trebling of even small dielectric losses are of importance.

Here again the use of the liquid monomeric styrol as the starting point is of importance inasmuch as the addition of small quantities of impurities produces very obvious differences in the electrical characteristics of the monomer. The dielectric power factor of the monomer is about ten times that of the polymer; thus, much more sensitive electrical readings can be taken and purification control is much simpler. During the polymerisation process the dielectric power factor is reduced gradually, as shown in Fig. 1, which illustrates a pure and an impure sample of monostyrol changing to polystyrol.

It is, therefore, now possible to produce polystyrol for industrial electrical purposes in such a way that the desired mechanical and electrical properties are predetermined, and are obtained by strict control of the process in which the raw material (monomer) is purified and transformed to the polymer. Various types of polymer so manufactured are marketed under the trade name "Superstyrex" and are the culmination of almost a decade of chemical and electrical research.

Commercial exploitation, until recently, has been hampered and delayed by the absence of supplies of monostyrol on a commercial scale. This material is now available from chemical plants in several countries, prices are becoming competitive, and it is obvious that widespread application of the material to the electrical field is likely to ensue.

In addition to the particular applications previously referred to, a study of the patent and technical literature of the last four years shows stimulation of interest in many directions. Con-

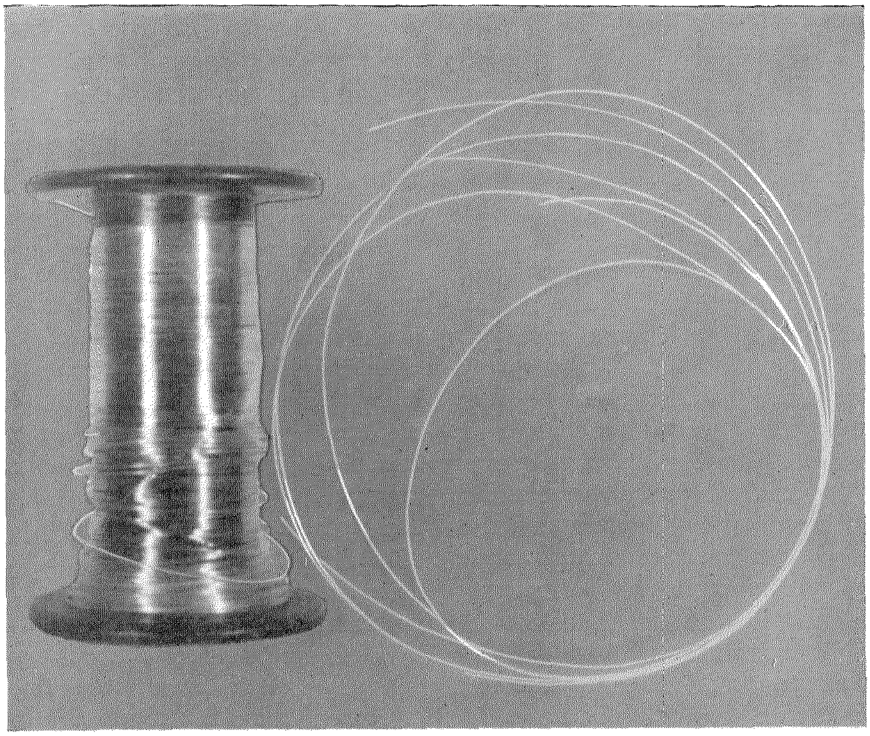


Fig. 2

densers, communication cables, moulded casings, etc., have all received attention ; lacquers have been developed ; and in general there is a tendency to consider the use of polystyrol for all cases where the highest grade of insulation is required.

The outstanding problem is that of employing a hard, glass-like material in situations in which toughness, flexibility, etc., are required. This necessitates engineering work of a high order ; firstly, to design the form of the insulation of the cable, apparatus, or machine in such a way that a variety of "Superstyrex" may be manufactured to suit ; secondly, to design a suitable variety of "Superstyrex." In the latter problem, little or no reliance can be placed on plasticisers. In general, plasticisers have to be considered as impurities, particularly in applications involving high frequency alternating fields.

Fortunately the range of polymers available permits of selection of a suitable type for almost any given purpose. As indicated in Fig. 2, threads may be formed, sufficiently flexible to admit of application to the insulation of wires or cables. To obtain good unplasticised thread, of course, the temperature of polymerisation and the temperature of extrusion must both be carefully chosen.

The polymer formed at an elevated temperature can be moulded into rigid insulating piece parts for all classes of radio, telephone and other electrical work where its superior electrical characteristics are of value. Its transformation into such piece parts, sheets, solid rod, tube, etc., is easily carried out by known moulding technique.

Rigid polystyrene mouldings are readily machinable provided a special technique is employed. The machined surface must be kept as near to atmospheric temperature as possible and definitely below the "elasticity temperature" of the mouldings. If the temperature is allowed to rise too high, the machined surface assumes rubber-like properties and, until re-cooled, further working is impracticable.

Polystyrene can be produced in the form of transparent films, similarly to cellulose esters found in this form. The film, particularly when manufactured from polystyrene formed at an elevated temperature, is semi-brittle unless plasticised. The tensile strength of these films is of the same order of magnitude as the cellulose ester films whilst the light stability is greater.

Polystyrene films find application as an interleaving tissue or lamination in electrical condensers on account of their very small moisture affinity, which obviates the necessity of special moisture sealing precautions on the finished condenser.

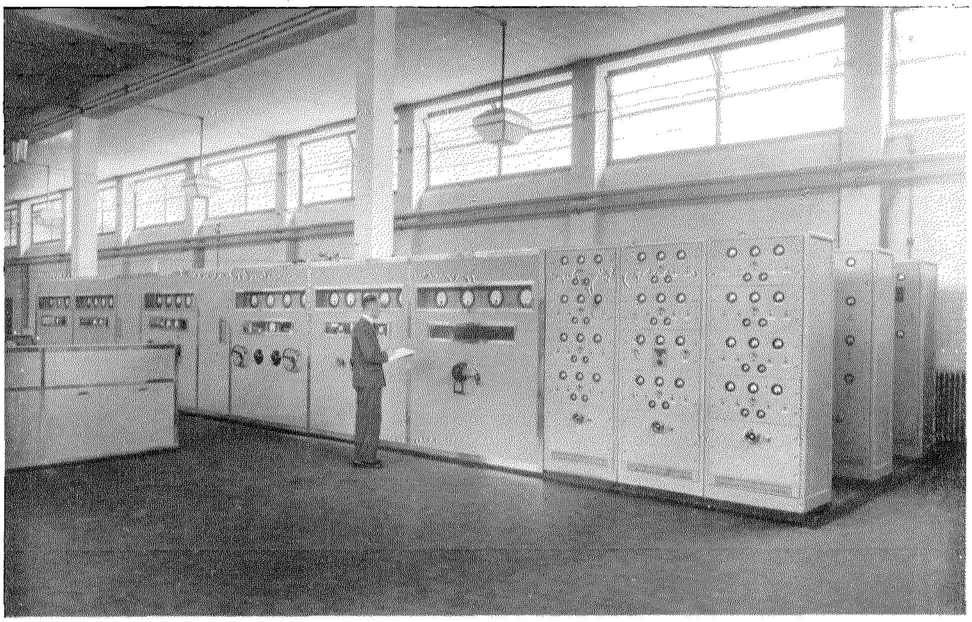
As already mentioned, it is anticipated that in the near future polystyrol will commence to play a very prominent part in the field of industrial insulation. Some of the reasons for this belief have been given, but the following additional considerations may be of interest.

Polystyrene, whether polymerised at room temperature or at an elevated temperature, has almost negligible water absorption characteristics when compared with other dielectrics of the same type. A thin sheet of room-temperature-polymerised styrene absorbs 0.03 per cent. water after immersion therein for three weeks, and represents the saturation value as the latter remains constant on prolonged immersion. It is 1/150 of the value obtained with cellulose acetate, which is the least moisture-absorbing cellulose ester in common use. Polystyrene shows a similar superiority over the naturally occurring hydrocarbon colloids such as rubber, de-resinated guttapercha, or balata. It is slightly superior to a highly refined hydrocarbon wax although, in this case, moisture absorption is of the same order of magnitude.

Chemically, polystyrene is very inert. It is unaffected by alkalies, aqueous solutions of most electrolytes and dilute mineral acids. Unlike liquid styrene, the long chain polymers are saturated with the exception of the benzene nucleus. They are not, therefore, readily oxidised and, unlike most of the synthetic rubbers, they do not absorb oxygen from the atmosphere. Pure polystyrene exhibits no effects of ageing, and a statement that a slight surface oxidation takes place should be taken with reserve. Oxygen absorption experiments have been carried out over long periods, but in every case these showed zero absorption.

The surface effect in question is probably due to the " drying off " of very slight traces of unpolymerised monomolecular styrene retained by the polymer. Lack of stability towards atmospheric oxygen has been one of the greatest drawbacks of practically all solid colloid hydrocarbon dielectrics, whether synthetic or naturally occurring. These include the synthetic rubbers, natural rubber, de-resinated guttapercha, balata, etc. The absence of ageing with polystyrene provides a dielectric exhibiting the valuable insulating properties of the colloid hydrocarbon without the poor ageing characteristics usually associated with this type of material.

Space does not permit inclusion of descriptions of the many possible combinations of polystyrol with other materials, although reference has been made directly to rubber mixtures and indirectly (in connection with power cable) to oil-arochlor-styrene mixtures. Such mixtures open up vast prospects of future possibilities in the insulation field as chemical and electrical research progresses.



THE DAVENTRY TRANSMITTERS

Standard Telephones and Cables, Limited, have designed, constructed and installed at Daventry, two High Power Short Wave Broadcasting Transmitters for the British Broadcasting Corporation British Empire Service. These Transmitters were placed in operation in time to play an important part in the Coronation broadcast programmes. On that occasion both transmitters operated for approximately twenty-one hours per day for four days.

The Transmitters are rated at 50 kW carrier power, which output is obtained down to a wavelength of 14 metres. As far as is known there are no Short Wave Broadcasting Transmitters to-day of equal power, at so low a wavelength, in use anywhere.

Besides their exceptionally high power, new technical features have been introduced in these equipments which are of very special interest, and will be described in a subsequent issue.

Supervisory Control of Traction Sub-Stations

By C. GORDON WHITE, B.Sc.(Eng.), A.R.C.Sc.I.,

Standard Telephones and Cables, Limited, London, England

SOME time ago there appeared in *Electrical Communication*[1] a description of Supervisory Equipment for controlling railway sub-stations whilst, more recently,[2] details were given of typical installations of control gear supplied for a variety of industrial enterprises. Since then there has been a steady increase in the demand for equipment of this kind, the advantages to be derived from its use having come to be more fully appreciated and the needs of industrial expansion and centralisation rendering it, in fact, well nigh essential.

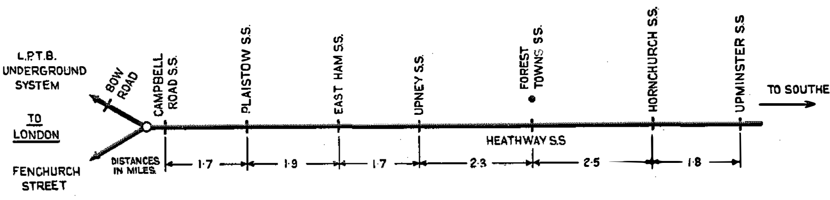


Fig. 1—London Midland and Scottish Railway—Bow-Upminster Line.

Increased application of supervisory control equipment has occurred particularly in railway and similar traction systems, involving the control of sub-stations through which the high tension supply is ultimately fed to the track or trolley wire system. In modern transport undertakings where high traffic densities are the rule, particularly in congested areas, continuity of service and flexibility in dealing with sudden load fluctuations are prime essentials, and can be attained in the most effective and economical manner by centralised control with complete supervision over the stations concerned and means for carrying out the necessary switching operations from a common centre.

Recent plans for development of railway electrification schemes in England and, more particularly, in the environs of London lend special interest, therefore, to two such installations on suburban railway systems. They provide for the supervisory control of unattended sub-stations operating on suburban lines in the vicinity of London ; and both are noteworthy because of the marked economy in pilot wires, a large number of facilities being provided over but one line pair which is common to a number of sub-stations.

Another point of similarity in these two installations is the selective telemetering system. Every fluctuation in the distant circuit is faithfully registered at the control centre without interference from the control and indication signals on the same line.

The first installation was supplied to the London Midland & Scottish Railway Company, for the control of sub-stations operating on the Bow-Upminster electrified line. The latter extends a distance of some twelve miles on the eastern outskirts of London (Fig. 1) and,

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[1] " The Selector System of Supervisory Remote Control as Applied to the Great Indian Peninsula Railway," by W. RDavies, *Electrical Communication*, January, 1931.

[2] " The Centralisation of Control of Power Networks," byE. M. S. McWhirter, *Electrical Communication*, January, 1935.

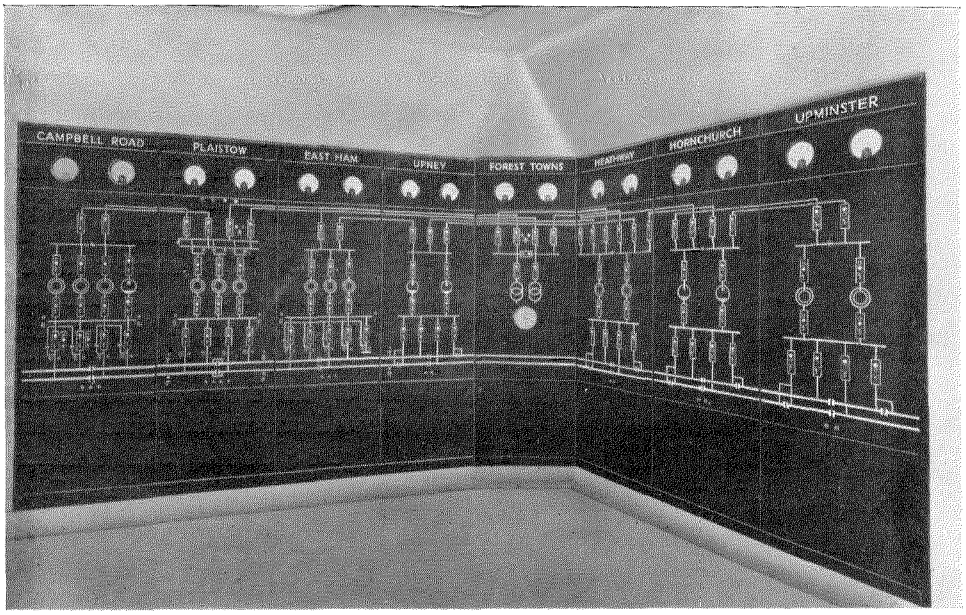

Fig. 2—Heathway Sub-Station—Control Board and Line Diagram.

through its close connection with the Underground System, handles extremely dense traffic loads.

The control centre is situated in the manually operated sub-station at Heathway, near Dagenham, Essex, whilst close by is the Forest Towns sub-station through which the supply from the County of London Electricity Supply Company is fed to the several traction sub-stations at 11 kV. It is then transformed down and fed via converters and rectifiers to the track circuits at 600 volts d.c.

The facilities provided include :

(*a*) Control and indication of :
  (1) 13 Rotary Converters
  (2) 5 Mercury Arc Rectifiers
  (3) 17 E.H.T. Feeder Breakers
  (4) 25 Track Feeder Breakers
  (5) 2 Protection Circuits.
(*b*) Control of Mass Firing of 12 Track Feeder Breakers in pairs at adjacent sub-stations.
(*c*) Indication of :
  (1) 13 E.H.T. Breakers
  (2) 2 Rotary Converters
  (3) 4 Track Feeder Breakers
  (4) 2 Tunnel Trip Circuits.
(*d*) Selection of any of 19 readings of d.c. volts and amperes.
(*e*) Constant proving of line continuity.
(*f*) Means for switching control and sub-station equipment to or from spare line.
(*g*) Indication of remote and local fuse alarms.
(*h*) Routine testing access equipment with portable test sets.

Telephone facilities are not included. They are adequately provided on the Railway Company's existing inter-station telephone system.

On the western section the three sub-stations Campbell Road, Plaistow, and East Ham are connected for control purposes on one system, all facilities being provided over a single telephone line pair connecting Heathway and Campbell Road and teeing-in intermediately at East Ham and Plaistow.

To provide against interruption of the system in case of line failure, an alternative line pair also connects these stations. Facilities are available for switching over all the associated control equipment, both at the control station and at each sub-station, from one line to the other, or vice versa, by a simple operation carried out at the control station.

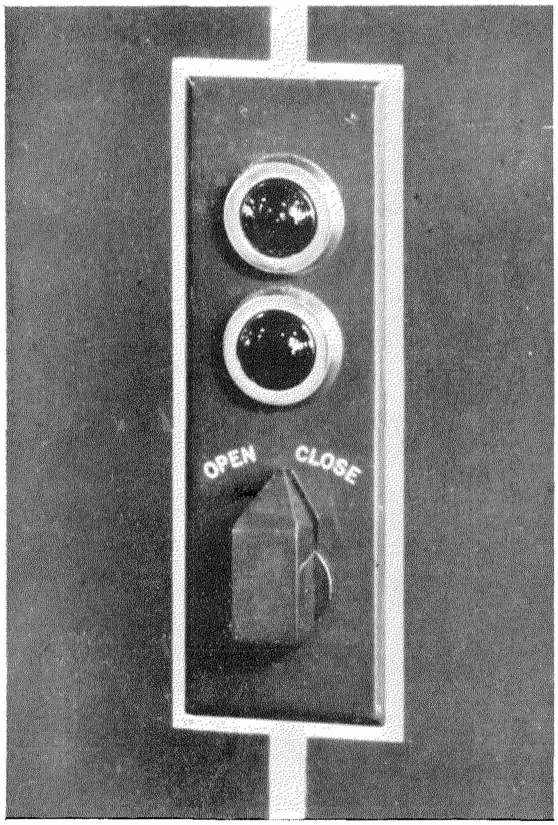

Fig. 3—Control and Indication Unit for Circuit Breaker.

Continuity of the line is proved by detection at the control station of a voice frequency current continuously generated at the terminal station, interruption of this current by failure of the line or a fuse alarm condition at any of the stations giving an appropriate signal at the control station.

The signalling system, by means of which controls and indications are effected, embodies the principles of the Constant Total Code System previously described.[3] Signals in the form of trains of impulses to and from the control station are employed for performing the desired operations, which, however, are effected only when the correct totality of each component train of impulses, as also of the complete train, has been proved.

The coding system for signals from the central station employs five digits, X Y A B and C, for each signal in a manner such that X + Y, and also A + B + C, each total a constant in all cases. The A B C code denotes the operation to be effected at the sub-stations which, all being very much alike in character, are conveniently arranged to have the same coding scheme. The X Y combination determines the destination of the subsequent A B C signal, according to whether it is intended for one particular station, a group of stations or all stations simultaneously. The maximum number of digits and the constant totals are chosen arbitrarily in relation to the ultimate requirements of the particular system concerned.

Whilst signals from the control station need be originated but one at a time, as, for instance, for switchgear control operation, meter selection, station check operation and the like, it is most desirable that the signals from the sub-stations giving the position of the various switchgear units should be returnable per station or group of stations in the shortest possible time; and, therefore, the scheme of signalling in this direction is somewhat different. Here the signals are arranged in two trains of impulses in which each impulse may be either positive or negative in accordance with the marking set up in the signal transmitting circuit. The first train constitutes the group code and indicates both the station of origin and the group concerned, while the second train comprises the position indications of the units included in that particular group. The number of groups, as also the units in each group, are chosen arbitrarily; and, for the equipment herein referred to, the two trains comprise in all 13 impulses. One such train gives the position of seven breakers or the like, four seconds only being required for the transmission and registration at the control centre, whilst the position of all machines and switches at these three sub-stations can be indicated in approximately 40 seconds.

Where, as in this case, two or more stations are parties on a common line, steps must be taken to ensure that two stations wishing to send signals at the same time cannot, under any circumstances, seize the line and thus mutilate the signals. Should conditions of simultaneity arise, one of the stations, having a pre-arranged order of preference, obtains control of the line to send its signal without mutilation, while the

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[3] See footnote [2].

other station (or stations) stores its signal and transmits it as soon as the line becomes free.

Position indication for each breaker is given on a pair of lamps, red (close) and green (open), any change being signalled automatically and registered: by steady lighting of the lamp for the new position, and a flashing light (about 60 cycles per minute) for the old position—as a ready means of identification—together with illumination of the name plate of the appropriate station and the sounding of a common alarm. Such a change is accepted by throwing the key associated with the breaker concerned to the new position indicated, whereupon the red or green lamp only, as the case may be, is left alight.

For control operations, the breaker key is thrown to "close" or "open" ("start" or "stop" if converters or rectifiers are concerned); and pre-selection, prior to completion of the operation, is indicated by "flicker" (at a frequency of 120 cycles a minute) on the lamp corresponding to the desired position.

When a check of a distant station is originated to verify that the indication on the board is in fact in agreement with the switchgear at the distant station, all the lamps for the station concerned are extinguished. They subsequently light up in groups as the incoming signals are received, any changes being registered and signalled in the manner already described.

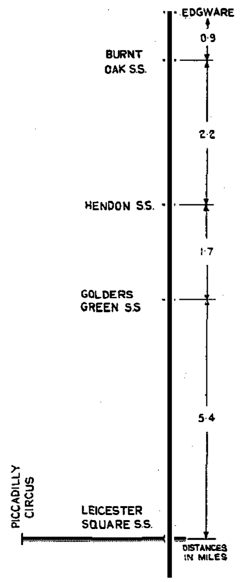

Fig. 5—*London Underground System: Golders Green—Edgware Line.*

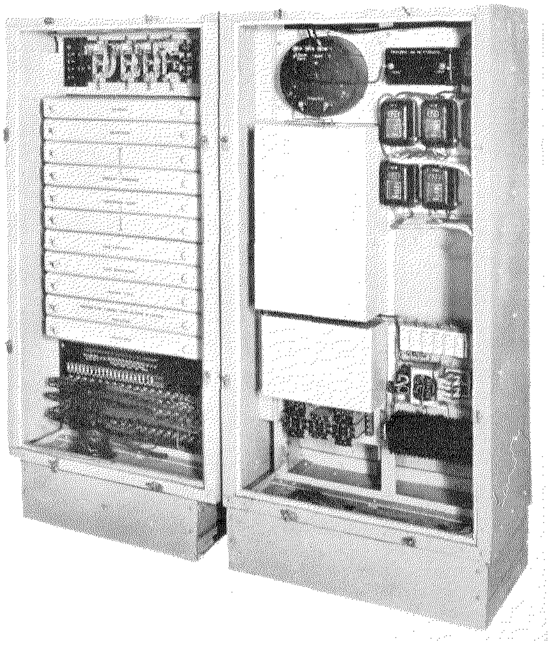

Fig. 4—*Campbell Road Sub-Station—Supervisory and Telemetering Equipments with Main Covers Removed.*

The other three unattended sub-stations, Upney, Hornchurch, and Upminster, have been controlled remotely from Heathway for some time past over a multicore system operating at 250 volts d.c. For these stations, equipment permitting uniform control procedure applicable to all the unattended stations on the network has been provided.

The circuit breaker symbols on the control board for all stations are the same; and the means of indicating changes automatically as well as carrying out the various controls on these two systems, are similar. These arrangements demonstrate in a striking manner the flexibility and adaptability of the telephone type apparatus units (namely, relays, selectors and the like), when applied in conjunction with the circuit design features generally used in automatic

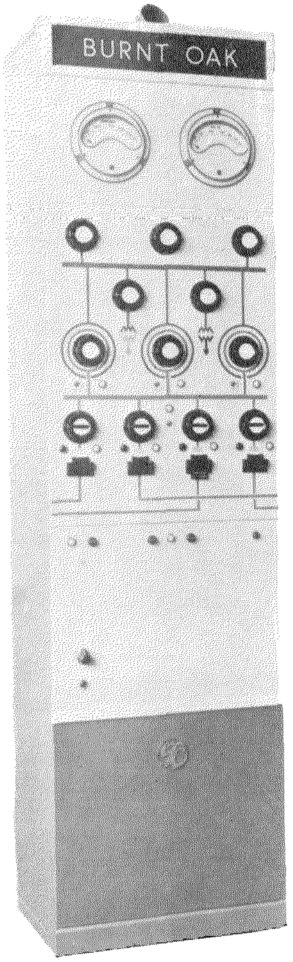

Fig. 6—*Golders Green Sub-Station—Supervisory System Control Board and Line Diagram.*

telephone systems, to purposes other than those for which they were originally designed.

The control board (see Fig. 2) comprises in all eight panels, one for each connected sub-station, combined to form a system line diagram covering the E.H.T., d.c., and track systems of the network. The a.c. section is coloured in red and the d.c. section in cream with a restful, blue-green coloured background. The high grade finish of the board is enhanced by the fact that no fixing screws of any kind are visible from the front. The board forms two sides of the control room. Access is provided to the apparatus at the rear by doors at each end and, to the rack wiring, by lift-off panels on the front.

Each breaker (see Fig. 3) is represented by a symbol appropriately located in the line diagram, consisting of an escutcheon plate on which is mounted two lamps, red (close) and green (open), together with a 3-position key, whilst manually operated isolators are represented by semaphore discs which can be set by hand.

Each of the meter selection keys, with associated pilot lamp, is positioned on the diagram in proximity to the circuit to be measured, whilst two indicating meters, scaled in volts and amperes, respectively, are fitted on each sub-station panel to conform with the stations connected on the multicore system for each of which a voltmeter and ammeter are permanently connected.

The station panels are each surmounted by a facia bearing the name of the station, which is illuminated from the rear when any alarm condition in respect of the station occurs. Illumination continues until the condition is accepted.

A typical sub-station installation, with main covers removed, is shown in Fig. 4. The equipment consists of two units, the one on the left housing the signalling relays, selectors, etc., all operating from a 50 volt d.c. supply, whilst that on the right is reserved for apparatus associated with the metering facilities, including the transmitting meter, the V.F. equipment and the interposing relays for switching the 600 volt circuits.

Provision is also made, in the diagram, for the indication of several units at Heathway itself and at Forest Towns Sub-Station nearby, local multicore cable directly connected to the switchgear being utilised for both stations. The resultant comprehensive diagram serves to present a complete and ever correct picture of the whole system, both H.T. and L.T., and thus materially assists in the efficient control of the complete network.

The second installation is on the London Underground Railways and is the first equipment of its kind to be used on this system. The unattended sub-station at Burnt Oak (Fig. 5) is controlled from the manually operated station at Golders Green some five miles away. These stations serve a section of the Hampstead tube which handles heavy traffic in a densely

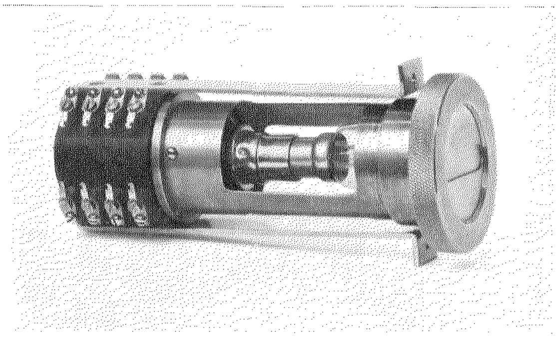

Fig. 7—Supervisory Control and Indication Unit—Semaphore Type.

populated district in the northern outskirts of London.

The operating principles and range of facilities generally are similar to those of the equipment described above, but, in this case, an existing multicore cable is retained for the control and indication of the track feeder breakers. All other facilities, including metering, are provided over a single line pair and with means for switching to a spare line should occasion demand.

The control board with system line diagram is shown in Fig. 6. It will be observed that the unit used for control and indication in this case is circular in shape and of the semaphore type. It comprises (Fig. 7) a barrel type key incorporating a single lamp and having a slotted aperture on the circular face. These units are located appropriately in the system diagram in such a way that when the slot is in agreement with the line of the diagram, the " close" position is indicated whereas the "open" position is that at right angles to the line.

Indications of changes are signalled by flashing of the appropriate indicator lamp. Such changes are accepted, i.e., audible alarm silenced and flashing changed to a steady light by turning the indicator through 90 degrees so as to be in agreement with the new position. The same unit is used also for control where this facility is included; and pre-selection is effected by setting it in disagreement with the existing indication by a turn through 90 degrees, and then overturning it through a small angle. With this unit the diagram need not normally be illuminated, the slotted aperture affording a ready indication of the condition of breakers and similar switchgear units.

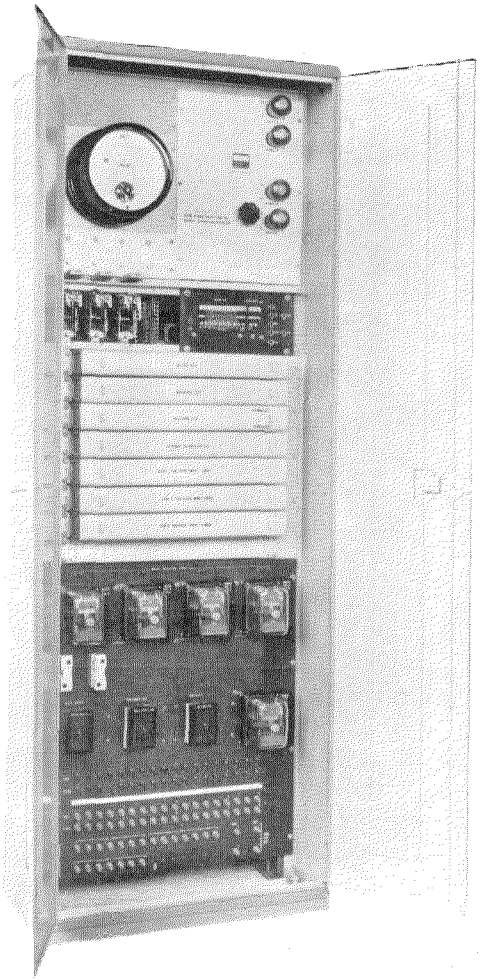

Fig. 8—Burnt Oak Sub-Station—Supervisory and Telemetering Equipment.

Fig. 8 shows the installation at the substation. Here the signalling apparatus is mounted in one unit with the 600 volt metering equipment which is suitably protected.

On traction systems, the rapidly fluctuating current and voltage readings encountered demand a readily responsive telemetering system; and, together with economy of line pilots so desirable on such systems, constitute requirements eminently satisfied by the Variable Frequency Continuous System of Telemetering incorporated in both equipments herein described. It is suitable for use on telephone type

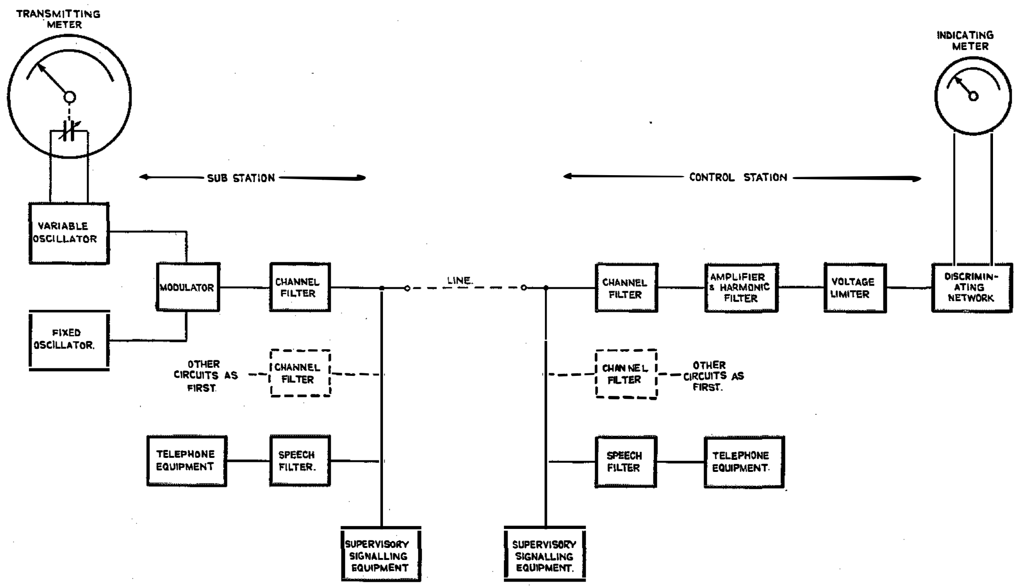

Fig. 9—*Block Schematic of Variable Frequency Continuous* (*V.F.C.*) *Telemetering System.*

circuits and enables meter indication to be provided simultaneously with the transmission of d.c. signals over the line pair used for control and indication purposes.

The method employed (Fig. 9) is to vary the frequency of an oscillator with the deflection on the transmitting meter and transmit the output to the indicating centre. Here a voltage limiter cuts the received wave to a definite amplitude, and a discriminating network then attenuates it according to the frequency, the output being rectified and registered on an ordinary d.c. milliammeter.

In the equipments referred to herein, where only one reading at a time is required, one channel of voice frequency, common in the case of the party line system to all connected stations, is employed; also, only one unit of receiving equipment is necessary at the control station with, of course, as many indicating instruments as may be desired.

At each sub-station too, only one transmitting instrument (Fig. 10) is required, since it is suitable for connection either to the 600 volt d.c. circuits for pressure readings or, alternatively, to an ammeter shunt for current readings, the connection in each case being completed, on receipt of the appropriate selection signal, by means of a suitable interposing relay, one for each circuit to be measured.

The main principles of the system can best be followed by reference to the block schematic shown in Fig. 9.

The transmitting meter carries a variable condenser of low capacity which, with the small potential difference on the plates, renders the torque imposed on the meter negligible compared with the other controlling forces. Two oscillators, one of fixed frequency and one controlled by the variable condenser on the meter, are used in conjunction with a modulator to give a beat frequency.

Filters to pass all frequencies within the band and virtually exclude all others are necessary with multi-channel indications and superimposed speech but, in the present equipments where only one channel is used, they are not required.

The receiving amplifier is of two stage transformer design with a high gain. The harmonics generated therein are in turn eliminated by passing the resultant output through the harmonic filter.

The voltage limiter maintains the wave, passed to the final network, at a constant amplitude by means of a special neon tube limiter. The discriminating network comprises a low pass filter of special design with a section to attenuate the harmonics generated by cutting the wave in the voltage limiter. The filter is designed to work near its cut-off point and provides an attenuation varying with the frequency within the band employed. The output wave varies in amplitude approximately inversely as the frequency.

The indicating instruments are d.c. milliammeters, suitably scaled, deriving their current from the V.F. wave of varying amplitude passed through a metal rectifier.

Among the advantages of this system may be mentioned the following :

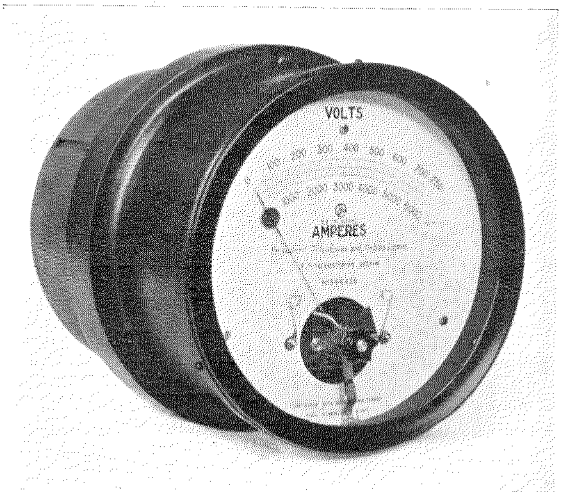

Fig. 10—*V.F.C. Transmitting Meter as used at Sub-Station.*

1. The band of frequencies used for one indication is narrow—50 to 80 cycles—and has sharply defined limits. Thus a number of simultaneous indications can be transmitted over a single line or, alternatively, one or two indications at the same time as speech ;
2. The indication is truly continuous at all parts of the scale so that small changes are immediately shown ;
3. No moving parts, other than the actual moving elements of the transmitting and indicating instruments, are employed ;
4. The indication is independent of the line attenuation over a range of 0–30 db. ;
5. The indication is independent of cross-talk and other induced interference, provided the induced voltage is not greater than half the indicating voltage, and only then when the interference falls within the band employed ;
6. The complete equipment may be operated entirely from the station mains, the load being about 3 watts for the transmitting equipment and 10 watts for the receiving equipment. The accuracy of the indication is scarcely affected by fluctuations in the mains voltage, a variation at the transmitting station of ±10 per cent. causing an error of only ±0.2 per cent. in the indication. Variation of voltage at the receiving station has no appreciable effect ;
7. The accuracy of the indication is only slightly affected by changing the oscillator valves. For instance, a maximum error of 0.5 per cent. has been observed on test when the regular oscillator valves were replaced by very old ones. Any such error is easily checked and corrected at the transmitting station by adjustment of the oscillator. This is possible because of the presence of a positive signal at zero and full scale deflections. No zero adjustment is made on the actual meters other than those usually required on normal meters.

Both installations were supplied in conjunction with the British Thomson-Houston Co., Ltd., of Rugby and London.

Ultra-Short Wave Communication

By E. H. ULLRICH, M.A., A.M.I.E.E.

This article is the substance of lectures on ultra-short waves and micro-rays given by the author.[1] *The single-channel radio telephone circuit between Barcelona and Majorca, and the nine-channel multiplex radio telephone link between Scotland and Ireland are described. Signal/noise ratio measurement results in Spain and Majorca are given.*

A comparison of the utility of wavelengths between 1 *and* 10 *metres on the one hand and* 14 *and* 30 *cm on the other is made, the conclusion being definitely in favour of the former band for commercial ultra-short wave radio telephone links.*

Brief reference is made to other uses of ultra-short waves.

ELECTROMAGNETIC means of communication were known to and used by the Ancients. Visual signalling by reflection of the sun's rays or the lighting of beacons was used in very early days. About 300 B.C., the Greeks transmitted signals by torches and other ingenious means. The question at once arises, therefore, why such means, with their intrinsic advantage of speed, remained undeveloped, even when no other electromagnetic signalling methods were available. It will be shown later that one of the most important applications of ultra-short waves in communication is in the linking-up of points within or almost within optical range of one another; the question, therefore, justifies some consideration. Prior to the development of rapid transport, there was no sustained demand for rapid communication. When, however, such demand did arise, particularly with the development of the steam locomotive, visual signalling did not meet practical requirements except for distances of the order of one kilometre. For long distances it was unreliable and, requiring optical visibility, was possible only between elevated points. This latter limitation is a serious handicap to the establishment of a nation-wide communication network except in conjunction with systems where optical visibility is not necessary. Nevertheless, Claude Chappe, having failed to obtain satisfactory electrical telegraph operation over long distances on account of insulation difficulties, started developing visual telegraph signalling in France in 1791; and, in 1852, when the Chappe System was replaced by the electrical telegraph, it covered more than 4000 kilometres and included 556 stations. Visual signalling was used also in Great Britain during the Napoleonic Wars.

For half a century the history of communication by electrical means was based on the transmission of electric waves along conductors, and important telephone networks were built up along these lines. A radical departure was the development of wireless signalling whereby the intelligence-carrying electric waves were set free from their conductors and launched into space. The new art was of immense utility, as it made communication with moving objects possible, no other communication means being available for this purpose except over short distances. For a long while its use was confined to telegraphy, the electrical waves being produced by means of sparks, arcs or high-frequency alternators, but the production of commercial vacuum tubes at about the time of the outbreak of the Great War soon led to radio telephony.

The new development at once assumed capital importance in the extension of the existing telephone networks. Whereas, in the telegraph field, submarine cable and radio

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[1] Lectures given before the Société Belge des Electriciens, Brussels; Engineers of Dutch Posts and Telegraph, Colonial Department; Army and Navy, The Hague; Polytechnical Society, Bucharest; Italian Electrotechnical Association, Rome, Milan, Turin; Norwegian Electrotechnical Society, Oslo; Swedish Electrotechnical Society, Stockholm; Society of Electrical Engineers, Prague; Societyof Engineers and Architects, Berne; Swiss Institution of Electrical Engineers, Zurich; and Union of Hungarian Electrotechnicians, Budapest.

existed as competitors; in the telephone field, such competition was hardly possible: submarine cable was uneconomical for long distances, and radio-telephony uneconomical for short distances. The linking-up of the telephone networks of Europe and North America was accomplished by radio, the transatlantic service being opened to the public in 1927 on the now low radio frequency of 57 kilocycles per second. In the years immediately following, long-distance commercial short wave radio-telephone links were established between Madrid and South America, New York and Buenos Aires, Buenos Aires and Great Britain, Amsterdam and Java, as well as between Great Britain and the outlying dominions of the British Empire and between other places.

For communication between fixed points radio has both "virtues" and "vices." Foremost among the virtues are the possibility of transmitting wide band-widths on short waves, and lower attenuation as compared with present-day cables. The width of band that can be transmitted increases as the wavelength is shortened. High quality programmes can thus be easily passed over short wave links, and on ultra-short waves television can be accommodated. The reduced attenuation means greater spans before a repeater station must be introduced, and it is for this reason that radio is as yet the only means of realising transoceanic telephony. The vices of radio, however, compromise to some extent its utility: the service which it offers is inferior in certain respects to that provided by high-grade, long-distance underground cables. Variability of propagation resulting in changes in the grade of transmission, and selective fading introducing distortion on short waves are the major obstacles to a perfect service. Propagation variations are so considerable that signals may disappear entirely, and it becomes necessary at certain times of the day to change the transmitted wavelength. These wavelength changes do not always become necessary at the same time each day, and radio operators in practically constant attendance are, therefore, needed at the transmitting and receiving stations. In addition, it is necessary to provide operators whose duty it is to regulate the speech level of subscribers so that the radio transmitter is substantially fully loaded regardless of speakers despite differences of 30 decibels in the incoming level. Without this level control, a weak talker would be received by his correspondent at so low a volume that the conversation might be impaired by the background noise of the receiver, such background noise often being at a much higher relative level at the end of a long radio link than at the end of a repeater section of underground cable. This defect of relatively high noise level is traceable to economic causes in general and, in the case of short waves, to peculiarities of

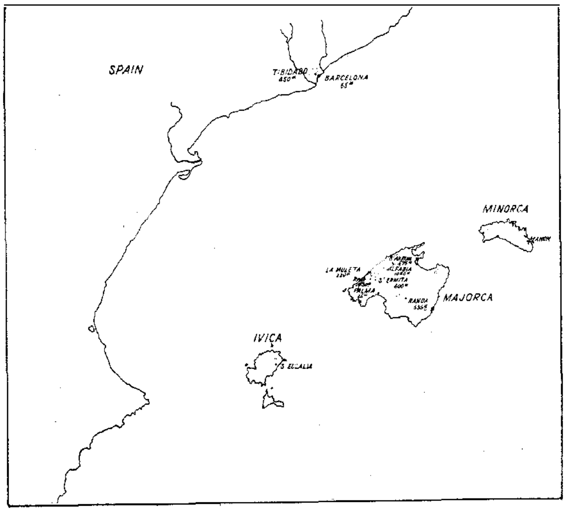

Fig. 1— Map of the Country Involved in the Tests Between Barcelona and Majorca.

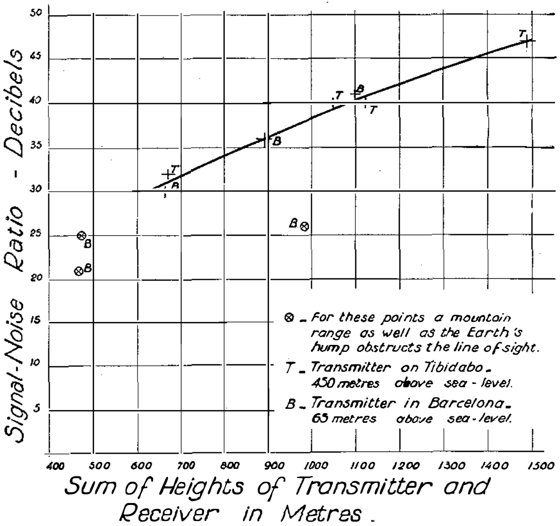

Fig. 2—Variation of Signal/Noise Ratios with the Sum of Transmitter and Receiver Heights.

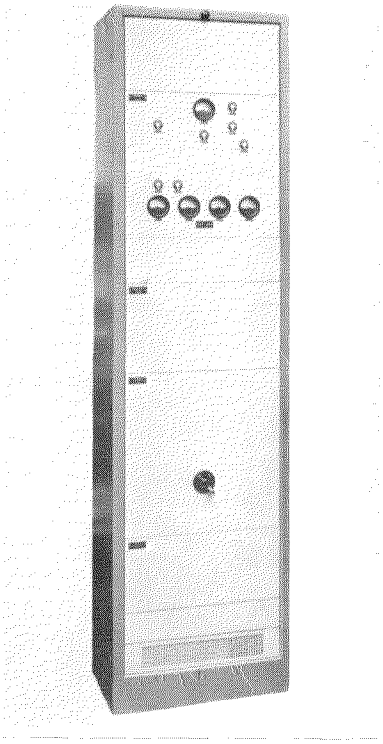

Fig. 3—10-*watt Ultra-Short Wave Transmitter* (*Front View*).

propagation. The fact that the overall attenuation of short wave links is actually less for long than for short distances explains why the noise level relative to the signal at the receiving station cannot be reduced by the same method as is used for repeatered cable circuits, viz., by a reduction of repeater spacing. Long wave transmission is handicapped by the inefficiency of radiating antennae, augmented by their lack of directivity, and by the high level of that type of electrical interference known as "static." The capital cost of the terminal stations is so high and the ether so congested in this wavelength band that long wave radiotelephony is rarely used.

The desiderata for a competitive radio link are stability of transmission equivalent, freedom from noise, reasonable capital cost and satisfactory operating expenses. To what extent these conditions can be met by ultra-short waves will be seen below. First, however, the advantages offered by these high frequencies will be discussed.

THE ULTRA-SHORT WAVE SPECTRUM AND ITS BAND-WIDTH ADVANTAGES

The wavelength band which has been used for radio telegraphy or telephony extends from 20 000 metres to 17 centimetres, i.e., from 15 kc p : s to 1 700 Mc p : s. The short wave band is usually considered as covering the range 100 to 8 metres (3 Mc p : s to 37.5 Mc p : s), the ultra-short wave band from 8 metres to about 50 centimetres (37.5 Mc p : s to 600 Mc p : s), and the micro-ray band from 50 centimetres to 10 centimetres (600 Mc p : s to 3 000 Mc p : s). The limits of the short wave band are defined by propagation peculiarities. Wavelengths shorter than 100 metres present the interesting phenomenon of negative attenuation at very long distances due to reflection from the Heaviside layer. The lower limit of the band is usually placed around 8 metres, inasmuch as early theoretical considerations showed that shorter wavelengths, instead of being reflected from the Heaviside layer, might succeed in penetrating the ionised upper atmosphere and leaving the earth. It is, therefore, around this frequency that long-distance propagation, with its advantages and disadvantages, was expected to cease. Naturally, the above limits are not very critical. The lower limit for ultra-short waves is determined, not by propagation peculiarities, but by a change in the technique of high frequency production which will be discussed in more detail later.

It may be stated in a general way that the greater the detail of the intelligence to be transmitted the greater the band-width required for such transmission. It is reasonable to allow 125 cycles per second for high-speed telegraphy, 2 750 cycles per second for commercial telephony and 2.5 Mc p : s for 405-line television. On account of the necessity of leaving space between adjacent bands, the total band-width occupied by double-side-band transmission may be taken as 400 cycles per second for telegraphy, 8 000 cycles per second for telephony and 6 Mc p : s for television. Between 20 000 metres and 100 metres, there is, accordingly, ether space for 7 462 telegraph channels, 373 telephone channels, but not one 405-line television channel; between 100 metres and 8 metres, for 86 250 telegraph, 4 312 telephone and 5 television; between 8 metres and 50 centimetres, for 1 406 250 telegraph, 70 312 telephone and 93 television; and between 50 centimetres and 10 centimetres, 6 000 000 telegraph, 300 000 telephone and 400 television. It will be seen that the number of channels which can be accommodated increases rapidly as the wavelength is reduced. The number of circuits which could be established increases, however, still more rapidly since, owing to the lack of long-distance transmission on ultra-short waves, several circuits might be satisfactorily accommodated on the same wavelength in different parts of the world.

COMMERCIAL RADIO TELEPHONE LINKS ON ULTRA-SHORT WAVES

Barcelona—Majorca Link

Towards the end of 1933 the question arose of linking Spain to the Balearic Islands by means of ultra-short waves. The shortest distance between the islands and the mainland being about 150 kilometres, the cost of a submarine telephone cable would have been considerable. The only telephone connection existing at the time was a short wave circuit from Madrid to Palma de Majorca; but, on account of the variability of short wave propagation, the reliability of this link was not considered to be satisfactorily high.

In order to choose the locations of the terminal stations, a series of tests was carried out covering the spring of 1934. It was not possible at this time to make the exhaustive tests which would have been desirable; it was accordingly decided to make measurements on one single wavelength, viz., 6 metres (50 megacycles per second), between several locations and, having thus determined the most suitable location, to choose the best wavelength for this link. As most of the telephone traffic from the Spanish side originates in the vicinity of Barcelona, it was naturally desirable that a site should be found near this city. Two locations appeared to be of particular interest. One was on the mountain of Tibidabo behind Barcelona since a direct line of sight exists on clear days to the island of Majorca; the other was the Cataluña telephone building in the middle of Barcelona itself since a terminal located there would be very convenient to maintain and supervise, and would dispense with the use of long telephone lines to the exchange. Likewise there were two sites in Majorca which appeared particularly promising. One was the telephone building in Palma on grounds of convenience; the other, the top of Alfabia Mountain whence there is direct visibility to Tibidabo.

The danger of electrical interference from

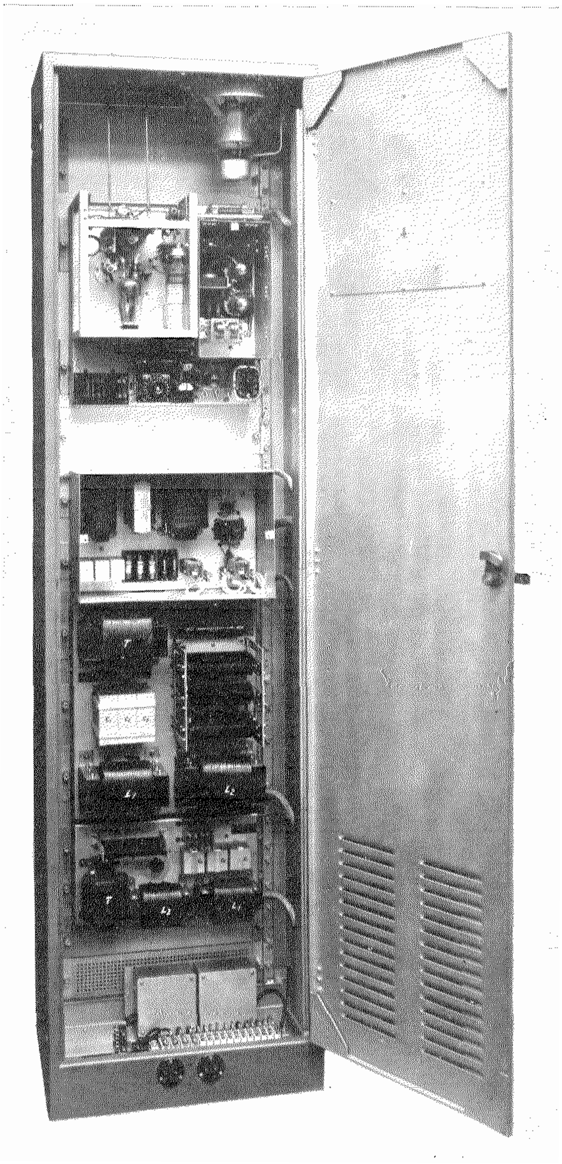

Fig. 4—10-*watt Ultra-Short Wave Transmitter* (*Rear View*).

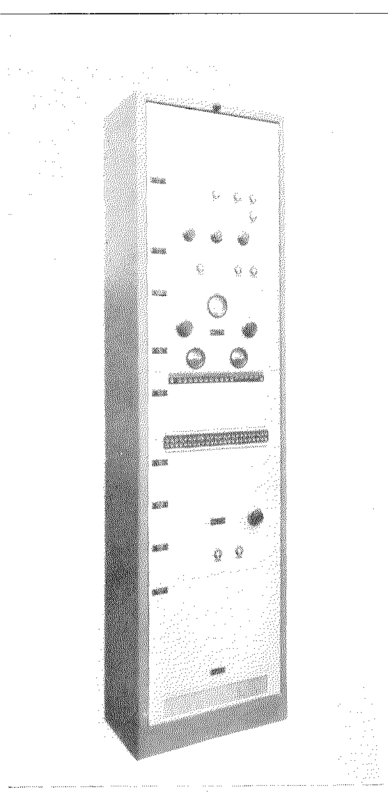

Fig. 5—*Receiver Bay for Ultra-Short Waves* (*Front View*).

motor cars and machinery was not overlooked, and one of the objects of the experiments was to determine to what extent such interference would disturb a commercial circuit.

In view of the reversibility of light, it was considered probable that propagation would be identical in both directions, and it was accordingly considered unnecessary to make two-way transmission measurements except when artificial interference existed at one of the receiving stations. At the Barcelona end, the transmitter delivered about 12-watts carrier to the aerial transmission lines and was capable of 100 per cent. modulation. The circuit consisted essentially of an uncontrolled master-oscillator, modulator and modulated amplifier. A directive transmitting antenna was used on the Tibidabo Mountain, producing a field strength at the distant station 15 db greater than a single half-wave element. The gain of the transmitting aerial on the telephone building at Barcelona was 9 db. The receiver used in Majorca was an ultra-short wave super-heterodyne, and directive receiving aerials were employed at all locations. The gain was 9 db over a half-wave dipole in each case, except at the Palma telephone building where the gain was 3 db, the space available not being sufficient to permit installing a more highly directive antenna.

The figure which decides the grade of a telephone circuit is the ratio of the wanted signal to unwanted noise. The method of making these measurements is to transmit from the transmitting station a suitable tone—in this case 1 000 p : s—at a definite percentage modulation of the transmitter and to adjust the output of the distant receiver so that a suitable deflection is obtained on a measuring instrument, such as a vacuum tube voltmeter. Modulation is then cut off from the transmitter and the low frequency amplification of the receiver increased until the average deflection of the measuring instrument is the same as when the tone was being transmitted. The change in amplifica-

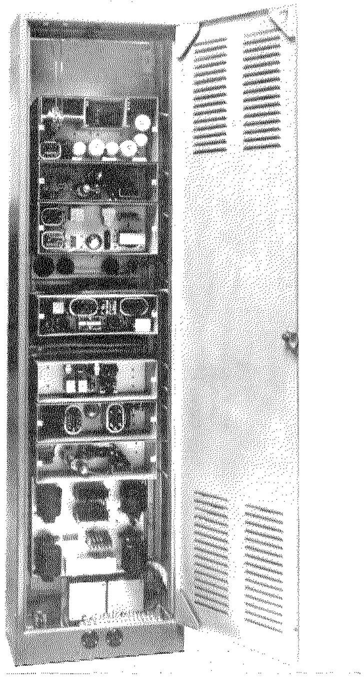

Fig. 6—*Receiver Bay for Ultra-Short Waves* (*Rear View*).

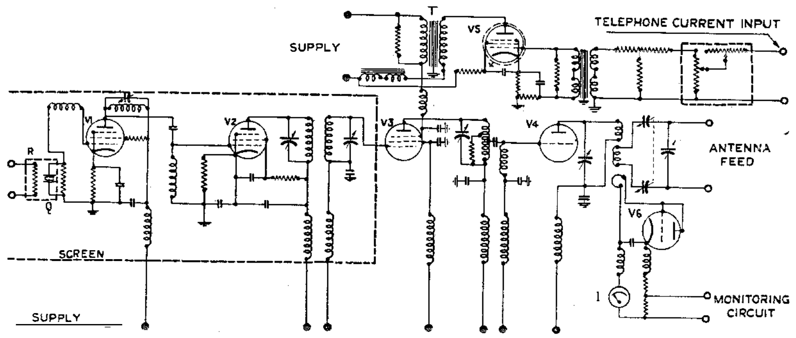

Fig. 7—*Schematic of Crystal-Controlled* 10-*watt Ultra-Short Wave Telephone Transmitter.*

V_1 Oscillator,
V_2 and V_4 Frequency doubler tubes,
V_3 Modulated amplifier,
V_5 L.F. amplifier,
V_6 Monitoring tube,
Q Quartz crystal,
R Heater,
T Modulation transformer,
I Antenna current indicator.

tion, usually expressed in decibels, is defined as the signal/noise ratio. Thirty to forty measurements spread over several days were obtained at each site, and the average was taken as the figure of merit of the site from the standpoint of a commercial service.

For a high quality commercial link a signal/noise ratio of 45 db on full modulation is required. In this case very little noise can be heard under normal telephone conditions and weak talkers, 30 db below maximum modulation, still have a signal/noise ratio of 15 db.

Fig. 1 shows the map of the country involved in the tests. Data regarding the transmission paths and the measurement results for the various sites are given in Table I. Except in the case of tests Nos. 2, 3 and 4, which were over paths with intervening mountains in Majorca, data are given showing the total distances and the distance from the test points to the points of tangency with the surface of the water. The overlapping distance of the lines from the test points to the points of tangency are also given. In most cases the overlap is shown as negative, which means that the two lines of sight do not meet and that transmission over this path is

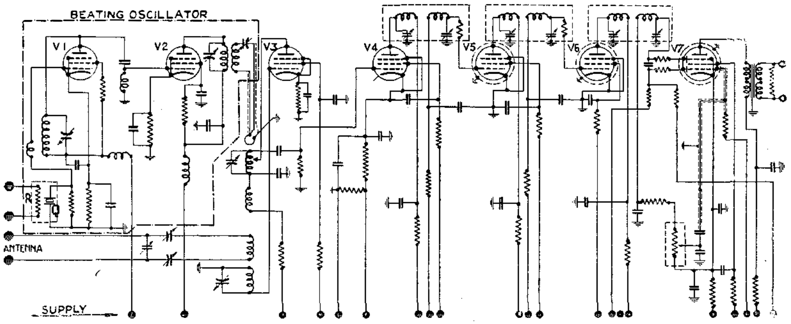

Fig. 8—*An Ultra-Short Wave Telephone Receiver with Crystal-Controlled Beating Oscillator.*

V_1 Oscillator,
V_2 Frequency-quadrupler,
V_3 H.F. amplifier,
V_4 First detector,
V_5 and V_6 I.F. amplifier stages,
V_7 Detector and L.F. amplifier,
Q Quartz crystal,
R Heater.

TABLE I

RESULTS OF ONE-WAY ULTRA-SHORT WAVE RADIO TESTS

BARCELONA—MAJORCA 50 MEGACYCLES PER SECOND (6 METRES)

Test No.	Barcelona.		Majorca.		Total Distance.	Geometric Distance to Point of Tangency.			Distance Allowing for Refraction.			Average Signal to Noise Ratio.
	Point A.	Elevation.	Point B.	Elevation.		Point A.	Point B.	Overlap.	Point A.	Point B.	Overlap.	
1.	Tibidabo	450 m.	S'Ermita	600 m.	199 km	75 km	87 km	–37 km	87 km	100 km	–12 km	40 db
2.	Tibidabo	450	Palma Telephone Building	25	210	75	Note (1)	—	87	Note (1)	—	19 (2)
3.	Tibidabo	450	Palma Radio Station	20	208	75	Note (1)	—	87	Note (1)	—	21
4.	Tibidabo	450	Randa	535	221	75	Note (1)	—	87	Note (1)	—	26
5.	Tibidabo	450	La Muleta	220	185	75	53	–57	87	61	–37	32
6.	Tibidabo	450	S'Arrom	675	192	75	93	–24	87	107	+2	40
7.	Tibidabo	450	Alfabia	1040	193	75	115	–3	87	132	+26	45 (4)
8.	Barcelona Telephone Building	65	Alfabia	1040	188	29	115	–46	33	132	–23	35 (3)
9.		65	S'Ermita	600	195	29	87	–79	33	100	–62	24 (3)
10.		65	Ram	830	197	29	103	–65	33	119	–45	30 (3)
11.		65	Alfabia	1020	189	29	114	–46	33	131	–25	35 (3)

(1) Distances from Point B to point of tangency not given, because in these cases diffraction takes place at intervening mountain ranges in Majorca and not at water surface as in the remaining cases.

(2) This measurement made with a 3 db receiving antenna in Majorca as compared to 9 db antenna used in all other tests.

(3) These measurements correspond to a 9 db transmitting antenna in Barcelona as compared to a 15 db antenna used in the tests from Tibidabo.

(4) As hum on transmitter was between 47 and 49 db, this signal/noise ratio corresponds to about 47 db.

due to diffraction. It has been shown by Schelleng, Burrows and Ferrell[2] that on account of refraction these radio waves do not follow a straight line. Two sets of figures have, therefore, been given for the distance from each terminal to the point of tangency, the one being based on pure geometrical considerations, and the second taking account of the curvature of the paths due to refraction. It will be noted that there are no cases of direct visibility on purely geometrical considerations, and in only two cases is there visibility taking refraction into account. The average signal/noise ratios based on 80 per cent. tone modulation is tabulated in the last column.

For the first test the summit of the Tibidabo mountain, lying on the outskirts of Barcelona and having transportation, telephone and power facilities, was selected at the Spanish end, and the grounds of an abandoned monastery known as S'Ermita, located about 12 kilometres from Palma, was chosen in Majorca, it being evident that this site would prove to be one of the more economical ones. An average signal/noise ratio of 40 db on tone showed this to be a possible solution from a transmission standpoint.

It was then decided to test immediately the possibility of locating the Majorca terminal on the Palma telephone building. Although no difficulty was experienced in picking up the carrier, the signal/noise ratio on tone was only 19 db, and the method of measurement did not take into consideration local interference of short duration and extremely high amplitude that made it impossible to understand more than an occasional word on speech. Towards the end of the test period, very severe, steady, local interference appeared, and it was so much stronger than the incoming carrier that it was impossible to make further measurement. Some of the interfering noise was definitely traced to the passing of tramcars and automobiles, interference from the latter being the more troublesome.

The next step was to determine definitely if commercial reception was feasible in the suburbs of Palma when local interference was not present. Tests were accordingly made at the Telephone Company's short wave station about 2 kilometres from the centre of the town. An average of 21 db was measured and speech was intelligible but the circuit was far from commercial. In view of these results it was quite clear that more than the elimination of local noise was necessary to obtain commercial reception on the Palma building. Vertical

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[2] "Ultra-short Wave Propagation," *Journal of the I.R.E.*, March, 1933, page 427 *et seq.*

polarisation had been used; but, although the use of horizontal polarisation might tend to reduce the effects of local interference, it was considered improbable that the gain would be sufficient to enable a satisfactory service to be established.

It is probable that by locating the transmitter at a point at a greater elevation above sea-level improved signal/noise ratios would have been obtained. A mountain, named Montserrat about 60 kilometres from Barcelona, is 1 200 metres high and, still farther from Barcelona towards the Pyrenees, a higher but less accessible point could be found. It was, however, more economical to raise the elevation of the receiving station in Majorca. A very flat accessible mountain named Randa, 535 metres above sea-level and about 30 kilometres east of Palma, appeared to have advantages for a future extension of the service in that it is within visible range of both the islands of Minorca and Iviça. Direct visibility to Tibidabo did, however, not obtain. An average signal/noise ratio of 26 db on tone was obtained.

The next point considered was La Muleta near the Port of Soller. It appeared particularly advantageous because of its accessibility, proximity of power supply and telephone lines. Its elevation is 220 metres. The average signal/noise ratio measured was 32 db.

The sixth site to be tried was S'Arrom at an elevation of 675 metres. Good results were obtained here but, on account of the intervening mountain range, visibility with the other two Balearic islands did not obtain so that the site would not be a good one for service to the latter. The site provisionally chosen for the Majorca terminal was the summit of the Alfabia Mountain 1 040 metres above sea-level.

The next tests were directed to checking the possibility of operating direct from one of the telephone company's buildings in Barcelona. The Cataluña building appeared to have definite advantages over the others. The line of sight to Majorca is practically unobstructed and the building is several storeys higher than the others. Moreover, the toll office is located there. The transmitter was moved to the roof of this building and tests to the 1 040-metre point in Majorca showed an average signal/noise ratio of 35 db with an antenna 6 db less efficient than the one used on the Tibidabo Mountain. Tests were then made between the Cataluña building and S'Ermita, 12 kilometres from Palma. There was, however, an 11 db loss in signal/noise ratio relative to the preceding test. The Majorca terminal was now transferred to a mountain known as Ram, just above S'Ermita and 830 metres above sea-level. Power was obtainable at a point 5 kilometres away. An average result of 30 db indicated that a commercial service would be possible, but serious difficulties were encountered in reaching the top of the mountain, which is very precipitous, and it was thought that a permanent solution might prove costly in the transportation of poles and other material.

The conclusion drawn from the measurements was that the most suitable site in Majorca was the Alfabia Mountain. For convenience of transport, the site was moved to a point slightly

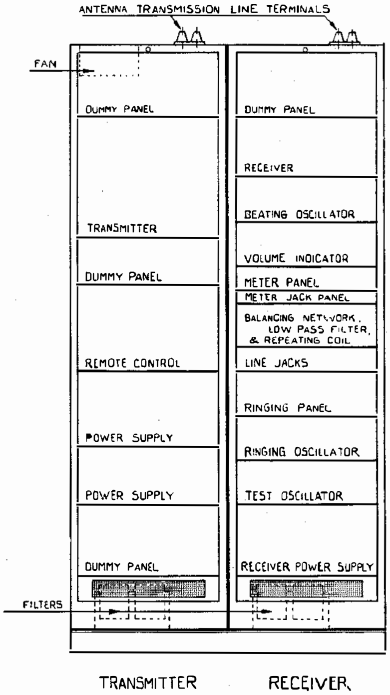

Fig. 9—*Panel Layout of Ultra Short-Wave Transmitter and Receiver.*

lower (1 020 metres above sea-level) and the same signal/noise ratios were measured. This point was decided upon as the site of the future Barcelona/Majorca ultra-short wave link.

Fig. 2 shows the signal/noise ratios plotted against the sum of the heights of the sending and receiving stations, the signal/noise ratios all being adjusted to correspond to transmitting and receiving aerials 15 and 9 decibels better, respectively, than a half-wave dipole. It must be remembered that the length of the transmission path was approximately the same in every case, viz., 200 kilometres. The fact that the points obtained for transmission from the 450-metre high Tibidabo Mountain and for the 65-metre high Cataluña building lie approximately on the same curve, shows that between the limits of 65 and 1 000 metres a reduction in the height of the receiver could be compensated by an equal increase in the height of the transmitter or vice versa. This conclusion applies to the case where the earth's hump is the only obstacle in the transmission path. Furthermore, a change in height of 100 metres causes a signal/noise ratio change of approximately 2 db.

A general conclusion can be drawn from these tests, namely, that a commercial link may be established even when optical visibility does not obtain between the two terminals and that, even when a high mountain stands directly in the transmission path, the establishment of a satisfactory link is by no means out of the question.

Although it had been shown that a commercial service could be established in the direction Barcelona-Majorca, it remained to be seen whether such service was feasible between the same terminals in the direction Majorca-Barcelona. The high level of electrical interference on the Cataluña building made it necessary to carry out a series of experiments with a view to a reduction of received noise. A luminous sign in the square, about 200 metres from the building, was a serious source of interference, and noise of the same type as that definitely identified as motor car interference at Palma was also present. A directive aerial, designed to discriminate against noises coming in the unwanted direction, ameliorated receiving conditions considerably when the necessary precautions had been taken to avoid pick-up in the transmission lines themselves. The aerials at both terminals, being of the horizontal rhombic type described by E. Bruce,[3] were designed so as to receive with substantially the same efficiency frequencies between 50 and 67 megacycles per second. Signal/noise ratios measured with different frequencies are given in Table II. It will be seen that by increasing the frequency from 50 to 67 megacycles per second, a gain of 27 db was obtained in the average signal/noise ratio. No attempt was made to determine what portion of this gain was due to improvement in propagation, but it is probable that by far the most of it was due to a drop in the intensity of electrical interference as the wavelength was shortened. It should, however, be mentioned that interference peaks occasionally reduced the signal/noise ratio at 67 megacycles per second to 42 db, still, however, showing a gain of 22 db over 50 megacycles per second.

As a further general conclusion it can, therefore, be said that if the receiver is located where electrical interference is present, a reduction in wavelength from 6 to 4.5 metres may be equivalent to a transmitted power increase of between 150 and 500 times. That is to say, the 10-watt transmitter at 4.5 metres may give reception equal to that of a 6-metre transmitter with a carrier power between 1.5 and 5 kilowatts.

TABLE II

Signal/Noise Ratio Variation Against Frequency on the Barcelona Telephone Building (Barcelona–Majorca U.S.W. Link)

Frequency	Signal/noise ratio on tone
50 megacycles	20 db
54·5 ,,	28 ,,
57 ,,	32 ,,
60 ,,	36 ,,
67 ,,	47 ,,

It was found later that fading occurred during the summer months. Measurements were made for one week on wavelengths of 3.5, 4, 4.5 and 5.5 metres (86, 75, 67 and 54 megacycles per

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[3] *Proceedings of the Institute of Radio Engineers*, August, 1931, page 1414 *et seq.*

second, respectively). The differences between maximum and minimum values were in excess of 35 db on 3.5 metres, equal to 35 db on 4 metres, 25 db on 4.5 metres, and 20 db on 5.5 metres. The minimum signal/noise ratio was best on 4.5 metres, being more than 10 db better than on 3.5 or 4 metres. Although the testing period was not sufficiently long to warrant absolute conclusions, it was clear that no gain was to be expected by increasing the frequency above 67 megacycles per second (4.5 metres), which had been used in the original tests.

In September, 1935, a commercial service between Majorca and Barcelona was opened to the public. The frequencies used were 65.6 megacycles per second (4.75 metres) towards Barcelona and 59.9 megacycles per second (5.01 metres) towards Majorca. Experimental services were established soon after over distances of 140 kilometres with the adjacent islands of Minorca and Iviça, but on account of the Civil War the two latter services were never opened to the public.

Figs. 3 and 4 show, respectively, front and rear views of the 10-watt ultra-short wave transmitters used; Figs. 5 and 6, front and rear views of the corresponding ultra-short wave receivers. Fig. 7 is the schematic of the transmitter with the quartz crystal-controlled oscillator on the left. When the output wavelength of the transmitter is 3.5 metres, the crystal oscillator has a frequency corresponding to 14 metres. The quartz crystal has an exceedingly small temperature coefficient—not more than three parts in a million per degree centigrade. A thermostat is, therefore, not required. A small heating element dissipating approximately one watt is provided in order to prevent the crystal holder from becoming damp when the transmitter is out of service. The output of the crystal oscillator drives a frequency doubler, followed by a pentode amplifier stage. This latter stage is suppressor-grid modulated and its output passes through a further frequency doubling stage which feeds the aerial. The advantages of this arrangement are that modulation may be effected with lower power; it is easier to amplify an ultra-high frequency lower than 3.5 metres (such as 7 metres); and, lastly, a gain of n decibels before doubling is equivalent to a gain of between n and $2n$ db after doubling. It may be seen that only one low frequency stage is provided, although a level of minus 25 db (referred to 1 milliwatt) is sufficient to obtain full transmitter modulation.

The question arises whether frequency doubling after modulation does not produce considerable distortion. It might at first sight appear that, if, for example, a 500 p : s tone is applied to the suppressor grid of the 7-metre amplifier stage, the modulation of the outgoing frequency would be at 2 × 500, that is, 1 000 p : s, due to the action of the output doubling stage. Were special measures not taken, it is certain that a very strong 1 000 p : s modulation would be present. By careful choice of the electrode voltages it is, however, possible to make the 3.5-metre antenna current a straight line function of the suppressor grid voltage so that, despite the existence of a doubler stage between the pentode amplifier and the aerial, undistorted modulation may be obtained. Measurements show that for 70 per cent. modulation the harmonics present do not exceed 3 per cent. An output of 10 watts carrier is obtained for all

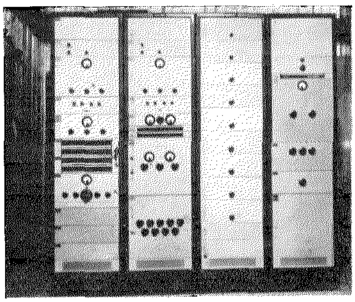

Fig. 10—9-*Channel Multiplex Equipment : Receiver.*

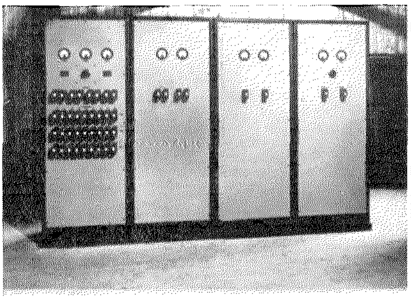

Fig. 11—9-*Channel Multiplex Equipment : Transmitter Power Supply.*

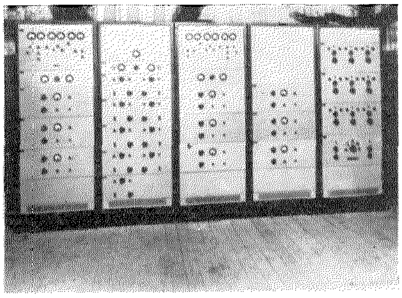

Fig. 12—9-*Channel Multiplex Equipment : Transmitter.*

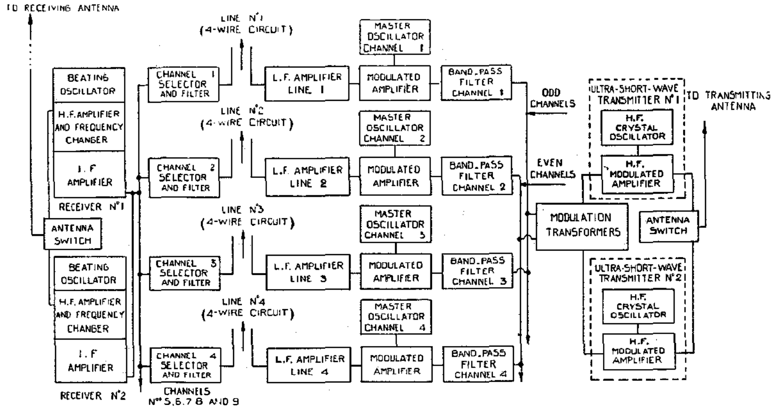

Fig. 13—*Diagram Schematic of a Terminal Equipment for a* 9-*Channel Ultra Short-Wave Multiplex Telephone Link.*

wavelengths between 3 and 7 metres (100 and 43 Mc p : s).

Fig. 8 gives a schematic of the receiver ; and Fig. 9, the panel lay-out of the transmitter and receiver corresponding to Figs. 3 to 6 inclusive.

The receiver, which also operates between 3.5 and 7 metres is capable of giving a maximum undistorted power output of + 12 db (referred to 1 milliwatt). It is designed for use on a 2-wire telephone circuit, the necessary 4-wire terminating set and compromise balancing network being provided. It is of the superheterodyne type, the beating oscillator being quartz controlled in a manner similar to that of the master oscillator of the transmitter. A high frequency amplifier, a first detector, two stages of intermediate frequency amplification, a second detector and a low frequency amplifier are used. An automatic gain control is provided to reduce any fading which may occur. A volume indicator, hybrid coil panel and other ordinary telephone requisites are supplied.

The transmitter and receiver can be remote-controlled from the distant telephone exchange. It is possible by means of this control to shut the station down entirely, to put both transmitter and receiver on, or to leave the transmitter off but the receiver on. This latter arrangement is used at times when traffic is light since, the receiver being on, any incoming calls can be received. When the telephonist wishes to establish a through circuit, the mere insertion of the required plug into the appropriate jack starts up the transmitter so that only a few seconds are lost before contact is established with the other side. The lost time is so short that it passes unnoticed even by the operator herself. The control circuits have been designed to work over a single conductor with earth return between the radio terminal and the telephone exchange. The only condition to be fulfilled by the conductor is that the total resistance, including that of the windings of the repeating coils, shall not exceed 1 900 ohms. In order to prevent a service breakdown due simply to a fault on the control circuits, it has been arranged that, if the control conductor is broken, both the radio transmitter and the radio receiver come into operation.

To cater for the case where 500 or 1 000 cycle ringing is not available over the telephone circuits, a ringing device translates 16– or 25–cycle ringing current into 4 000 cycles per second for transmission over the radio link. At the receiving station this 4 000-cycle ringing current is re-translated into the 16– or 25–cycle current required to operate the ringers.

Testing facilities are provided to enable the exchange operator to check whether the local receiver is operating satisfactorily. By means of the remote control, she switches on a local oscillator at the radio terminal, operating at the frequency of the distant transmitter. If the receiver is in proper working order, about 15 seconds later, she receives ringing tone showing that her testing oscillator has been duly received by her own receiver.

The whole transmitter and receiver equipment is operated direct from 110 or 220 V 50 cycle per second mains.

Highly directive aerials were used in Majorca for both transmitting and receiving. The measured gain was approximately 18 decibels over a half-wave dipole in each case. The type of aerial was that described by E. Bruce.[4] The transmitting aerial consisted of three horizontal rhombuses, 4 wavelengths on a side, placed one above the other at half wavelength spacing. The receiving aerials consisted of 6 inverted vertical V's, 4 wavelengths long on a side, placed side by side at half wavelength intervals. On the Cataluña building in Barcelona, there was, unfortunately, not enough space to provide such highly directive antennae. The transmitting and receiving aerials each consisted of an array of 4 full-wave elements spaced half a wavelength and fed at the centres, reflectors being placed a quarter of a wavelength behind each such element. The gain was 12 db over a single half-wave element. An operator was normally in attendance at both terminals to ensure that the transmitter was loaded to substantially full modulation even on weak talkers. On Sundays, however, the traffic being lighter and the signal/noise ratio at Barcelona higher on account of the lack of electrical interference, the presence of an attendant was entirely dispensed with.

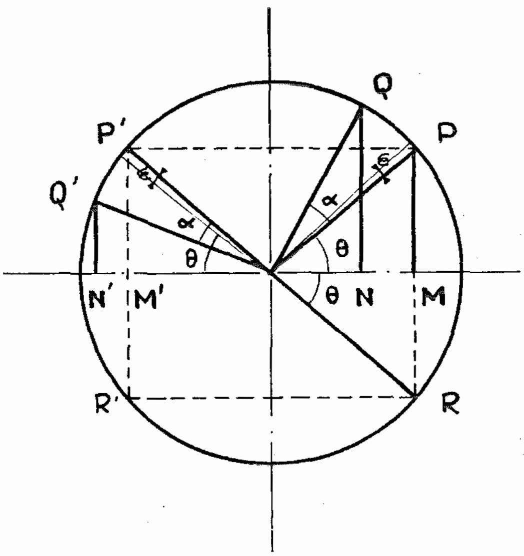

Fig. 14.

The time during which the link was out of service was a few minutes daily, this lost time being accounted for by all causes. No calls were cancelled on account of the radio circuits being uncommercial. Statistics for the first six months of operation showed an increase of 40 per cent. in the revenue from this service due to the substitution of the ultra-short wave link between Barcelona and Majorca for the short-wave link between Madrid and Palma.

Nine-channel Multiplex Equipment

As previously mentioned, a wide wavelength band is available on ultra-short waves. It is also easier to pass a wide frequency band through commercial apparatus at these very high frequencies than at lower frequencies, since a commercially-made tuned circuit passes a total band-width which is of the order of 2 per cent. of the frequency to which the circuit is tuned. These frequencies are, therefore, well suited to multi-channel transmission where several telephone circuits are superposed on one radio carrier. Figs. 10, 11 and 12 show a nine-channel radio telephone equipment used to establish nine radio telephone circuits between Scotland and Ireland across St. George's Channel over an optical path approximately 65 kilometres long. Fig. 13 shows the block schematic of the system. The nine incoming telephone channels modulate auxiliary carrier currents of low radio frequency, which are mixed together and employed to modulate the outgoing ultra-high frequency carrier.

The ultra-short wave transmitter unit is essentially the same as the 10-watt transmitter already described with the exception that a push-pull output stage has been added in order to bring the antenna carrier power up to 50 watts and that modulation is effected on this output stage.

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[4] *Proceedings of the Institute of Radio Engineers,* August, 1931, page 1414 *et seq.*

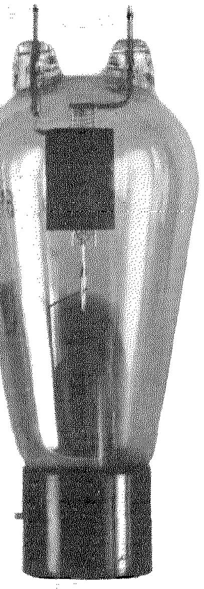


Fig. 15—Tube for Waves above 50 cm.

It is quite evident that a fault in the ultra-short wave unit would be a catastrophe; a fault in one channel is serious, but the failure for any appreciable time of 9 channels is disastrous. The ultra-short wave unit, being common to all 9 channels, is therefore provided in duplicate. The reserve unit is normally not under tension but, if a fault such as the failure of a tube occurs, the power supplies and the aerial are automatically switched from the service to the reserve unit, and a fault is signalled to the distant remote-control point.

On the receiving side the aerial picks up a high frequency carrier modulated by 9 channels. As in the case of the ultra-short wave transmitter unit, that part of the receiver which is common to all channels is duplicated. Automatic switching in the case of a fault is, however, not provided, inasmuch as the switching apparatus in the case of the small currents of some of the receiving tubes would be so delicate as to give rise to the danger of false operation. The disappearance, however, of 9 channels cannot pass unnoticed for long and, as the telephone operator knows that she may rely upon the transmitters at both ends, she is able to conclude that the failure is due to her own receiver. In this case, by the operation of a remote-control key, she substitutes the reserve receiver unit for the defective one.

Manual changeover of the transmitter units is likewise provided by remote control. Thus the reserve transmitter may be tested at regular intervals.

The receiver is a superheterodyne, in the output of the second detector of which the 9 auxiliary carrier frequencies of the distant transmitter are present. Each auxiliary carrier, together with its side-bands, is separated out by means of filters, amplified and rectified to reproduce the original speech frequencies corresponding to the channel in question. After amplification these speech frequencies are passed out to the line at the required level.

It is easy to mix together 9 channels, but to separate them out again without noticeable crosstalk is a problem on its own. In order that crosstalk may not be noticeable when a signal/noise ratio of 45 db is measured on a volume indicator, the signal-to-cross-talk ratio must be at least 55 db. In other words, intermodulation between the different channels must be exceedingly small. This condition would be met if all the parts of the equipment which are common to the 9 channels had a strictly straight line output-input characteristic. Since, however, modulators and demodulators are present, this condition is fundamentally impossible of fulfilment.

The problem is solved by giving the modulators and detectors as far as possible a square law characteristic. Care is then taken that the output of all the remaining common parts is as far as possible a straight line function of the input. The secondary frequencies which are generated in the modulators and detectors correspond to the sums and differences of each pair of frequencies passing through these elements. If now all the auxiliary carrier frequencies lie within an octave, all the secondary frequencies lie outside the band of these auxiliary frequencies. In the case of the equipment under discussion, all the auxiliary frequencies lie between 150 and 300 kc p : s, so that all the secondary frequencies corresponding to the sums lie between 300 and 600 kc p : s, and all the secondary frequencies corresponding to the differences lie between 0 and 150 kc p : s.

The secondary frequencies can, therefore, be removed by the simple process of filtration.

The equipment has been designed for unattended operation and is remote-controlled from the nearest telephone exchange. In addition to the full-service and shut-down conditions, a third arrangement is available under which the receiver is in operation so that the incoming channels are established but the transmitter power supply is removed. When a call is received, the full-service condition is restored by the exchange supervisor by means of the remote control.

The equipment has been in commercial service since August, 1936, giving very satisfactory results. The signal/noise ratios obtained on each of the 9 channels for maximum modulation has exceeded 45 db on all occasions with few exceptions, and the variation of transmission equivalent from the input of the transmitter to the output of the distant receiver does not normally exceed 2 decibels, a figure comparable with that obtained with open wire lines. In the six months of service no fading has been observed, but this does not exclude the possibility of a signal-strength variation of a few decibels since an automatic gain control is employed on each channel to overcome the effects of fading. Any considerable fall in signal, however, would produce a corresponding fall in signal/noise ratio ; and experience shows that if such signal variations do take place, they are not sufficiently severe to disturb the circuit from the viewpoint of a high-grade telephone service.

Other Propagation Results

A similar steadiness of signal was observed over a 35-kilometre optical path between Escalles near Calais, France, and St. Margaret's Bay, Dover, England, between June and December, 1933. Observations were carried out over a period of six months on wavelengths of 3.4 and 6 metres (88 and 50 megacycles per second). In view of the fact that the experiments were not primarily directed towards the taking of signal-strength measurements, variations of as much as 6 db might have passed unnoticed. No fading was, however, observed, so that the path in question may be considered to be fading-free on both these wavelengths.

The experience of other experimenters in this field also shows that fading is usually negligible over optical paths on wavelengths longer than 3 metres.

Necessity of Technique Change for Micro-rays

One of the most important developments in the history of the communication art was the appearance of the commercial triode, which for many years served as an ideal amplifying device for all purposes. As the frequency is increased, however, practical limitations to its utility arise. The circuits connected to grid and plate become so small that their major part lies inside the tube envelope and it is difficult to couple them to other circuits. The reactance of small capacities falls so low that the charging currents become considerable and increase the power losses. The inter-electrode capacities represent such small impedances that it is difficult to prevent amplifiers singing, even though screening of electrodes or neutralisation be adopted.

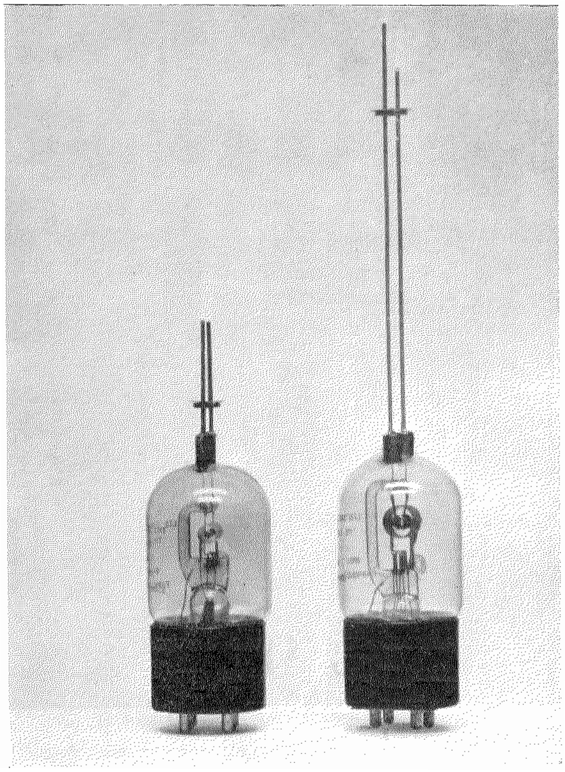


Fig. 16—*Micro-ray Tubes.*

The latter procedure becomes complex due to the inductance of the leads and to phase changes produced in the inter-electrode spaces by the finite transit time of the electrons. In the simple theory of the vacuum tube which has served for nearly a generation, the transit time of electrons between electrodes is tacitly assumed to be negligible. When this condition no longer applies, the control exercised by the grid on the electron stream absorbs considerable power from the grid drive and the grid input resistance may fall well below 1 000 ohms.

It is worth while to consider briefly the simplified vacuum tube theory. A charge on the grid controls the electron stream by direct action on the electron itself. If the grid is sufficiently negatively biassed, no grid current can arise since the electrons have a negative charge ; therefore, the grid-cathode conductance must be zero. This is, however, not a complete statement of the facts. Although it is true that the grid, if sufficiently negatively biassed, cannot accept any electron current, it is not true that it cannot accept displacement currents. Furthermore, it is well to remember the third law of motion—action and reaction are equal and opposite. If the charge on the grid exercises a direct action on the electron, does not then the electron exercise a direct reaction on the charge on the grid ?

Action and reaction in this case do in fact exist. During the passage of the electron from the cathode to the grid, the grid charge retards the electron and thus receives energy from it while, during its passage from the grid to the plate, the electron is accelerated by and receives energy from the grid charge. If the grid potential remains constant during the passage from the cathode to the plate, the energy received back by the electron is equal to the energy it originally gave out. This can easily be seen if it is imagined that the grid potential is kept constant by means of a resistanceless battery. When the electron passage has been completed, the battery has given up no energy, since no direct current has flowed. There is thus no energy loss and the grid-cathode conductance is zero. If however, the grid potential varies during the passage of the electron from the cathode to the plate, this equality no longer obtains, since the quantities of energy given up and received back by the electron depend on the grid voltage.

The mathematical treatment of the problem is complicated by the interaction of the electrons which make up the space charge. In order to understand the phenomenon qualitatively, we shall neglect this interaction. Furthermore, we shall only consider the simple case in which no high frequency impedance exists in the plate circuit, that is, the case in which the plate voltage is constant.

Let the grid have a constant negative bias, and let a small alternating voltage be applied to it. Consider an electron which leaves the cathode at a time when the grid voltage is positive and increasing, i.e., at a point *P* of the cycle represented in Fig. 14.

Although the energy transfer takes place continuously during the whole of the electron transit time, a further simplification is introduced by considering that any energy transfer takes place at definite moments of the transit period. The grid voltage will, therefore, have a phase :

$$\theta+\varepsilon$$

when the electron which leaves the cathode at the point *P* delivers its energy to the grid. ε is a phase change corresponding to a time less than that required for the electron to travel from the cathode to the grid. It is in reality a function of θ and the alternating grid voltage, but the error involved in assuming it to be constant may be made smaller than any preassigned quantity we care to mention, provided the amplitude of the grid alternating component is made sufficiently small. We are, therefore, justified in considering it as constant.

The energy transferred being linearly proportional to the grid voltage, the effects of the constant bias and the alternating component may be treated separately. We have already shown that the effect of the constant bias is zero, so that the alternating component alone need be considered. For a point *P* as shown in the figure, this alternating component is positive, so that the a.c. grid component, by attracting the electron, gives it energy proportional to :

$$\sin(\theta+\varepsilon).$$

During its passage between the grid and the plate, the electron gives back energy proportional to:

$$\sin(\theta+\alpha),$$

where α is the phase of the grid voltage when the electron reaches some point between grid and plate. α is, therefore, necessarily greater than ε. Thus the total energy given by the grid to each electron is:

$$\sin(\theta+\varepsilon) - \sin(\theta+\alpha) = -2\cos\left(\theta+\frac{\alpha+\varepsilon}{2}\right)$$
$$\sin(\alpha-\varepsilon)$$

which, it may be noted, is negative during almost the whole half cycle in which the grid voltage is increasing, but positive when the grid voltage is decreasing.

The number of electrons which leave the cathode in a small unit of time depends on the grid voltage. Consider point P' where the grid has the same voltage as at P with, however, the difference that the voltage is now decreasing. As the grid voltages are equal at P and P', the number of electrons leaving the cathode in a small interval of time is equal in both cases. Each electron receives from the grid energy proportional to:

$$\sin(\pi-\theta+\varepsilon) = \sin(\theta-\varepsilon)$$

and gives the grid energy proportional to:

$$\sin(\pi-\theta+\alpha) = \sin(\theta-\alpha)$$

The total energy, therefore, given up by the grid in a small unit of time for pairs of electrons corresponding to points P and P' is, therefore, proportional to:

$$\sin(\theta+\varepsilon)+\sin(\theta-\varepsilon)-[\sin(\theta+\alpha)+\sin(\theta-\alpha)]$$
$$=2\sin\theta\,(\cos\varepsilon-\cos\alpha)=\sin\theta\,(\alpha^2-\varepsilon^2)$$

since α and ε are both small.

Consider points R and R' in Fig. 14. Here the grid charge receives energy from each electron pair since θ is now negative. The energy transfer for each electron pair is again proportional to:

$$\sin\theta\,(\alpha^2-\varepsilon^2)$$

Since, however, more electrons leave the cathode at points P and P' than at R and R' because the grid is less negative at P and P', it follows that there are more pairs of electrons which take energy from the grid charge than give energy to the grid charge. Furthermore, α and ε are both proportional to fT, where f represents the frequency of the a.c. grid voltage and T the electron transit time from cathode to plate.

From this it can be concluded that:

1. The positive grid cathode conductance is linked up with the fact that more electrons leave the cathode when the grid is less negative than when it is more negative.
2. The energy loss and, therefore, the grid cathode conductance, are proportional to the square of the product of the frequency and the electron transit time.

When the power thus absorbed exceeds that which can be drawn from the plate, no amplification is possible and oscillations can no longer be maintained with the usual oscillator circuits. A change in technique becomes necessary. One of the main objects in the design of tubes for ultra-short waves is, therefore, to reduce the electron transit time. This may be accomplished by increasing the plate voltage or by reducing the dimensions of the tube. Since it is also necessary for reasons already set forth to keep the inductance and capacity of the electrode connections low, the usual procedure is to reduce the size of the tube. Fig. 15 shows a Western Electric Company tube designed for ultra-short wave working. It will be seen that the grid and plate leads are kept as short as possible and pass directly through the glass in order to reduce dielectric losses.

MICRO-RAY LINKS

Micro-ray Generation

When the production of oscillations by the classical reaction method is no longer possible, it becomes necessary to adopt other means. The name "Micro-rays" has been given to wavelengths shorter than 50 cm since it is in this neighbourhood that the change in technique occurs. Historically, the problem was solved before the question was asked. It is, however, interesting to consider the solution of the problem in the light of the foregoing.

It has been seen that nearly all the electrons leaving the cathode while the grid voltage is increasing give energy to the grid, and those leaving while the grid voltage is decreasing take energy away. If it were possible to arrange for more electrons leaving the cathode while the grid voltage is increasing than when it is

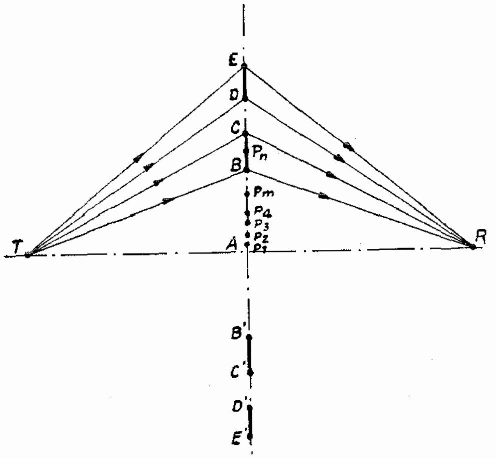
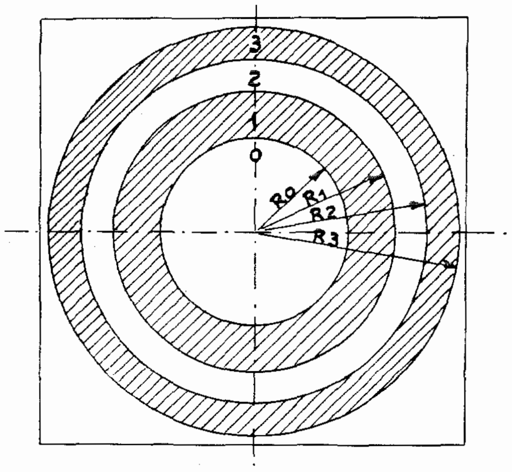


Fig. 17-A—*Section of a Zone Plate for Micro-rays.*

decreasing, the grid-cathode space would represent a negative conductance and oscillations could then be maintained in the grid circuit. Fortunately, it is not essential that these extra electrons should be coming out of the cathode; it is only necessary that they should be at the cathode at the right moment. They may well arrive from another electrode, by which they may have been emitted or reflected.

The positive grid-cathode conductance, the cause of which has just been seen, will operate against any negative grid-cathode conductance which may be generated by other means. The first suggestion which, therefore, occurs to the mind is to operate the cathode in voltage saturation so that this positive conductance may be reduced to zero. By so doing we do, indeed, destroy the property on which the negative-grid triode depends for amplification. This, however, leaves the plate free to be used as a reflecting electrode, and it must, therefore, be given a voltage equal to or slightly less than that of the cathode. It now, of course, becomes necessary to give the grid a positive voltage in order that the electrons may be attracted from the cathode. The electron which leaves the cathode at a moment when the grid potential is decreasing receives energy from the grid circuit, and if the voltage of the reflecting electrode is properly chosen, it can be arranged that this energy-absorbing electron gains sufficient energy to reach the plate and is removed from the tube, while the energy-giving electron has not enough energy to reach the plate and is reflected. It may, therefore, travel backwards and forwards several times before it finally comes to rest on the grid. Inasmuch as the electrons which leave the cathode at the moment when the grid potential is decreasing, are rapidly removed from the sphere of action, the grid-cathode conductance becomes negative.

There are two classes of devices based on electron inertia, namely, positive grid diodes and triodes on the one hand, and magnetrons on the other. Both these devices already appear to have a certain utility. Positive grid triodes have been used commercially to establish the micro-ray teleprinter and radio-telephone service across the English Channel, between Lympne and St. Inglevert, over an optical distance of 56 kilometres. The output power obtainable is about half a watt on wavelengths between 15 cm (2 000 megacycles per second) and 30 cm (1 000 megacycles per second), and oscillations have been maintained down to 6 centimetres (5 000 megacycles per second). Although giving considerably greater output power, magnetrons have not so far been used in commercial service on account of modulation difficulties. Fig. 16 illustrates positive grid triodes used to establish the commercial service referred to. The plate is cylindrical and the grid is a spiral about a wavelength long so that



$R_0 = 23{\cdot}5$ cm, $R_1 = 34$ cm, $R_2 = 42$ cm, et $R_3 = 50$ cm.

Fig. 17-B—*Front View of a Zone Plate for Micro-rays.*

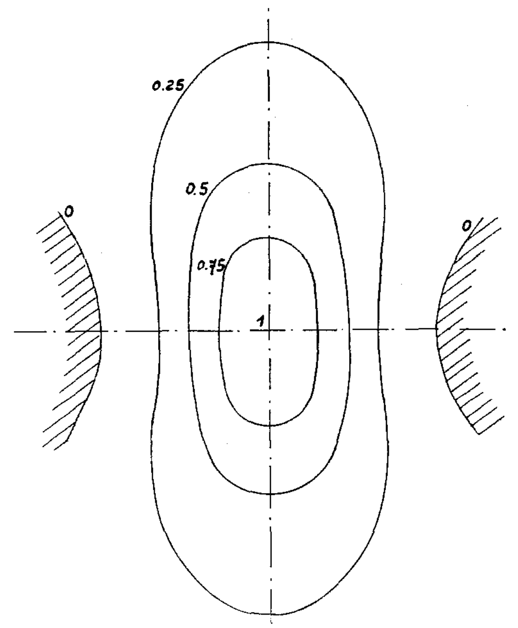


Fig. 18—*Projection on to the Director Plane of Lines of Equal Intensity on a Paraboloidal Mirror.*

we no longer have the case of a simple electrode. Two lead-outs are provided to form a continuous transmission line from the aerial to the interior of the tube. Oscillations are maintained due to the existence of negative leakance along that part of the transmission line which is constituted by the grid ; no attempt is made here to explain the action, which is complex and has been treated elsewhere.[5] The frequency of oscillation is determined largely by the geometry of the tube but varies slightly according to the voltages applied to grid and plate. It is found by experiment that, with any given transmission line and load, the same frequency can be generated by the micro-ray tube for different pairs of values of grid and plate potential, the output being different for every pair. By this means it is possible to obtain substantially straight-line modulation.

Micro-ray Concentration

In order to concentrate the rays, the usual devices known in optics may be used, such as lenses, zone plates, parabolic reflectors, etc. Thus a double convex lens of 70 centimetres diameter and 1 metre radius of curvature brought rays from a source 5.9 metres in front of the lens to a focus 40 centimetres behind it, the strength of received signal at this point being increased by 10 db by the lens action.

The principle underlying the design of zone plates is shown diagrammatically in Figs. 17-A and B. Consider an infinite surface $ABCDE \ldots B'C'D' \ldots$ a section of which is shown in Fig. 17-A. Choose points $BCDE \ldots B'C'D'E' \ldots$ so that $TBR\text{–}TAR = TB'R\text{–}TAR = TCR\text{–}TBR = TC'R\text{–}TB'R = TDR\text{–}TCR$, etc. $= \frac{1}{2}\lambda$.

Let T be a point source of wavelength λ. In order to determine the effect at any point of the radiation of T we can, applying Huyghens's principle, disregard T and consider every point on the plane EAE' as a new source whose relative phase and intensity are the phase and intensity (at the point) of the ray arriving from T. The intensity at R is the vector sum of the contributions from all the secondary sources on the plane EAE'. The intensity at the point R due to the secondary source at B is opposite in sign to that of the secondary source A, since TBR is half a wavelength longer than TAR, so that there is a phase difference of 180°. In the same way the intensity at R due to the secondary source C is opposed to that due to the secondary source B but in phase with that of the secondary source A. To every secondary source P_1, P_2, P_3, etc., between A and B, there corresponds a secondary source between B and C, whose effect at R is of opposite sign. If, therefore, the resultant of the intensities at R due to all

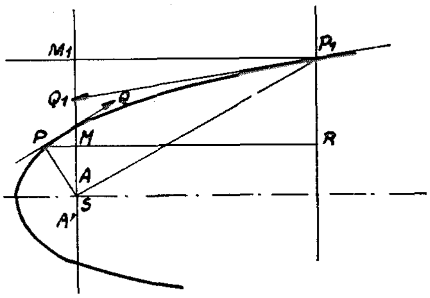


Fig. 19—*Symmetrical Section of a Paraboloidal Mirror.*

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[5] "Production and Utilisation of Micro-Rays," by A. G. Clavier, *Electrical Communication,* July, 1933.

sources between A and B is considered positive, the resultant of the effects of all the sources between B and C must be considered negative. In the same manner the effect due to the sources between C and D will be positive and that of the sources between D and E negative.

This argument applies to any section through T and R so that, by rotating Fig. 17-A about TR we obtain a disc in place of line AB, and rings in place of lines BC, CD, and DE, etc. This disc and these rings are called zone plates.

If an obstruction is put in the path of secondary rays coming from the zones BC, DE, etc., it follows that the resultant signal at R will be increased. In a test zone-plate, made as shown in Fig. 17-B, aluminium rings, represented by zones 0, 1, 2 and 3, were fixed on a 5 mm thick board made of wood. A doublet excited at approximately 19 cm was placed 60 cm in front of the zone plate just described, and the resulting intensity 60 cm behind the zone plate was measured by means of a thermocouple. The galvanometer deflections (which are substantially proportional to the power received) were as follows :

Zone plate entirely removed	19
Screen without aluminium rings	16
Screen with rings 0, 1, 2 and 3, in position ..	4
Screen with ring 0 removed	41
Screen with rings 0 and 1 removed	9
Screen with 0 and 2 removed but 1 and 3 allowed to remain	118
Wooden screen removed and rings 1 and 3 in place ..	139
Rings 1 and 3 removed, 0 and 2 and wooden board remaining	34

Thus this zone-plate, 1 metre in diameter, gives in this case a power gain of 139/19, i.e., 8.6 db at the point on to which it is focussed.

A much higher concentration of rays can, however, be obtained from a paraboloidal mirror with the radiator situated at its focus. Theory and practice show that, for a given diameter of opening of the paraboloidal mirror, the greatest concentration of rays at a long distance is obtained when the focal plane is coincident with the aperture. Fig. 18 shows the projection on to the director plane of lines of equal intensity on the paraboloid. The interpretation of this figure, which is due to R. Darbord[6] is that an element of the paraboloid, situated on a line whose projection on the director plane is marked 0.5, contributes to the field at a distance along the axis of the reflector 0.5 of the field contributed by an element situated directly behind the antenna, provided the projected areas of these two elements are equal; the hatching denotes surfaces whose contribution tends to reduce the resultant field at a distance along the axis of the reflector, with the result that the beam is wider in the plane of symmetry through the radiator than in the plane of symmetry at right angles thereto. The measured beam width is $\pm 3.7°$ and $\pm 2.2°$ in these planes respectively for a 10 db loss of audio signal. The measured gain along the axis is between 22 and 23 db.

The existence of destructive areas can easily be shown. Fig. 19 represents a symmetrical section of the paraboloid through the focus, the radiator AA' being in the plane of the paper. Let P and P_1 be two points, one on the left and one on the right of the focal plane. If we represent the polarisation at the radiator by $A'A$, the ray striking the reflector at P will excite currents in the conducting surface of the reflector in the direction PQ, where Q is the point of intersection of $A'A$ and the tangent at P. This has a component proportional to MQ, where PM is perpendicular to $A'AQ$. A ray, incident on the reflector at the point P_1, however, will excite an elementary area at P_1 in the direction P_1Q_1 which has a component proportional to M_1Q_1. It can be seen from the figure that MQ and M_1Q_1 are in opposition. The change of phase in the path SPR being exactly equal to the change of phase in the path SP_1, the contributions to the signal at a distance along the axis are of opposite sign for elementary areas situated at P and P_1. This fact is of fundamental importance in the design of a mirror, since it follows that, if the mirror encloses the antenna, destructive areas must occur whenever the symmetrical section of the mirror in the plane of the aerial is a smooth curve. It should be noted that the existence of such destructive areas does not depend upon the shape of the mirror; their extent does indeed, but their existence does not. The question arises why in the case of searchlights, the parabolic mirror of which encloses the light source, no destructive areas can be seen on the mirror. The explanation is that

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[6] *L'Onde Electrique*, 1932, Vol. 11, page 53.

light has a rotating polarisation so that parts of the mirror, which represent a destructive area at one moment, have a positive effect at the next moment, and the average effect of each point of the mirror is positive.

The locus of points of zero intensity is the locus of points T on the paraboloid where the plane through the antenna and the point T cuts the tangent plane at T along a line which is itself perpendicular to the antenna. In this case the contribution of an elementary area at T to the field at a distance along the axis of the reflector has a polarisation perpendicular to that of the radiator and, since by symmetry the resultant polarisation at any distant point situated on the axis is the same as that of the antenna, the contribution at T to the useful signal is zero.

It will be seen that practically all the radiation which leaves the antenna in a forward direction never reaches the distant station. This loss of power may be overcome by the use of the hemispherical mirror placed in front of the antenna so as to throw back all the forward radiation on to the reflector situated behind the antenna. In order that these forward rays may reach the reflector in phase with the backward rays, it is necessary that they be subjected to a phase change of 360° or a multiple thereof. Allowing for a phase change of 180° at reflection at the hemispherical mirror, we should at first conclude that the radius of the latter would have to be an odd multiple of a quarter-wavelength. Here, however, a curious phenomenon, well known in optics, is encountered; it is known as the Gouy effect, after its discoverer. The rays reflected by the hemispherical mirror are accelerated in phase, so that after passage through the focus the phase has been advanced by 180° more than would normally be accounted for by path length. For this reason the radius of the hemispherical mirror must be a multiple of a half-wavelength. An average value of the measured gain due to the hemispherical mirror is 3 db.

While the performance of reflecting systems has so far been discussed from the standpoint of transmission, the argument, by virtue of the reciprocity theorem, will apply equally to reception. This is confirmed by experiment.

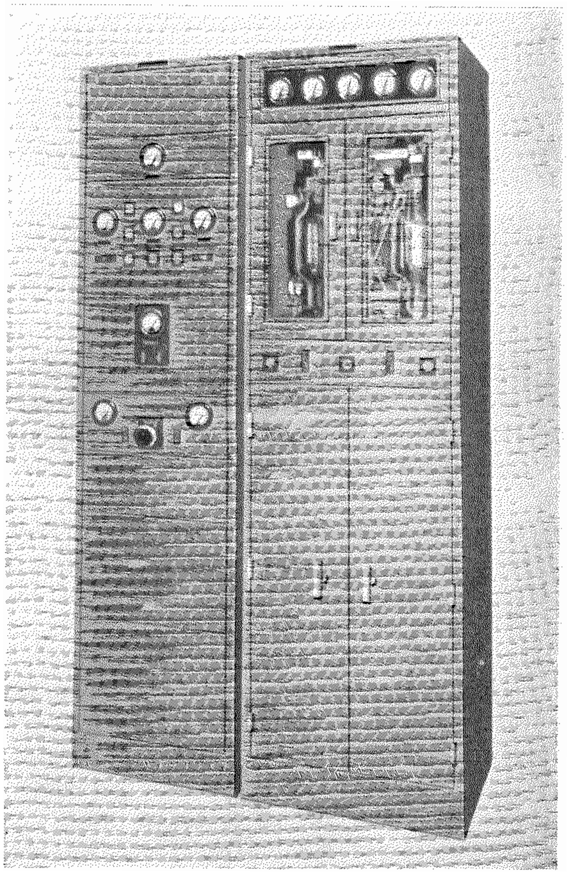

Fig. 20—500-*watt Ultra-Short Wave Telephone Transmitter.*

Micro-ray Propagation and Equipment

Two two-way circuits have been established across the Straits of Dover. The first was an experimental link, installed in February, 1931, between the terminal stations of Escalles near Calais and St. Margaret's Bay near Dover, while the second was a commercial link connecting the aerodromes of Lympne and St. Inglevert. This latter link not only uses the shortest wavelength of any commercial station in the world—17.4 cm—but also constitutes the longest micro-ray circuit in regular operation up to the present time. The English terminal of this link was built to Air Ministry order by Standard Telephones and Cables, Ltd., London, while the French terminal, to the order of the French Air Ministry, was built by Le Matériel Téléphonique, Paris. A full description of the equipment has been given elsewhere.[7]

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[7] "The Anglo-French Micro-Ray Link Between Lympne and St. Inglevert," by A. G. Clavier and L. C. Gallant, *Electrical Communication*, January, 1934.

Fading was found to exist on both links during the summer months.[8, 9.]

THE OPTIMUM WAVELENGTH BAND AND ITS ECONOMIC POSITION VIS-A-VIS WIRED CIRCUITS

From the propagation results cited above it may be concluded that ultra-short waves between 3.5 and 6 metres (86 and 50 megacycles per second) are very well suited to the establishment of high-grade telephone circuits.

In the case of long distances beyond the optical range it must be expected that technical operators will be required at the radio stations, and the grade of service may not always reach the standard of reliability required of high-grade wired networks. Nevertheless, a satisfactory commercial service is attainable. On wavelengths between 14 and 30 centimetres (2 140 and 1 000 megacycles per second), however, severe fading is experienced even over optical paths of 35 kilometres length. At what wavelength between 3 metres and 30 centimetres (100 and 1 000 megacycles per second) this severe fading begins to set in has not yet been determined. Ultra-short waves longer than 6.5 metres (46 megacycles per second) are known to be propagated on occasion to long distances; 7.2 metres (41.5 megacycles per second) transmitted from the Alexandra Palace in London has been received in South Africa.

No reliable information, however, has come to the author's knowledge of long distance transmission of wavelengths shorter than 6 metres (50 megacycles per second); and, inasmuch as the difficulty of generating ultra-short wave power of highly stable frequency increases as the wavelength is shortened, the most desirable band would appear to be between 3 and 6 metres (100 and 50 megacycles per second).

In this part of the spectrum long-distance propagation, with the consequent danger of overhearing in unexpected places and of interference reducing the grade of the circuit, appears to be absent. The high degree of frequency stability which can be attained makes it possible to use highly selective receivers, even on unattended equipments, so that no reduction in signal/noise ratio owing to unnecessarily wide receiver band-widths is occasioned. Despite an added measure of privacy owing to greater directivity of transmission and the use of less well-known methods of generation, there is, on account of instability of propagation, little incentive to use very short wavelengths such as 30 centimetres for radio links forming part of a commercial telephone network.

No definite generalised answer can be given to the question of when this optimum ultra-short wave system proves in economically over other means of communication. Each case requires individual consideration inasmuch as there are many individual factors which must be taken into account and which may completely alter any generalised conclusion. It may, however, be stated that where open-wire or cable construction is possible without abnormal installation difficulties or maintenance charges, the ultra-short wave radio equipment is not the economic solution. In cases of short deep water crossings which would involve deep-sea cable, there appear to be cases where the radio alternative is the cheaper both in first cost and annual charges. On account of the danger of damage to cables by the dragging of ships' anchors, ultra-short wave equipment is being increasingly used for river and shallow sea-water crossings where ship traffic is heavy. Other cases, where the existence of natural obstacles makes the radio path considerably shorter than the length of the cable or open-wire route, require individual study.

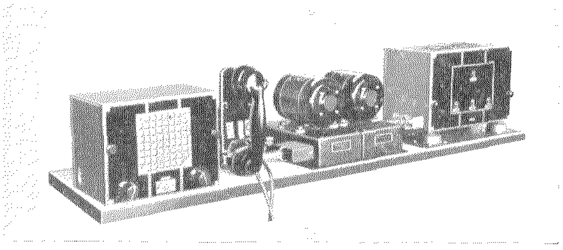

Fig. 21—Ultra-Short Wave Equipment for Police Cars.

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[8] "Micro-Ray Communication," by W. L. McPherson and E. H. Ullrich, *Journal of I.E.E.*, 1936, Vol. 78, No. 474.

[9] "Propagation Tests with Micro-Rays," by A. G. Clavier, *Electrical Communication* January 1937

COMMUNICATION WITH MOBILE UNITS

In addition to its utility in connection with commercial telephone networks, the ultra-short wave band is particularly suitable for communication with mobile units. One of the most important applications is to the linking-up of police cars with police headquarters. The field of transmission being limited to relatively small areas, it is possible for several cities within a reasonable distance of one another to use the same frequency without interference, and the rapid diminution in the strength of artificial interference as the wavelength is shortened, results in a low level of industrial interference. The receivers used both at headquarters and on the cars are highly sensitive superheterodynes with strong automatic gain control ensuring substantially constant output level despite very considerable variations of signal strength. The car transmitters have an output carrier power of 5 watts; the headquarters' transmitters may have powers of 5, 50 or 500 watts carrier, all transmitters, both those for use at headquarters and those for use on the cars, being quartz crystal-controlled. Fig. 20 shows a Western Electric Company 500-watt headquarters' transmitter and Fig. 21 the apparatus used on the cars. Means are provided to cut off the carrier during quiet periods in order to economise power and reduce the danger of interference with other stations of the system operating on the same wavelength. The equipment covers a range of 10 to 7.14 metres (30 to 42 megacycles per second).

Low-power portable ultra-short wave equipments have been developed for military purposes.

OTHER APPLICATIONS OF ULTRA-SHORT WAVES

Ultra-short wave transmitters of powers up to 40 kilowatts peak with a power drain of approximately 300 kilowatts are available. The latter rating applies to the television transmitter shown in Fig. 22. The wavelength range is from 6 to 7.5 metres (50 to 40 megacycles per second). The television frequencies between 20 cycles per second and 2.5 megacycles per second grid-modulate the last high frequency amplifier stage, while the band from zero to 5 cycles per second, necessary in order to regulate the brightness of the picture, is imposed on the high frequency carrier by grid modulation of the penultimate high frequency amplifier.

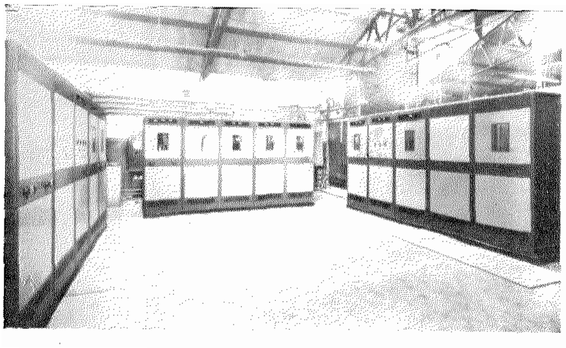


Fig. 22—40 *kW* (*peak*) *Ultra-Short Wave Transmitter for Television.*

In Fig. 22 the left-hand group of bays comprises the last two stages of the zero frequency amplifier and the first three stages of the radio frequency amplifier. The centre group of bays comprises the last two stages of the radio frequency amplifier and the last two stages of amplification of modulating frequencies above 20 cycles per second. The right-hand group covers the first two amplifier bays for these latter frequencies, the first amplifier bay for frequencies below 5 cycles per second, and two control bays.

The use of ultra-short waves for the guidance of aircraft has been treated elsewhere and will not be discussed in detail herein. Suffice it to say that the directivity, so easily obtainable at very high frequencies, and the limited range of propagation render waves in the ultra-short wave band particularly suitable for this purpose. A large number of important aerodromes in Europe have been equipped with ultra-short wave blind approach and instrument-landing equipments designed and manufactured by C. Lorenz, A.G., Berlin, Germany.

In recent years high frequency technique has rapidly assumed considerable importance in the medical field. Diathermy apparatus, used to heat the tissues of the body, has been found to be of immense value in the treatment of certain illnesses, and the rôle played by ultra-short waves is particularly important. As, on

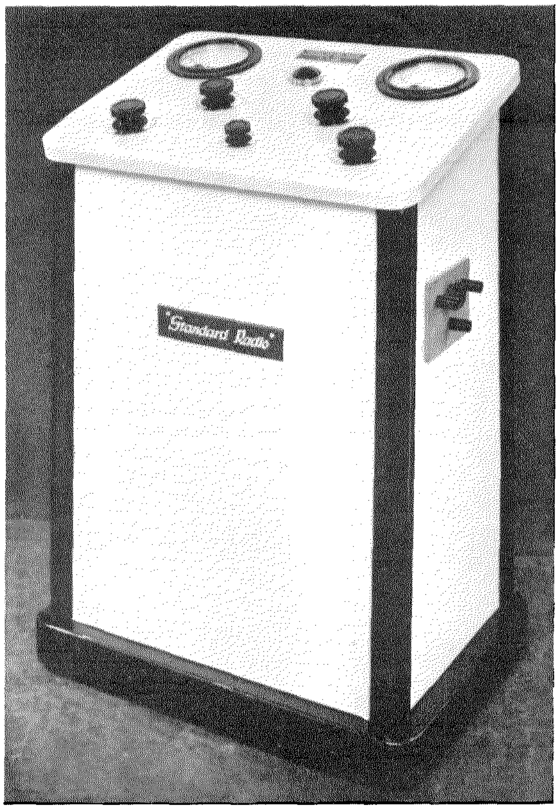


Fig. 23—Ultra-Short-Wave Diathermy Apparatus.

account of the low reactance of small capacities at very high frequencies, it is possible to insulate electrodes, the treatment may be applied without necessitating the removal of clothing and high frequency burns do not occur.

Animal tissue possesses both resistance and capacity. Although the electrical network corresponding to a tissue is one of great complexity, it may be satisfactorily represented by a resistance shunted by a resistive condenser. As different tissues require different electrical constants for their representation, it is clear that it is possible by wavelength change to increase or decrease relative heating effects on one tissue as compared with another. Selective heating effects with insulated electrodes become manifest on wavelengths shorter than 10 metres (30 megacycles per second). Spark equipments with an output of 150 watts on any wavelength between 6 and 15 metres (50 and 20 megacycles per second), and vacuum tube apparatus generating 300 watts on wavelengths of 6 and 30 metres (50 and 10 megacycles per second) are available. Fig. 23 shows the ultra-short-wave vacuum tube diathermy equipment.

CONCLUSION

From the foregoing it will be concluded that reduction of the wavelength is desirable for radio telephone communication on account of the fall in the level of interference and the increase in directivity which it is possible to obtain with any given size of antenna structure. Nevertheless, a point is reached when variability of propagation sets in and tends to outweigh these advantages. The most useful band lies between 1 and 10 metres (300 and 30 megacycles per second), the range from 6 metres to 3 metres (50 to 100 megacycles per second) being ideal for high-grade radio telephone networks. On account of shadow effects the longer end of the ultra-short wave band is best indicated for communication with mobile units such as police cars. Although long-distance propagation sometimes occurs, the level of the unwanted signal is rarely higher than that of the interference due to industrial machines and sparking plugs of motor cars in a crowded city; and the power of the transmitters is sufficiently high to ensure a level of interference exceedingly low compared with the wanted signal. The bandwidth available in the ultra-short wave range is so large that high-quality transmission or multi-channel systems may be employed. Considerable development, therefore, may be anticipated in the use of this wavelength band.

Recent Telecommunication Developments of Interest

A NEW High Vacuum Cathode Ray Tube has been developed by Standard Telephones and Cables, Limited, and is available in two types differing only in the properties of their fluorescent screens. One, the 4063-AB, has a blue screen of high actinic value suitable for photographic purposes; the other, the 4063-AW, a white screen suitable for visual work.

Owing to the use of a high vacuum, and the consequent absence of a beam of comparatively heavy positive ions necessary for focussing gas filled cathode ray tubes, these new tubes can be worked at very much higher speeds; thus lending themselves to the study of extremely high frequency transient phenomena. Moreover, voltages up to 5 000 may be applied to the tubes and the resulting higher spot brilliance compared with existing gas filled tubes makes them very suitable for obtaining high speed photographic records. Traces of transients lasting no longer than 1½ microseconds have been successfully photographed.

Cathode Ray Tube.

An additional advantage of the high vacuum type of tube is inherent freedom from the defect of non-linearity between the deflecting potentials and the spot deflection in the neighbourhood of the origin, a defect known as "origin distortion."

The intensity of the light spot can be controlled by altering the potential of the control electrode without appreciably changing the focus.

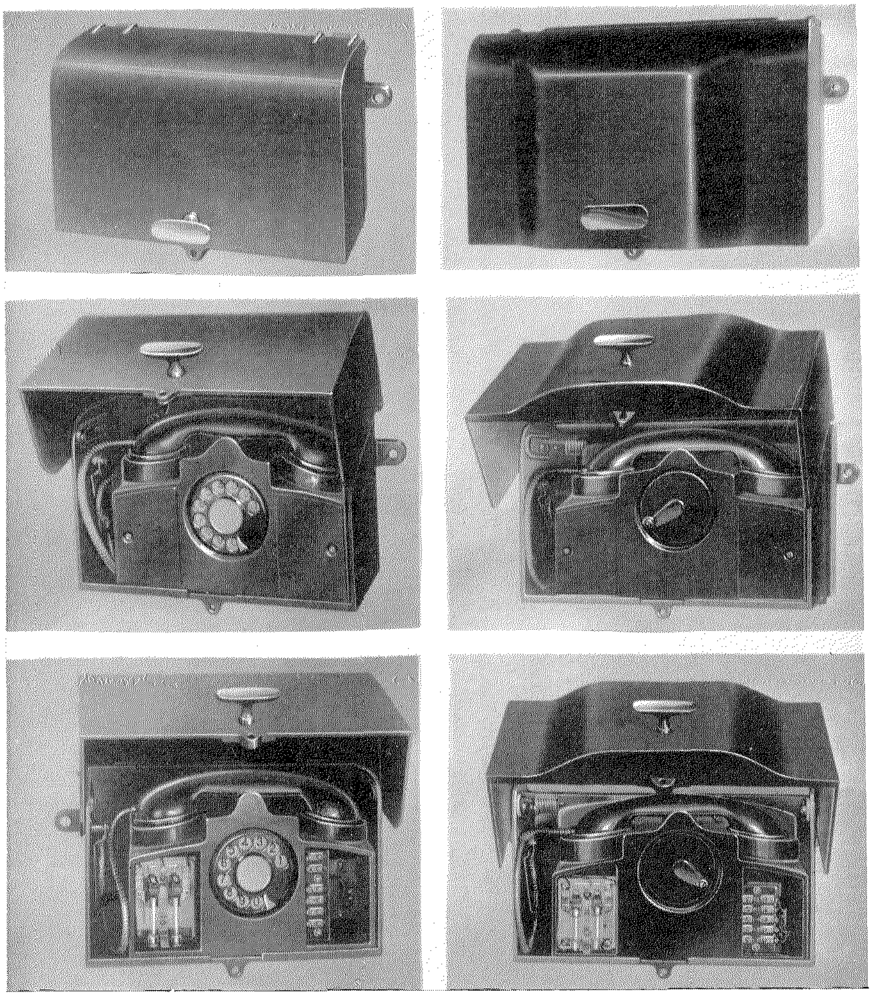
While the diameter of these tubes is too small for their adoption in commercial television receivers, they are quite suitable for small scale experimental television reception.

The average characteristics of these high vacuum tubes are:

Heater voltage 2 volts.
Nominal heater current 2 amperes.
First anode voltage 250 volts (max.).
Second anode voltage approx. one third of third anode voltage.
Maximum third anode voltage 5 000 volts.
Control electrode voltage 0–50 volts.
Diameter 6⅛″ (156 mm).
Overall length 21″ (535 mm).
Base: high voltage cathode ray tube 12 contact type.

• • •

NEW types of Subscribers' Sets for outdoor and other special uses have been developed by the Bell Telephone Manufacturing Company, Antwerp. One type is for common battery manual or automatic use and another for local battery use. The latter is also produced with the universal circuit, making it convertible to common battery and automatic working.



Outdoor Subscribers' Sets showing Common Battery and Local Battery Sets.

These sets are designed for use by road patrolmen, on wharves, in plants covering large areas, etc. The novelty consists in the arrangement of standard apparatus components mounted in an enamelled, stainless aluminium housing, completely protecting the interior against rain. Ventilation is provided and all apparatus components are treated to withstand high humidity conditions.

The universal circuit of the local battery type set permits ready convertibility from local battery to common battery working by the substitution of the proper induction coil, the latter being provided with screws rather than with soldered connections. If desired, a telephone dial can be added.

Standards of transmission and reception previously described[*] are maintained.

• • •

AN interesting Permanent Public Address System, primarily for the imitation of church bells, has been installed in the tower of St. Elizabeth Church in Vienna by Vereinigte

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[*] "A Moulded Bakelite Set with a New Microtelephone," *Electrical Communication,* April, 1936.

Telephon-und Telegraphen-fabriks Aktien-Gesellschaft.

The horns, two metres in length, are placed in the belfry of the steeple and face the four directions of the compass. Screens are used to exclude pigeons, so that the horns are scarcely visible from the ground. The public address apparatus is located in the steeple chamber and is connected by short leads to the speakers. On a table in the steeple chamber are mounted two 20-watt amplifiers, together with a double gramophone. Two identical but overlapping records are used, giving a perfect illusion of the pealing of church bells.

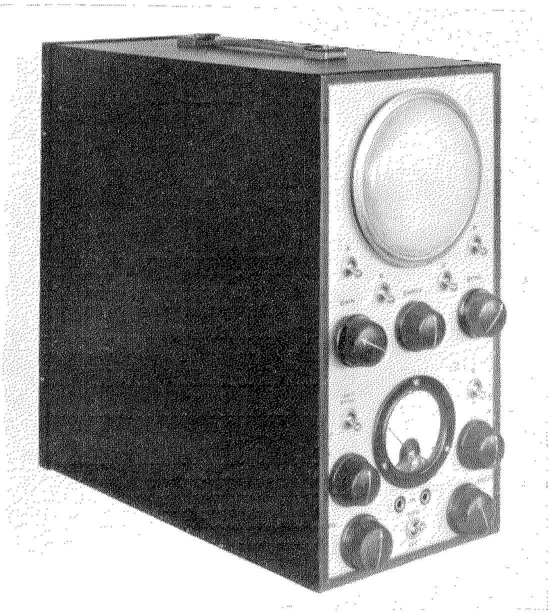
Highly satisfactory and impressive results have been obtained with the equipment, the sound being full and pleasing, even from some distance. The loudspeakers are used not only for the "ringing" of the " church bells," but also for reproducing speech and music.

● ● ●

THE No. 74320-A A.C. Mains-operated Portable and Self-contained Cathode Ray Oscillograph, a recent development of Standard Telephones and Cables, Limited, London, has proved generally useful in industrial, educational and communication fields.

Its potential applications include: development and research, production testing, and sales and educational demonstrations, involving telephone transmission, speech input, carrier, public address and radio rediffusion equipment, as well as broadcast receivers and all types of valves.

The sweep frequency is adjustable from about 3 p : s to 70 000 p : s and is suitable for viewing waves from about 10 p : s to 500 000 p : s. The sensitivity is 1 volt per mm at a 300 volt anode potential and 2½ volts per mm at a 750 volt anode potential. A single stage amplifier, with flat characteristics from 15 to 15 000 p : s and linear over the whole screen at all anode voltages, increases the sensitivity sevenfold (gain of 17 db).



Portable Cathode Ray Oscillograph.

This oscillograph unit contains a No. 4050 cathode ray tube (shielded against magnetic and electrostatic interference by a permalloy screen), a linear time base, a single stage amplifier and all necessary mains-operated power supply equipment.

The overall dimensions are 14 × 8 × 14½ inches (356 × 203 × 368 mm). The weight is 36 lb. (16.3 kg).

Telephone and Telegraph Statistics of the World

Compiled by Chief Statistician's Division, American Telephone and Telegraph Company

Telephone Development of the World, by Countries
January 1, 1936

COUNTRIES	NUMBER OF TELEPHONES			Per Cent of Total World	Telephones Per 100 Population
	Government Systems	Private Companies	Total		
NORTH AMERICA:					
United States	—	17,423,871	17,423,871	49.74%	13.69
Canada	192,220	1,016,595	1,208,815	3.95%	10.99
Central America	12,356	13,571	25,927	.07%	0.36
Mexico	1,337	112,949	114,286	.33%	0.61
West Indies:					
Cuba	600	38,794	39,394	.11%	0.93
Puerto Rico	537	13,076	13,613	.04%	0.79
Other W. I. Places	7,580	15,705	23,285	.07%	0.34
Other No. Am. Places	—	12,936	12,936	.04%	3.66
Total	214,630	18,647,497	18,862,127	53.85%	10.63
SOUTH AMERICA:					
Argentina	—	327,149	327,149	.93%	2.64
Bolivia	—	2,367	2,367	.01%	0.07
Brazil	1,924	196,982	198,906	.57%	0.41
Chile	—	55,161	55,161	.16%	1.21
Colombia	7,964	29,592	37,556	.11%	0.39
Ecuador	3,499	2,954	6,453	.02%	0.26
Paraguay	—	2,974	2,974	.01%	0.33
Peru	—	22,272	22,272	.06%	0.34
Uruguay	20,000	13,000	33,000	.09%	1.62
Venezuela	700	19,000	19,700	.05%	0.58
Other So. Am. Places	2,861	—	2,861	.01%	0.52
Total	36,948	671,451	708,399	2.02%	0.76
EUROPE:					
Austria	272,139	—	272,139	.78%	4.00
Belgium**	339,592	—	339,592	.97%	4.09
Bulgaria	22,267	—	22,267	.06%	0.36
Czechoslovakia	190,098	—	190,098	.54%	1.25
Denmark†	16,911	376,616	393,527	1.12%	10.64
Finland	4,093	145,176	149,269	.43%	3.94
France	1,441,273	—	1,441,273	4.11%	3.38
Germany†	3,269,952	—	3,269,952	9.34%	4.87
Great Britain and No. Ireland	2,551,117	—	2,551,117	7.28%	5.44
Greece	8,467	23,986	32,453	.09%	0.48
Hungary	130,472	739	131,211	.38%	1.47
Irish Free State†	36,093	—	36,093	.10%	1.19
Italy	—	543,835	543,835	1.55%	1.25
Jugo-Slavia	47,298	1,663	48,961	.14%	0.33
Latvia†	68,488	—	68,488	.20%	3.49
Netherlands	366,325	—	366,325	1.05%	4.32
Norway*	123,987	79,406	203,393	.58%	7.05
Poland	126,517	104,337	230,854	.66%	0.68
Portugal	15,137	41,240	56,377	.16%	0.78
Roumania	—	63,092	63,092	.18%	0.33
Russia¶	861,181	—	861,181	2.46%	0.49
Spain	—	341,390	341,390	.98%	1.38
Sweden	641,179	1,415	642,594	1.83%	10.28
Switzerland	399,532	—	399,532	1.14%	9.59
Other Places in Europe	89,530	12,740	102,270	.29%	1.32
Total	11,021,648	1,735,635	12,757,283	36.42%	2.24
ASIA:					
British India†	25,952	43,364	69,316	.20%	0.02
China	80,000	90,000	170,000	.49%	0.04
Japan†	1,131,748	—	1,131,748	3.23%	1.62
Other Places in Asia	153,322	79,132	232,454	.66%	0.14
Total	1,391,022	212,496	1,603,518	4.58%	0.15
AFRICA:					
Egypt	52,740	—	52,740	.15%	0.24
Union of South Africa	150,000	—	150,000	.43%	1.73
Other Places in Africa	95,623	1,978	97,601	.28%	0.08
Total	298,363	1,978	300,341	.86%	0.20
OCEANIA:					
Australia*	532,377	—	532,377	1.52%	7.92
Hawaii	—	25,560	25,560	.07%	6.55
Netherlands East Indies	37,302	3,688	40,990	.12%	0.06
New Zealand†	166,565	—	166,565	.47%	10.59
Philippine Islands	6,000	21,342	27,342	.08%	0.20
Other Places in Oceania	3,852	328	4,180	.01%	0.18
Total	746,096	50,918	797,014	2.27%	0.86
TOTAL WORLD	13,708,707	21,319,975	35,028,682§	100.00%	1.63

* June 30, 1935. ** February 29, 1936. † March 31, 1936.
¶ U.S.S.R., including Siberia and Associated Republics.
§ Includes approximately 16,700,000 automatic or " Dial " telephones, of which about 44% are in the United States.

Telephone and Telegraph Wire of the World, by Countries
January 1, 1936

		MILES OF TELEPHONE WIRE			MILES OF TELEGRAPH WIRE		
COUNTRIES	Service Operated By (See Note)	Number of Miles	Per Cent of Total World	Per 100 Population	Number of Miles	Per Cent of Total World	Per 100 Population
NORTH AMERICA:							
United States	P.	87,200,000	54.89%	68.50	2,260,000	31.97%	1.78
Canada	P.G.	5,121,000	3.22%	46.55	359,000	5.08%	3.26
Central America	P.G.	61,000	.04%	0.85	21,000	.30%	0.29
Mexico	P.	565,000	.36%	3.01	100,000	1.41%	0.53
West Indies:							
Cuba	P.	275,000	.17%	6.47	12,000	.17%	0.28
Puerto Rico	P.	34,000	.02%	1.97	2,000	.03%	0.12
Other W. I. Places	P.G.	107,000	.07%	1.54	9,000	.13%	0.13
Other No. Am. Places	P.	22,000	.01%	6.23	11,000	.16%	3.12
Total		93,385,000	58.78%	52.61	2,774,000	39.25%	1.56
SOUTH AMERICA:							
Argentina	P.	1,300,000	.82%	10.51	200,000	2.83%	1.62
Bolivia	P.	5,500	.003%	0.17	5,000	.07%	0.16
Brazil	P.	754,000	.48%	1.57	111,000	1.57%	0.23
Chile	P.	215,000	.13%	4.71	50,000	.71%	1.10
Colombia	P.	145,000	.09%	1.51	21,000	.30%	0.22
Ecuador	P.G.	9,000	.01%	0.36	4,000	.06%	0.16
Paraguay	P.	7,000	.004%	0.78	3,000	.04%	0.33
Peru	P.	66,000	.04%	1.00	13,000	.18%	0.20
Uruguay	P.G.	110,000	.07%	5.40	8,000	.11%	0.39
Venezuela	P.	80,000	.05%	2.37	7,000	.10%	0.21
Other So. Am. Places	G.	6,000	.004%	1.10	500	.01%	0.09
Total		2,697,500	1.70%	2.88	422,500	5.98%	0.45
EUROPE:							
Austria	G.	679,000	.43%	9.99	49,000	.69%	0.72
Belgium**	G.	1,886,000	1.19%	22.71	35,000	.49%	0.42
Bulgaria	G.	67,000	.04%	1.09	7,500	.11%	0.12
Czechoslovakia	G.	658,000	.41%	4.34	82,000	1.16%	0.54
Denmark†	P.	1,296,000	.82%	35.03	7,500	.11%	0.20
Finland	P.	272,000	.17%	7.18	40,000	.57%	1.06
France	G.	5,394,000	3.39%	12.66	486,000	6.88%	1.14
Germany†	G.	16,000,000	10.07%	23.82	190,000	2.69%	0.28
Great Britain and No. Ireland†	G.	12,353,000	7.77%	26.34	272,000	3.85%	0.58
Greece	P.G.	95,000	.06%	1.39	35,000	.49%	0.51
Hungary	G.	412,000	.26%	4.61	45,000	.64%	0.50
Irish Free State†	G.	127,000	.08%	4.19	22,000	.31%	0.73
Italy	P.	1,600,000	1.01%	3.67	268,000	3.79%	0.61
Jugo-Slavia	G.	220,000	.14%	1.47	53,000	.75%	0.35
Latvia†	G.	284,000	.18%	14.49	4,500	.06%	0.23
Netherlands	G.	1,200,000	.75%	14.16	15,000	.21%	0.18
Norway*	P.G.	629,000	.40%	21.80	22,000	.31%	0.76
Poland	P.G.	1,080,000	.68%	3.18	52,000	.73%	0.15
Portugal	P.G.	142,000	.09%	1.96	15,000	.21%	0.21
Roumania	P.	227,000	.14%	1.18	44,000	.62%	0.23
Russia¶	G.	1,400,000	.88%	0.80	600,000	8.49%	0.34
Spain	P.	1,770,000	1.11%	7.15	90,000	1.27%	0.36
Sweden	G.	2,298,000	1.45%	36.77	21,000	.30%	0.34
Switzerland	G.	1,440,000	.91%	34.58	14,000	.20%	0.34
Other Places in Europe	P.G.	351,000	.22%	4.55	16,000	.23%	0.21
Total		51,880,000	32.65%	9.09	2,485,500	35.16%	0.44
SIA:							
British India†	P.G.	540,000	.34%	0.15	450,000	6.37%	0.12
China	P.G.	650,000	.41%	0.14	137,000	1.94%	0.03
Japan†	G.	4,185,000	2.64%	6.00	235,000	3.32%	0.34
Other Places in Asia	P.G.	720,000	.45%	0.44	188,000	2.66%	0.12
Total		6,095,000	3.84%	0.57	1,010,000	14.29%	0.09
FRICA:							
Egypt	G.	331,000	.21%	1.53	37,000	.52%	0.17
Union of South Africa†	G.	600,000	.38%	6.92	30,000	.43%	0.35
Other Places in Africa	G.	308,000	.19%	0.26	143,000	2.02%	0.12
Total		1,239,000	.78%	0.84	210,000	2.97%	0.14
OCEANIA:							
Australia*	G.	2,559,000	1.61%	38.05	99,000	1.40%	1.47
Hawaii	P.	92,000	.06%	23.59	0	.00%	0.00
Netherlands East Indies	G.	245,000	.15%	0.36	20,000	.28%	0.03
New Zealand†	G.	600,000	.38%	38.14	32,000	.45%	2.03
Philippine Islands	P.G.	69,000	.04%	0.49	11,000	.16%	0.08
Other Places in Oceania	P.G.	10,000	.01%	0.43	4,000	.06%	0.17
Total		3,575,000	2.25%	3.86	166,000	2.35%	0.18
TOTAL WORLD		158,871,500	100.00%	7.40	7,068,000	100.00%	0.33

NOTE: Telegraph service is operated by Governments, except in the United States and Canada. In connection with telephone wire, P. indicates that the telephone service is wholly or predominantly operated by private companies, G. wholly or predominantly by the Government, and P.G. by both private companies and the Government. See preceding table.

* June 30, 1935. ** February 29, 1936. † March 31, 1936.

¶ U.S.S.R. including Siberia and Associated Republics.

Telephone Development of Large and Small Communities—January 1, 1936

COUNTRY	Service Operated By (See Note)	NUMBER OF TELEPHONES In Communities of 50,000 Population and Over	NUMBER OF TELEPHONES In Communities of less than 50,000 Population	TELEPHONES PER 100 POPULATION In Communities of 50,000 Population and Over	TELEPHONES PER 100 POPULATION In Communities of less than 50,000 Population
Australia*	G.	316,900	215,477	9.75	6.20
Austria	G.	210,600	61,539	9.56	1.34
Belgium**	G.	239,336	100,256	6.78	2.10
Canada	P.G.	665,786	543,029	18.78	7.28
Czechoslovakia	G.	96,928	93,170	5.56	0.69
Denmark	P.	206,892	182,608	19.50	6.95
Finland	P.	55,608	93,661	11.30	2.84
France	G.	770,448	670,825	8.66	1.99
Germany†	G.	2,120,098	1,149,854	7.56	3.27
Great Britain and No. Ireland†	G.	1,865,560	744,440	7.01	3.67
Hungary	G.	99,843	31,368	4.79	0.46
Japan†	G.	759,026	372,722	3.53	0.77
Netherlands	G.	239,357	126,968	6.82	2.56
New Zealand†	G.	67,342	99,223	11.92	9.84
Norway*	P.G.	80,718	122,675	19.88	4.95
Poland	P.G.	137,830	93,024	2.70	0.32
Spain	P.	211,528	129,862	4.07	0.66
Sweden	G.	250,329	392,265	23.64	7.56
Switzerland	G.	182,001	217,531	20.52	6.64
Union of South Africa†	G.	90,271	61,900	7.83	0.82
United States	P.	9,929,998	7,493,873	19.32	9.87

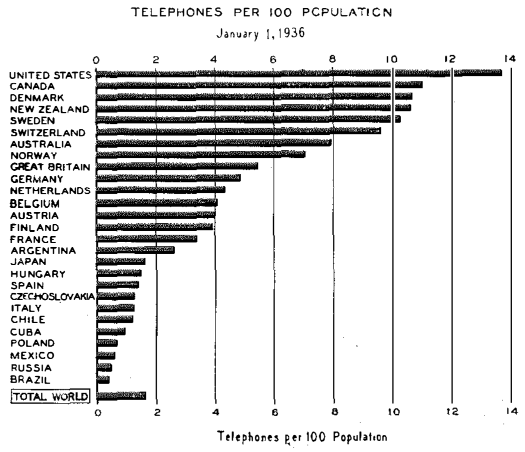
NOTE : P. indicates that the telephone service is wholly or predominantly operated by private companies, G. wholly or predominantly by the Government, and P.G. by both private companies and the Government. See first table.

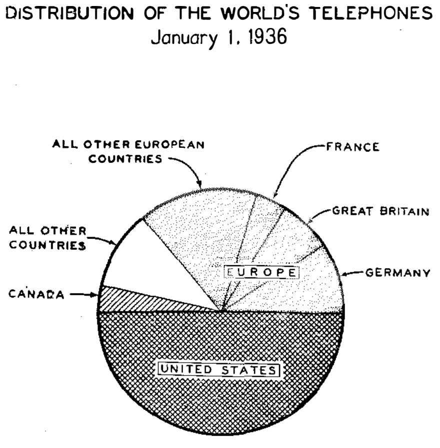
* June 30, 1935. ** February 29, 1936. † March 31, 1936.

Telephone Conversations and Telegrams—Year 1935

COUNTRY	Number of Telephone Conversations	Number of Telegrams	Total Number of Wire Communications	PER CENT OF TOTAL WIRE COMMUNICATIONS Telephone Conversations	PER CENT OF TOTAL WIRE COMMUNICATIONS Telegrams	WIRE COMMUNICATIONS PER CAPITA Telephone Conversations	WIRE COMMUNICATIONS PER CAPITA Telegrams	WIRE COMMUNICATIONS PER CAPITA Total
Australia	469,000,000	15,303,000	484,303,000	96.8	3.2	69.9	2.3	72.2
Austria	630,000,000	1,708,000	631,708,000	99.7	0.3	92.9	0.2	93.1
Belgium	275,000,000	5,317,000	280,317,000	98.1	1.9	33.2	0.6	33.8
Canada	2,303,000,000	10,254,000	2,313,254,000	99.6	0.4	210.8	0.9	211.7
Czechoslovakia	270,000,000	3,890,000	273,890,000	98.6	1.4	17.8	0.3	18.1
Denmark	640,000,000	1,649,000	641,649,000	99.7	0.3	173.9	0.5	174.4
Finland	259,000,000	744,000	259,744,000	99.7	0.3	68.6	0.2	68.8
France	914,225,000	28,052,000	942,277,000	97.0	3.0	21.5	0.7	22.2
Germany	2,433,585,000	16,764,000	2,450,349,000	99.3	0.7	36.3	0.3	36.6
Great Britain and No. Ireland	1,850,000,000	53,428,000	1,903,428,000	97.2	2.8	39.6	1.1	40.7
Hungary	150,000,000	1,903,000	151,903,000	98.7	1.3	16.8	0.2	17.0
Japan	4,303,000,000	57,315,000	4,360,315,000	98.7	1.3	62.2	0.8	63.0
Netherlands	385,000,000	2,903,000	387,903,000	99.3	0.7	45.7	0.3	46.0
Norway	238,500,000	2,802,[illegible]00	241,302,000	98.8	1.2	82.9	1.0	83.9
Poland	518,000,000	3,360,000	521,360,000	99.4	0.6	15.3	0.1	15.4
Spain	806,000,000	25,000,000	831,000,000	97.0	3.0	32.7	1.0	33.7
Sweden	950,000,000	3,681,000	953,681,000	99.6	0.4	152.2	0.6	152.8
Switzerland	282,000,000	1,744,000	283,744,000	99.4	0.6	67.9	0.4	68.3
Union of South Africa	260,000,000	6,670,000	266,670,000	97.5	2.5	30.1	0.8	30.9
United States	25,000,000,000	175,000,000	25,175,000,000	99.3	0.7	197.0	1.4	198.4

NOTE : Telephone conversations represent completed local and toll or long distance messages. Telegrams include inland and outgoing international messages.





Telephone Development of Large Cities
January 1, 1936

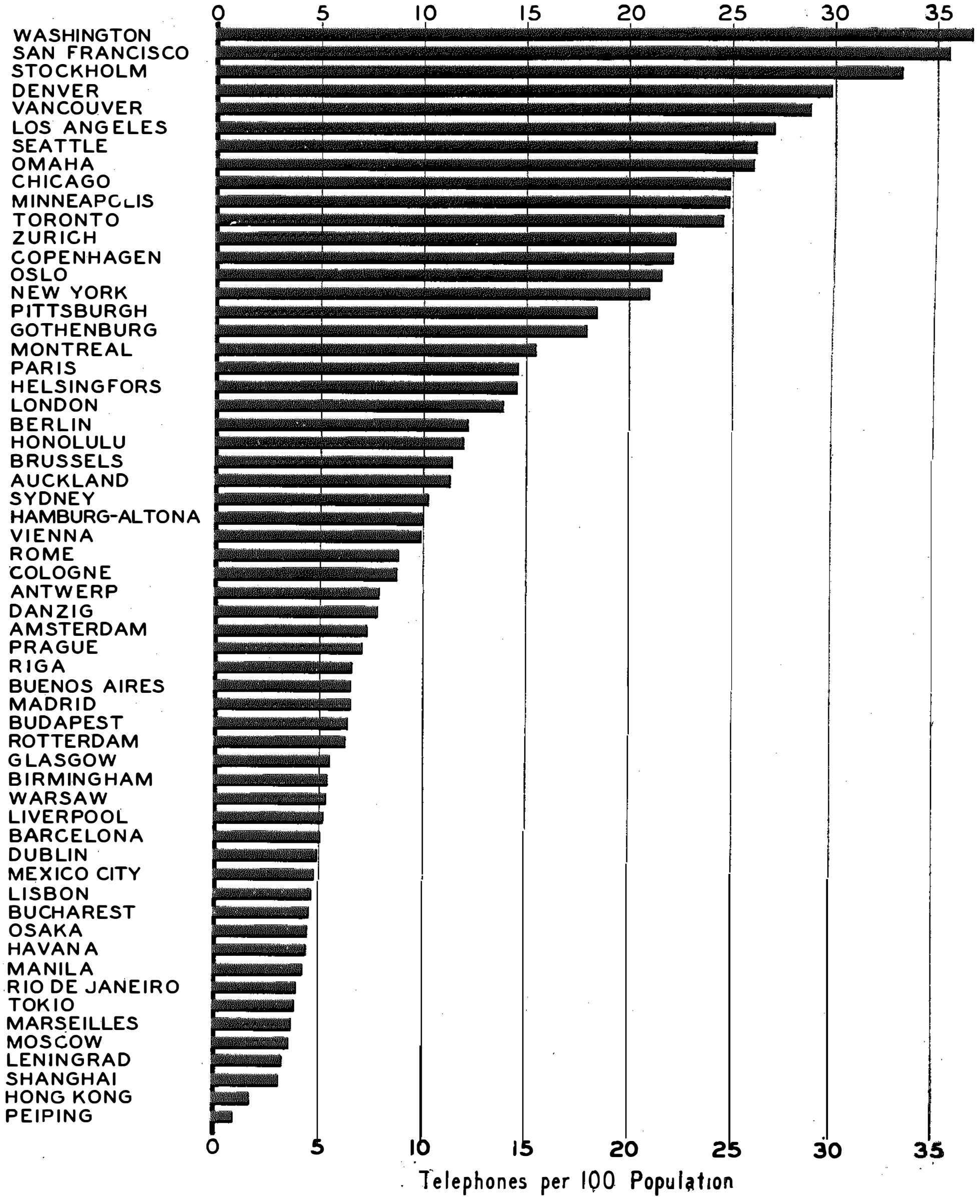
Country and City (or Exchange Area)	Estimated Population (City or Exchange Area)	Number of Telephones	Telephones Per 100 Population
ARGENTINA:			
Buenos Aires	3,000,000	195,715	6.52
AUSTRALIA:			
Adelaide	315,000	30,445	9.67
Brisbane	306,000	29,126	9.52
Melbourne	1,008,000	111,622	11.07
Sydney	1,255,000	128,628	10.25
AUSTRIA:			
Graz	153,000	11,223	7.34
Vienna	1,876,000	184,840	9.85
BELGIUM:**			
Antwerp	527,000	41,404	7.86
Brussels	976,000	111,059	11.38
Liege	422,000	24,825	5.88
BRAZIL:			
Rio de Janeiro	1,820,000	70,746	3.89
CANADA:			
Montreal	1,070,000	165,231	15.44
Ottawa	186,100	36,453	19.59
Toronto	778,200	191,545	24.61
Vancouver	187,500	53,978	28.79
CHINA:			
Canton	1,070,000	8,600	0.80
Hong Kong	860,000	14,549	1.69
Peiping	1,560,000	12,483	0.80
Shanghai††	1,660,000	51,190	3.08
CUBA:			
Havana	704,000	30,688	4.36
CZECHOSLOVAKIA:			
Prague	928,000	65,537	7.06
DANZIG:			
Free City of Danzig	230,000	17,843	7.76
DENMARK:			
Copenhagen	825,000	182,946	22.18
FINLAND:			
Helsingfors	270,000	39,193	14.52
FRANCE:			
Bordeaux	269,000	20,972	7.80
Lille	202,000	17,471	8.65
Lyons	672,000	36,321	5.40
Marseilles	970,000	35,627	3.67
Paris	2,910,000	422,755	14.53
GERMANY:†			
Berlin	4,225,000	513,610	12.16
Breslau	628,000	43,571	6.94
Cologne	762,000	66,581	8.74
Dresden	789,000	65,436	8.29
Dortmund	581,000	24,938	4.29
Essen	672,000	31,420	4.68
Frankfort-on-Main	649,000	62,723	9.66
Hamburg-Altona	1,627,000	161,387	9.92
Leipzig	761,000	66,565	8.75
Munich	832,000	82,835	9.96
GREAT BRITAIN AND NO. IRELAND:†			
Belfast	415,000	20,252	4.88
Birmingham	1,220,000	65,876	5.40
Bristol	418,000	24,664	5.90
Edinburgh	445,000	37,055	8.33
Glasgow	1,200,000	65,897	5.49
Leeds	517,000	27,748	5.37
Liverpool	1,205,000	62,663	5.20
London—			
(Telecommunications Region)	9,450,000	960,709	10.17
(City and County of London)	4,472,000	617,213	13.80
Manchester	1,106,000	70,085	6.34
Newcastle	472,000	21,665	4.59
Sheffield	522,000	22,803	4.37
HAWAII:			
Honolulu	145,000	17,263	11.91
HUNGARY:			
Budapest	1,387,000	88,627	6.39
Szeged	139,000	2,065	1.49
IRISH FREE STATE:†			
Dublin	430,000	21,065	4.90
ITALY:			
Milan†	1,050,000	91,695	8.73
Naples	885,000	27,685	3.13
Rome	1,050,000	91,869	8.75
JAPAN:†			
Kobe	925,000	37,636	4.07
Kyoto	1,100,000	44,745	4.07
Nagoya	1,100,000	37,391	3.40
Osaka	3,050,000	135,098	4.43
Tokio	5,970,000	226,028	3.79
LATVIA:†			
Riga	387,000	25,654	6.63
MEXICO:			
Mexico City	1,390,000	65,731	4.73
NETHERLANDS:			
Amsterdam	790,000	58,028	7.35
Haarlem	164,000	13,178	8.04
Rotterdam	620,000	38,950	6.28
The Hague	520,000	49,949	9.61
NEW ZEALAND:†			
Auckland	207,000	23,427	11.32
NORWAY:*			
Oslo	250,000	53,825	21.53
PHILIPPINE ISLANDS:			
Manila	425,000	18,023	4.24
POLAND:			
Lodz	930,000	16,044	1.73
Warsaw	1,290,000	68,461	5.31
PORTUGAL:			
Lisbon	660,000	30,248	4.58
ROUMANIA:			
Bucharest	646,000	29,209	4.52
RUSSIA:			
Leningrad	3,100,000	99,463	3.21
Moscow	4,100,000	144,669	3.53
SPAIN:			
Barcelona	1,110,000	55,569	5.01
Madrid	1,015,000	66,148	6.52
SWEDEN:			
Gothenburg	258,000	46,269	17.93
Malmö	141,000	22,639	16.06
Stockholm	446,000	148,433	33.28
SWITZERLAND:			
Basel	152,000	34,003	22.37
Berne	114,000	26,284	23.06
Geneva	148,000	27,870	18.83
Zurich	273,000	60,705	22.24
UNITED STATES: (See Note)			
New York	7,178,000	1,503,712	20.95
Chicago	3,410,000	849,889	24.92
Los Angeles	1,335,000	360,506	27.00
Pittsburgh	1,023,900	188,871	18.45
Total 10 cities over 1,000,000 Population	22,023,000	4,546,669	20.65
Milwaukee	772,000	139,960	18.13
San Francisco	699,500	248,652	35.55
Washington	550,000	201,884	36.71
Minneapolis	508,000	126,342	24.87
Total 10 cities with 500,000 to 1,000,000 Population	6,586,600	1,371,979	20.83
Seattle	418,500	109,296	26.12
Denver	305,000	90,902	29.80
Omaha	241,000	62,676	26.01
Hartford	239,000	55,862	23.37
Total 33 cities with 200,000 to 500,000 Population	10,106,800	1,847,598	18.28
Total 53 cities with more than 200,000 Population	38,716,400	7,766,246	20.06

NOTE: There are shown, for purposes of comparison with cities in other countries, the total development of all cities in the United States in certain population groups, and the development of certain representative cities within each of such groups.

* June 30, 1935. ** February 29, 1936. † March 31, 1936. †† International Settlement and French Concession.

TELEPHONES PER 100 POPULATION OF LARGE CITIES

January 1, 1936



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