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TELEVISION ENGINEERING

in Science, Industry and Broadcasting

THE title of these notes will be the theme of the Institution's next Convention to be held from July 1st-5th, 1959. Once again Cambridge will be the venue, and the meetings will take place in the Clerk Maxwell and Green Lecture Theatres of the Cavendish Laboratories.

Increasing attendance at Institution Conventions makes it impossible to accommodate all members and delegates in one College. By courtesy of the appropriate authorities, therefore, arrangements have been made for delegates to be accommodated in a number of Colleges, including Downing, Peterhouse, Sidney Sussex and Christ's.

Observations made on a previous editorial in the *Journal* on Convention venues *show members' appreciation for Conventions being held within the precincts of a University, and more especially Cambridge. The extended arrangements made for accommodation should be adequate, although it is not too early to request that members should give early advice of their intention to be present. Overseas engineers are always especially welcomed at Institution Conventions; those readers are particularly invited to inform the Institution as soon as possible of their intention to join the Convention.

The theme is one which has been very carefully debated by the Council, taking into consideration the views of the appropriate Committees and particularly the 1959 Convention Committee. It is intended that the proceedings shall cover the application of television engineering in the broadest sense and not be limited to the more popular aspects of television engineering. Thus every member, whatever his immediate work, will find the papers and discussions of interest to him.

It is worth recalling that the Institution's post war Conventions have been devoted to:—

> Telecommunications, nucleonics, valves, radio communication and broadcasting, radar and navigation aids, television engineering (1951), audio frequency engineering, industrial electronics and electronics in automation.

Past Conventions have indicated the increasing activities of the radio and electronics engineer; they afford examples of how the purpose of the Institution and the work of its members can materially help not only in the fields of communication and navigation, but also aid scientific research and a wide range of industries.

Members may still submit papers for the consideration of the Convention Committee, and such offers should be accompanied in the first instance by a synopsis of the paper's proposed contents. Contributions covering the theoretical assessment of the problems encountered in designing television equipment for use other than for domestic broadcasting will be especially welcomed.

Arrangements for the 1959 Convention will ensure that opportunity is provided for a wide exchange of opinion and experiences both formally and informally. It will also be an occasion for the social functions which have traditionally become part of the Institution's Conventions.

Members may, therefore, look forward with particular interest to the fifth Convention arranged by the Institution since the war.

G.D.C.

* *J. Brit.I.R.E.*, 17, p. 241, May 1957.

INSTITUTION NOTICES

Radio Industry Council Dinner

The Guest of Honour at this year's Dinner of the Radio Industry Council on November 19th at the Dorchester Hotel, London, was the Chancellor of the Exchequer, the Right Hon. D. Heathcoat Amory, P.C., M.P. The Institution was represented officially by the President-elect, Professor E. E. Zepler, and Mr. G. D. Clifford, General Secretary.

Education Committee's Visit to R.A.F. Technical College

Members of the Education Committee were invited to pay an official visit to the R.A.F. Technical College, Henlow, on 24th October. The Institution already exempts from the Graduateship Examination cadets from Henlow who obtain a Higher National Diploma in the appropriate subjects, and the visit provided opportunity to discuss changes in the examination syllabus and the curricula of the College.

On the previous evening Professor Emrys Williams (Vice-President) and Mr. G. D. Clifford (General Secretary) were guests of honour at a dinner held in the R.A.F. Technical College Mess.

The Institution of Production Engineers

The Institution of Production Engineers has recently published a list of professional bodies, corporate members of which will be granted exemption from Parts 1 and 2 of the Associate Membership Examination. The Brit.I.R.E. is included in this list. Exemption only applies to candidates for corporate membership of the Institution of Production Engineers who hold, or have held, adequate managerial status on the production side of industry.

To complete the I.P.E. Associate Membership Examination such applicants are required to pass Part 3.

Institution Visit

Advice has already been sent to members in the London and Home Counties area of the visit arranged by the Technical Committee to Vauxhall Motors Ltd., Luton, on Thursday, December 4th. Members resident outside this area wishing to take part should write at once to the Institution.

Medical Electronics Group

Mention was made in the Annual Report of the intention to set up specialized groups of members who are professionally concerned with one or other of the many aspects of radio and electronic engineering. The Council has now authorized the establishment of the first group, which is made up of members who are active in the field of medical electronics.

The constitution of the first committee is as follows:—

- W. J. Perkins (Member)—Chairman.
- R. Brennand (Associate Member)
- J. I. Brown (Associate Member)
- K. Copeland (Associate Member)
- N. W. Ellis (Associate Member)
- Dr. C. A. F. Joslin, M.B., B.S. (Associate Member)
- C. W. Miller, D.Sc., M.Sc. (Associate Member)

The Group will be principally concerned with the arrangement of meetings in collaboration with the Programme and Papers Committee, and it will also assist in the procurement of papers for publication only.

Variety Reduction Essay Prize Competition

To encourage the study of Variety Reduction, the British Productivity Council has decided to promote a Variety Reduction Essay Prize Competition.* The competition will be divided into two categories—the first being an Open Competition, for which a prize of up to 150 guineas will be awarded, and the other being a Student Competition for which a prize of 15 guineas will be awarded. Additional prizes may be awarded for papers in either category if, in the opinion of the B.P.C., such awards are merited.

Further information may be obtained from the Institution or direct from: The British Productivity Council, 21 Tothill Street, London, S.W.1.

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* Effective production methods demand the maximum utilization of the manufacturers' plant, labour and other resources. At the same time, the consumer expects a choice of products. Variety Reduction, therefore, is one of the most important undertakings of management if these two concepts are to be balanced.

INTERNATIONAL RADIO ORGANIZATIONS
Some Aspects of their Work*

by

R. L. Smith-Rose, C.B.E., D.Sc., Ph.D., F.C.G.I.†

Dr. Smith-Rose is Vice-President of U.R.S.I. and international chairman of Study Group V of C.C.I.R. and was specially invited by the Institution's Technical Committee to submit this paper.

SUMMARY

A brief historical outline is given of the growth of communications from the inland postal service to international telegraph, telephone and radio services. The inauguration of the International Telecommunications Union and its technical consultative committees is described, and details are given of the present work of the International Radio Consultative Committee (C.C.I.R.). A corresponding review is given of the activities of the International Scientific Radio Union (U.R.S.I.) the object of which is to foster international co-operation in fundamental research and provide the scientific basis on which operational communications and other applications of radio are developed and maintained.

1. Introduction

It is quite obvious to anyone who has given the matter the slightest thought that radio transmissions, for whatever purpose they may be used, cannot be confined to national boundaries. Whenever a series of electromagnetic waves is started by operating a radio transmitter, these waves spread out in all directions and travel over the earth and through space; while subject to various degrees of attenuation, reflection, diffraction and so on, they are nevertheless theoretically capable of being detected anywhere on a receiving device of sufficient sensitivity. In practice, of course, a limit is set by the possibility of making the arriving waves or signals operate an audio, visual or mechanical responder amidst the general level of radiation known as noise, which arises from natural causes such as thunderstorms, or from man-made sources such as electrical machinery. Although the frequency or wavelength spectrum available in present radio practice is very wide, it is nevertheless necessary to duplicate in different places the use of the same frequencies, and this in itself clearly sets up both a national and international problem in the curtailing or avoidance of mutual interference.

*Manuscript received 18th September, 1958. (Paper No. 475.)

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U.D.C. No. 621.396-61

Before pursuing this radio problem any further, however, the growth of the international aspects of the communication of information will be reviewed.

2. Inland Communication by Post

First it must be made clear that by communication is meant the conveyance of information from one place to another beyond the range by which two men can talk to one another or even signal by semaphore or flash lamp methods. It must also be assumed that we are not concerned with whatever simple type of information can be conveyed by such methods as the beating of drums or the use of bonfires and smoke trails. From the time when man learnt to write and read, he soon desired to communicate with his fellow men at a distance by means of the written word. Passing over the phase when messages were written on slabs of stone or chips of wood, we arrive at a time in the early part of the eighteenth century when letters were conveyed up and down Great Britain first by runners, then by postboys on horseback and later by mailcoaches. The speed was naturally not very great by modern standards. For example, in 1715, the time allowed for the mail between London and Edinburgh was six days. Towards the end of the century—1798—this was reduced to three nights and two days, by travelling at what was called "a marvellous velocity", which was highly dangerous and liable to cause sudden death due to an affection of the brain! By 1836 the speed of some of the mail coaches was nearly ten miles an hour, and this could be kept up over very long distances, so that the journey from London to Edinburgh—400 miles—was accomplished in 45½ hours. (London to York—197 miles in 20 hours; and London to Holyhead—259 miles in 27 hours.)

The first half of the nineteenth century saw the invention of the steam locomotive and in 1830 the Liverpool and Manchester Railway was opened, followed in a few years by the forerunners of the various railways radiating north, east, south and west from London. While it would seem an obvious change to carry the mails on the trains curious objections were raised as to the safety of such procedure particularly since the trains might travel through the night. Eminent persons of the time suggested that it would be necessary to have policemen along the line or alternatively that the lines should have gas or other lights installed throughout their length.

Now in these early days the cost of the mails—or postage as we now term it—was determined by the distance and was payable on delivery by the recipient of the letter. In 1837 the average cost of sending a letter was about 7d., the charge for the distance between London and Edinburgh and Glasgow being about 1s. 3d. (Remember that this was some 120 years ago when pence and shillings were of much greater value than they are today.) The system of payment on delivery was subject to many delays and much fraud, and a notable step forward was made by the reforms introduced by Rowland Hill who amidst much opposition, established the principles first of prepayment and secondly of a uniform postal rate throughout the country. This plan was incorporated in the budget of 1839, and Rowland Hill was appointed to a post at the Treasury in 1840 to superintend the introduction of his scheme. After a preliminary experiment, a uniform rate of 1d. for letters not exceeding half an ounce was introduced in January of that year. Philatelists will know that the first 1d. black postage stamps, which are so much sought after, were issued in May 1840 according to the catalogue. In spite of the initial opposition to his proposals, Rowland Hill later became chief secretary to the Post Office, he was knighted in 1862, and following his death in 1879 he was buried in Westminster Abbey.

3. Telegraphy and Telephony by Wire

It was in the first half of the nineteenth century also, that communication by electrical means (as it is now called) was initiated. Applied telegraphy dates practically from the year 1835 when Cooke and Wheatstone collaborated and presented to the world the needle telegraph system, which was quickly followed by developments leading to the morse and direct reading telegraph printers in use today. The first Central Telegraph Office was set up in London in 1850, and the system was soon extended by submarine cable to establish communication with towns on the continent of Europe, while the first Atlantic cable was laid in 1866. Ten years later Alexander Graham Bell invented the telephone, and from then onwards the technique and practice of telegraphy and telephony over wires rapidly developed in the second half of the nineteenth century. Before the century closed, however, the work of Hertz, Sir Oliver Lodge and Admiral Sir Henry Jackson (the first chairman of the Radio Research Board) culminated in Marconi's demonstration of the possibilities of signalling without wires. The successful transmission of signals across the Atlantic in 1901 was the beginning of the widespread development of radio communication which took place in the first half of this, the twentieth century.

4. The Universal Postal Union

It is evident that to send a letter to a foreign country on a postage prepaid basis, there must be agreement as to the distribution of the cost and arrangements for its collection. When the message has to travel over several countries the negotiations can become somewhat involved unless there is some agreed convention covering all the details of transit and finance. At first the rates for foreign postage were varied and were settled by bargaining between individual postal administrations, the charges being assessed according to the different units of weight and cost pertaining in each of the several countries through which the mail had to be transported. In 1874 the Swiss Government called a meeting in Berne to which representatives from various countries were invited, and the result was the formation of the Postal Union. The central idea of this Union was to treat all the countries forming it as a single territory for postal purposes, and uniform rates for the transport of letters and papers were established. While a good deal of opposition was at first encountered from the various countries who expected to supply their services at a loss, it was later realized that it was for the common good that the postal services should be developed and that this would be to the benefit of all in the long run. The business of the Postal Union is conducted at Berne where an appropriate U.P.O. monument was erected to commemorate the 25th anniversary of its foundation.

5. The International Telecommunication Union

The formation of the Union dealing with international postal services was preceded by the Telegraph Union which was the outcome of a conference held in Paris in 1865, and is the oldest of the interdepartmental international organizations. The object of this Union, to which the practice of telephony was added in due course, was to deal not only with the financial aspects of the subjects but also to organize the necessary uniformities of technique and codes to enable the telegraph and telephone signals to pass over the wires and cables installed in the various countries.

On the introduction of radio at the beginning of the present century, attention was first devoted to developing this new means of communication. It soon became clear, however, that this new service would need to be protected on both national and international levels and rules laid down to govern its use. After preliminary discussions initiated by the German government, the first International Radiotelegraph Conference was held in Berlin in 1906. As a result, a convention was drawn up and signed by some twenty-seven countries defining the service regulations and rules of procedure to be followed in wireless communication particularly between ships and shore stations. At later conferences (see Table 1), the system whereby frequency bands are apportioned between the different services was worked out and put into practice, and the various nations undertook to notify the frequencies in use, which subsequently were collected in the well-known Berne lists.

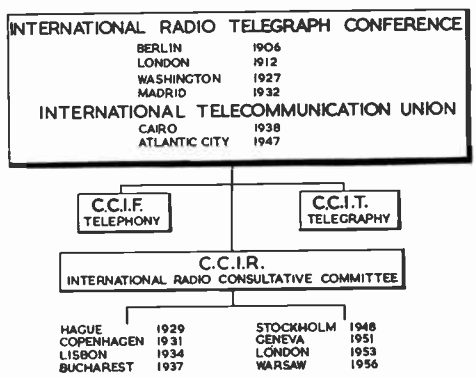
In 1947 at the Atlantic City Conference some major changes were made in the constitution and practice of the International Telecommunication Union which had then become one of the specialized agencies of the United Nations. Among the reforms carried out at this time were first the establishment of a permanent secretariat supported by the member countries and acting through a Plenipotentiary conference or the Administrative Council; and secondly the provision of specialized secretariats on a similar footing for the International Telegraph Consultative Committee (C.C.I.T.)* and the International Radio Consultative Committee (C.C.I.R.), similar to that already existing for the International Telephone Consultative Committee (C.C.I.F.).* Also a new permanent body was created under the title of International Frequency Registration Board (I.F.R.B.), the essential functions of which were:

(i) to record systematically frequency assignments in order to ensure their international recognition:

and (ii) to give advice to members of the Union to assist in the operation of the maximum practicable number of radio channels in those portions of the spectrum where harmful interference may occur.

At the Atlantic City conference also, a frequency allocation table was drawn up for the three regions into which the world is divided for

Table 1



* These are now combined into a single International Consultative Committee for Telegraphy and Telephony (C.C.I.T.T.).

radio communication purposes. This has been put into force for a portion of the radio spectrum and is used as a basis for negotiation as development takes place among the various services such as television, frequency modulation broadcasting and mobile radio communication. The main features of the organization of the Union and its duties were confirmed at a plenipotentiary meeting at Buenos Aires in 1952, but the main technical problems are discussed, and resolved where possible, by the work of the consultative committees[5].

6. The International Radio Consultative Committee

The C.C.I.R. was established in November 1927 at an international radio conference held in Washington. It was charged with the study of technical questions which are of interest to international radio communications, and which are submitted by administrations and private operating agencies, constituting its membership. The function of C.C.I.R. is limited to the expression of an opinion on the various questions studied and transmission of their viewpoint to the Bureau of the I.T.U.

The first assembly was at the Hague in 1929, when some 200 delegates attended representing 50 states and private companies as well as two international unions interested in certain aspects of radio science and broadcasting respectively[2]. Broadly the work of C.C.I.R. is to provide the technical basis for the establishment of working standards on protection ratios for various services, the minimum field strengths to be protected, the maximum desirable transmitter power, aerial efficiency and directivity, and receiver discrimination: it is also responsible for the collection, standardization and distribution of field strength curves and corresponding transmission curves for maximum usable frequencies. All this technical work and the corresponding standards are kept under constant review with the aid of the published technical literature supplemented by the contributions from the participating members.

During the next three meetings which were held in Copenhagen[3], Lisbon and Bucharest (in 1937), the subject of radio wave propagation became of steadily increasing importance in connection with the selection of frequencies for different services, including direction finding, navigational aids and broadcasting, both in temperate and tropical latitudes. Following the post-war Atlantic City Conference of the I.T.U., the fifth meeting of C.C.I.R. was held in Stockholm in 1948. It was on this occasion that the growing importance of wave propagation was recognized by the formation of three study groups—in place of one previously—to deal with this subject. These are the now well-known Study Groups IV, V and VI which deal with Ground Wave, Tropospheric and Ionospheric Propagation respectively, and which have made continuous technical studies in these subjects at all the remaining Plenary Assemblies, up to and including that held in Warsaw in 1956[6, 9].

The C.C.I.R. is thus concerned with the resolution of the more technical problems which arise in various international radio conferences, especially those affecting the allocation of radio frequencies for use by different services and in various parts of the world. It is not concerned with frequency allocation as such, but rather with the provision of a detailed understanding of what is technically possible in the matter of equipment, operating technique, and—by no means least important—the propagation characteristics of radio waves over the entire frequency spectrum. The manner in which this technical work is carried out is described briefly in the following section.

Table 2

Study Groups of C.C.I.R.

I	Transmitters
II	Receivers
III	Complete Radio Systems
IV	Ground Wave Propagation
V	Tropospheric Propagation
VI	Ionospheric Propagation
VII	Radio Time Signals and Standard Frequencies
VIII	International Monitoring
IX	General Technical Questions
X	Broadcasting
XI	Television
XII	Tropical Broadcasting
XIII	Operation Questions
XIV	Vocabulary

6.1. *The Study Groups of C.C.I.R.*

Under the existing arrangements the work of C.C.I.R. is organized under fourteen Study Groups, the titles of which are given in Table 2, which indicates the manner in which the technical work is distributed. The first three groups are concerned with the general problem of the operation of radio communication services of all kinds with the utmost efficiency and economy of space in the frequency spectrum. At the transmitting end, the specification and measurement of the effective bandwidth of emissions are dealt with; while at the receiving end the sensitivity and noise factor of receivers developed for the various radio services—telegraphy, telephony, sound and television broadcasting—are reviewed. The third study group is concerned with the factors which are useful to the I.F.R.B., in dealing with the problem of frequency allocation for the complete radio systems employed by different services. A continuous study is made of the ratios of signal/noise and wanted signal/interference required for satisfactory service, together with an assessment of the grade of service, the allowances to be made for fading and atmospherics, together with the effectiveness of directive aerial systems at great distances.

Of the three groups dealing with wave propagation, Study Group IV is concerned with the general investigation over the entire radio-frequency spectrum of the propagation of waves over the ground, and the effect of variations of ground conductivity and of irregular terrain such as hills and trees on this propagation. An atlas of theoretical curves giving the calculated field strength at various distances over a smooth earth is maintained, and the extent to which the various factors mentioned above affect these idealized curves is studied in order to assist the choice of site of transmitting stations for various purposes. The general problem of determining the extent to which the propagation is modified by refraction or reflection in the lower atmosphere is assigned to Study Group V which deals with tropospheric wave propagation. In addition to studying the variation of field strength at various distances and the influence of the height and directive properties of transmitting aerials, a statistical analysis of the results is used in an attempt to correlate these with the meteorological conditions prevailing at the place and time of the measurements. The extension of broadcasting and television into the v.h.f. and u.h.f. bands requires an application of such propagation knowledge to secure the most economical use of the channels available and the need to accommodate more stations, frequently operated by different nations, in each channel. The planning, establishment and operation of general communication services and especially of wideband radio systems in the above and the s.h.f. bands, also requires an up-to-date knowledge of the propagation phenomena met with in all parts of the world.

The problems of high frequency communication are dealt with by Study Group VI under the title "Ionospheric Radio Propagation". The work of this group includes the preparation and practical application of forecasts of radio transmission conditions all over the world, the choice of a suitable solar or ionospheric index on which these may be based, and the general investigation of atmospheric radio noise. There is now a considerable measure of international agreement on the most useful form for presenting forecasting information on world-wide charts, and a recent activity of the group has resulted in revised charts assessing the strength of the atmospheric noise to be expected at various times in different parts of the world. It is natural to find that the activities of Study Groups V and VI of C.C.I.R. are closely connected with the programmes of the corresponding commissions of U.R.S.I.[7].

Study Group VII is charged with the task of providing a world-wide service of standard frequency transmissions and time signals conforming to agreed standards of accuracy and generally operated in specially assigned channels designed to minimize harmful interference. The somewhat difficult technical problems associated with the monitoring of frequencies and field strengths of transmitting stations is constantly under review by Study Group VIII. The difficulties experienced by monitoring stations in identifying transmissions in the absence of call signs, is one of a number of general technical questions which are considered by Study Group IX. One of the major activities of this group is the study of broadband radio relay systems of the types used for multichannel telephony and for television. The characteristics of equipment for transmitting photographs and documentary material, such as meteorological charts, over radio links have been specified by this group, in conjunction with the associated committee dealing with the corresponding line problems. Study Group IX deals with various marine questions, and has been responsible for securing agreement on the characteristics of alarm signals, both manual and automatic, for use on the radio telegraphic calling and distress signal on 500 kc/s, and the corresponding telephony signals on 2182 kc/s.

Various problems associated with broadcasting and television, particularly in their many international aspects, are dealt with by Study Groups X and XI respectively. On the sound broadcasting side, the technical standards for recording on magnetic tape and film have been formulated in order to facilitate international exchange of both sound and television programmes. Although, even after much discussion, the standards used for television differ markedly in European countries, many technical problems associated with transcontinental links have been resolved. The future possibilities for approaching greater uniformity in the extension of transmissions to the u.h.f. band is still under active investigation, as are also the various technical problems associated with colour television.

In tropical parts of the world a broadcasting service has to compete with the interference caused by very intense atmospheric noise, and Study Group XII has made recommendations on the type of transmitting aerials which, while giving a good field strength within the service area of the broadcasting station, cause a minimum of interference at long distances. This is associated with advice on the minimum protection ratio required in the tropical broadcasting bands; but the question of limiting the maximum power to be used by high-frequency transmitting stations in tropical regions has long been a controversial issue[8].

Study Group XIII is concerned with various operational questions which may be put to it from time to time and which do not appear to be appropriate to other groups. These have included, for example, the service codes and procedure, maintenance of auto-alarm equipment, classification of bearings and positions in direction finding, identification of radio stations and any problems arising from the use of maritime radar equipment. "Vocabulary" is the title of Study Group XIV which is thus clearly occupied with the formulation of terms and definitions used in all radio technical work, and the incorporation of these as may be agreed in the wider vocabulary established by the International Electrotechnical Commission.

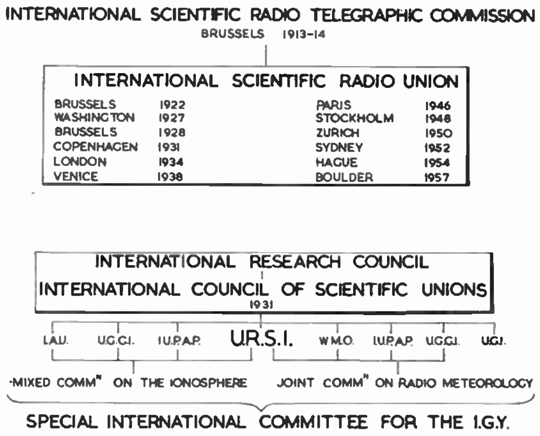
6.2. *Administration and Publications of C.C.I.R.*

The C.C.I.R. is administered from its office in Geneva with a permanent Director and Vice-Director appointed by international agreement, and assisted by an appropriate technical and secretarial staff. This organization forms part of the permanent secretariat of the International Telecommunications Union to which it is the technical adviser on radio matters in parallel with the corresponding International Consultative Committee on Line Telegraphy and Telephony (C.C.I.T.T.). The proceedings of all Plenary Assemblies of C.C.I.R. are published in two volumes, one giving the full texts of the various recommendations made and the study programmes and questions under review; while the other gives the detailed minutes of the various meetings of study groups and full assembly[10]. These publications are made available to all participants through the national administrations and other membership.

7. The International Scientific Radio Union (U.R.S.I.)

The origin of the International Scientific Radio Union (U.R.S.I.) goes back to 1913, when a small meeting was held in Brussels to discuss the formation of an international commission to carry out scientific experiments in wireless telegraphy—as it was then called[1, 4]. Although the first full meeting of this commission was held early in the following year, it was not until after the 1914-1918 war that scientists were again able to consider organized international co-operation in radio research. It was then suggested that this field warranted the formation of a separate union similar to that of other scientific unions under international sponsorship. The original parent body was re-named the International Council of Scientific Unions (I.C.S.U.) in 1931 and this is responsible for a

Table 3



number of international unions in the major scientific fields. These Unions, once their statutes have been approved, are free to manage their own affairs, reporting triennially to the parent body which acts in an advisory capacity. Since 1945 I.C.S.U. has also provided liaison with Unesco.

As is generally the case with international bodies, U.R.S.I. is a federation of national committees or administrations; and this country is represented by the British National Committee for Scientific Radio maintained under the auspices of the Royal Society.

The first General Assembly of U.R.S.I. was held in Brussels in 1922, and the details of the eleven succeeding assemblies are given in Table 3, which also shows the relationship of U.R.S.I. to the other scientific unions, and certain special joint committees including the most recently formed one concerned with the programme of the International Geophysical Year[12]. Apart from an interval caused by the 1939-1945 war, the Union has met fairly regularly at intervals of two to four years. On two occasions—at Copenhagen in 1931 and at Stockholm in 1948—there were joint meetings with C.C.I.R. Although this was tangible evidence of the general wish to ensure a closer relationship between the two organizations, later experience has shown that it is preferable that they should meet separately. Under present conditions the general assemblies of the two bodies are staggered and each is meeting at three-year intervals.

By and large U.R.S.I. is the organization which, in the radio field· conducts fundamental research and so provides the scientific basis on which operational communications and other applications of radio technique are developed and maintained. The objects of the Union are broadly to foster international co-operation in scientific radio investigations, and to promote the establishment and use of a common nomenclature and measurement technique and the intercomparison of standards used in scientific radio work. The present membership of U.R.S.I. comprises some twenty-four countries, in each of which a national scientific committee has been set up. The work of the Union is shared among seven commissions, the titles of which, shown in Table 4, explain their fields of activity.

7.1. *The Scientific Commissions of U.R.S.I.*

Commission I has done much useful work in encouraging steady progress in the establishment of national standards of frequency and their intercomparison, both directly and through the medium of standard frequency and time signal transmissions. It has also recently agreed on the most accurate value of the velocity of electromagnetic waves in a vacuum, and recommended its use for all scientific and engineering work. At the present time it continues to encourage an intercomparison between national laboratories of standards of power and field strength measurement. The activities of Commission II are directed towards an adequate description of the physical properties of the troposphere and the effect of these on the propagation of—mainly—very short radio waves through this part of the atmosphere. The work is organized in three main classes, which deal with radio propagation to distances first within

Table 4

Commissions of U.R.S.I.

I	Radio Measurement and Standards
II	Radio and Troposphere
III	Ionospheric Radio
IV	Radio Noise of Terrestrial Origin
V	Radio Astronomy
VI	Radio Waves and Circuits
VII	Radio Electronics

the horizon and secondly beyond the horizon, and also with the correlation of radio waves with meteorological conditions. The effect of irregularities of the ground, together with its electrical properties at the very high frequencies used is studied concurrently with the variations produced by changing atmospheric or climatic conditions. Special efforts are made to secure the co-operation of national meteorological authorities in providing the relevant information required by the radio scientists.

The work of Commission III on "Ionospheric Radio" comprises some of the oldest research in the radio field in which international co-operation has been very effective in advancing scientific knowledge of the propagation of radio waves by the influence of the ionosphere. In the early 1920's special U.R.S.I. transmissions were arranged from two stations—Leafield in England and Paris—for the daily observation of field strength in various countries. But the main programme of studying the ionosphere in detail began with the second International Polar Year of 1932-33· the forerunner of the present International Geophysical Year[12]. This period marked the beginning of the present practice of regularly observing the characteristics of the ionosphere by the aid of pulse emissions at vertical incidence. British and German delegations co-operated with the Norwegian Government in stations near the Arctic Circle, where the condition known as ionospheric black-out was first observed. From this beginning has grown the vast network of some 150 observatories now making measurements on the ionosphere during the IGY. For over 30 years the time-table of the observations, the type of records to be made and the nomenclature of the subject have been organized on a successful international basis under the auspices of U.R.S.I. Among its recent activities, Commission III is encouraging member countries to undertake rocket and satellite programmes for investigation of the atmosphere and surrounding space,and urges collaboration between the nations engaged in such enterprises.

Commission IV deals with Radio Noise of Terrestrial Origin and has pursued a continuous policy of studying the strength and direction of arrival of atmospherics which cause so much disturbances to many radio communication circuits. Some of the results of the work have been of direct benefit to meteorologists, who now use networks of direction finding stations for locating the sources of atmospherics at regular intervals. These sources can be identified with storm areas at various distances up to 1,000 or 2,000 km, and provide useful additional information to the meteorologist as an aid to forecasting weather conditions. In addition the work of U.R.S.I. has been largely responsible for the production of world-wide charts indicating the order of magnitude of atmospherics in radio reception.

The young and virile subject of radio astronomy has been developed in the past ten years or so in various parts of the world and Commission V is now one of the most active sections of U.R.S.I. in regard to international discussions and collaboration. In addition to the general programme of measuring solar and cosmic radiation, and the identification and location of radio stars, there are active sub-committees dealing with the nomenclature of the subject, the establishment of a basic index of solar radiation at radio frequencies· and the need for international co-operation in the protection of bands of frequencies for the use of radio-astronomers. The remaining two commissions are concerned with basic theory and practice in relation to Radio Waves and Circuits, and Radio Electronics, respectively. These, like the other commissions, operate by correspondence and the holding of symposia, and discussion and planning sessions at General Assemblies. In this way, over the entire field of scientific radio, workers with common interest are brought together from their various countries, to discuss the problems and future plans, and obtain that direct personal contact which is so necessary and so fruitful in the pursuit of modern scientific research.

7.2. *Administration and Publications of U.R.S.I.*

The International Radio Scientific Union is administered by a General Secretary, Treasurer and small staff with offices in Brussels. The work is carried out under the advice of a Board of officers comprising the President and Vice-presidents of the Union. An Information Bulletin is published bi-monthly, and this supplies all national members and others interested with current news of the Union itself and of related activities in other fields. Following each General Assembly of the Union a series of Proceedings—one for each Commission and one on Administrative matters—is published. These contain in full the national reports of progress between the assemblies· minutes of the sessions held by the Commissions and sub-commissions and a full list of the resolutions adopted at the final meeting of the General Assembly. The former practice of publishing other scientific contributions in full has now been abandoned. A list of titles of papers presented is included in the Proceedings, but it is considered that it is preferable for such papers to be published in the normal scientific periodical literature of the country of origin[11, 13]. These Proceedings of U.R.S.I., which are available in both English and French editions, are published with the financial help of the United Nations Educational, Scientific and Cultural Organization (U.N.E.S.C.O.).

8. References

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Brit.I.R.E. BENEVOLENT FUND

NOTICE OF ANNUAL GENERAL MEETING OF SUBSCRIBERS

NOTICE IS HEREBY GIVEN that in accordance with the Rules the Annual General Meeting of Subscribers to the Institution's Benevolent Fund will be held on WEDNESDAY, NOVEMBER 26th, 1958, at the London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, London, W.C.1. The meeting will commence at 6.45 p.m. (immediately after the close of the Annual General Meeting of the Institution).

AGENDA

1. To confirm the Minutes of the Annual General Meeting of Subscribers held on 27th November, 1957. (Reported on page 66, Volume 18 of the *Journal*, January, 1958.)

2. To receive the Annual Report of the Trustees. (Published on pages 641-3 of this *Journal*.)

3. To receive the Income and Expenditure Account and Balance Sheet of the Benevolent Fund for the year ended 31st March, 1958. (Published on page 642.)

4. To elect the Trustees for the year 1958-59.

   Rules 5 and 6 state :—

   5. The Trustees of the Fund shall consist of not more than five and not less than three members of the Institution who have been elected at an Annual General Meeting of Subscribers to the Benevolent Fund.

   6. The Trustees shall be elected at the Annual General Meeting by all members *who have subscribed to the Fund* during the preceding twelve months, ended March 31st in each year, and the Trustees shall hold office until their successors are appointed.

   The present Trustees, who offer themselves for re-election, are :—

   G. A. Marriott, B.A. (Immediate Past President).
   Rear Admiral Sir Philip Clarke, K.B.E., C.B., D.S.O. (Past President).
   A. A. Dyson, O.B.E. (Member).
   A. H. Whiteley, M.B.E. (Companion).
   G. A. Taylor (Member) (*Honorary Treasurer*).

5. To appoint Honorary Solicitors.

   The Trustees recommend the re-appointment of :—
   Messrs. Braund & Hill, 6 Gray's Inn Square, London, W.C.1.

6. To appoint the Honorary Accountant.

   The Trustees recommend the re-appointment of :—
   Mr. R. H. Jenkins, F.C.A., 42 Bedford Avenue, London, W.C.1.

7. Any other business.

By Order of the Trustees,
(*Signed*) G. D. CLIFFORD
(*Honorary Secretary*)

(*The Rules governing the operation of the Benevolent Fund are published in the List of Members.*)

Brit.I.R.E. BENEVOLENT FUND

ANNUAL REPORT OF THE TRUSTEES FOR THE YEAR 1957-58

The Trustees of the Benevolent Fund have pleasure in submitting the following Report on the working of the Fund during the year, and in doing so extend sincere thanks to all those who have given it their support.

The way in which the Benevolent Fund is achieving its objects is shown by the fact that since the end of the last war nearly £4,000 has been distributed in grants. Whilst the Fund was only started in 1932, contributions received have always enabled invaluable help to be given to applicants and at the same time allowed a reasonable reserve to be built up as an insurance against future requirements.

Donations.—The Income Account for the year ended 31st March 1958, is noteworthy in one respect—the subscriptions and donations received are the highest since 1954. This increase is due not only to the fact that more members are supporting the Fund, but that the average subscription per member is higher. The Trustees are most grateful for the interest and support given to the work of the Fund, and hope that this Report will urge those members who have not yet subscribed to become regular supporters. At present, there are still under a thousand members contributing, which is only a small percentage of the total membership. The Trustees hope that more members will agree that the Fund is worthy of support.

In this connection, the Trustees once again emphasize the desirability of all subscribers donating under a deed of covenant. It is estimated that if every member who at present subscribes to the Fund entered into such a covenant, the Fund would benefit by approximately another £500 a year *without any additional expense being incurred by the donor.* The Honorary Secretary of the Fund will be pleased to give further information regarding payments by deed of covenant.

The support received from industrial organizations and other bodies connected with the radio industry is always greatly valued by the Trustees. Appreciation is therefore recorded for the donations regularly received from Electric and Musical Industries Ltd., and from the Radio Industries Clubs of London and Manchester.

Grants.—It is obviously impossible to give full details of every case which comes before the Trustees. The following examples, however, will indicate the way in which the Fund has given help in the past twelve months.

Case 929/26: This case was brought to the attention of the Trustees just before the end of March 1957, and subscribers will have noted the preliminary details in the last Report. It involved an Associate Member of the Institution whose illness resulted in his being invalided out of the Royal Air Force, and who was most anxious to maintain a reasonable standard of education for his three children. The Royal Air Force Benevolent Fund had undertaken responsibility for the children's primary education and the Trustees were able to reassure the member that they would take over this responsibility when the children were old enough to be admitted to one of the boarding schools supported by the Institution. The Trustees regret to report that the member died a few months ago but co-operation between the Institution's Benevolent Fund and the Royal Air Force Benevolent Fund will ensure that the children continue to receive the same standard of education as the father would have provided.

Case 441/10: Although this case has been referred to in several past Reports, the Trustees believe that subscribers will share their pleasure in knowing that the difficulties of a widow and her three daughters are now reaching a happy conclusion. The mother has made excellent progress in her employment, and the second girl will complete her education next year and start on her career. The youngest child is still receiving boarding school education at the Royal Wolverhampton School, and whilst some financial help is still being given to the Mother, the Trustees believe that this will not be required at the same level next year.

Case 122/15: For many years the Trustees have been concerned in assisting a member to provide his family with an adequate income

THE BRITISH INSTITUTION OF RADIO ENGINEERS
BENEVOLENT FUND

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st MARCH, 1958

1957 £		£ s. d.
438	Grants	483 1 5
150	Purchase of Bursaries at Reed's School	150 0 0
6	Postage and Stationery	7 6 7
—	Sundry Expenses	14 1 4
497	Balance being surplus for the year carried to Reserve Account	780 15 7
£1,091		£1,435 4 11

1957 £		£ s. d.
794	Subscriptions and Donations	1,126 1 7
297	Interest Received (Gross)	309 3 4
£1,091		£1,435 4 11

BALANCE SHEET AS AT 31ST MARCH, 1958

1957 £		£ s. d.	£ s. d.
	RESERVE ACCOUNT		
	Balance as at 1st April, 1957	7,073 5 10	
7,073	*Add* Surplus for Year	780 15 7	
			7,854 1 5
	CURRENT LIABILITIES		
38	Amount due to The British Institution of Radio Engineers to General Fund		— — —
£7,111			£7,854 1 5

For Trustees :—

Signed
- G. A. MARRIOTT (*Chairman*)
- G. A. TAYLOR (*Honorary Treasurer*)
- A. H. WHITELEY
- G. D. CLIFFORD (*Honorary Secretary*)

1957 £		£ s. d.	£ s. d.
	FIXED ASSETS		
	Investments at Cost :—		
	£200 3% Savings Bonds 1960/70 ...	191 3 6	
	£200 3% Savings Bonds 1965/75 ...	182 15 9	
	£1,200 3½% War Loan	954 12 6	
	£200 British Electricity 3% Guaranteed Stock 1968/73	155 19 6	
	£1,500 British Transport 4% Guaranteed Stock 1972/77	1,430 4 1	
	£4,000 4% Consolidated Stock ...	3,526 16 0	
	500 Jays & Campbells (Holdings) Limited 5½% Cumulative Preference Shares of £1 each	354 2 0	
	Associated Newspapers Limited—200 Deferred Shares of 5s. each ...	166 4 6	
	£100 6% L.C.C. Loan 1975/78 ...	99 4 4	
	£200 6¼% Liverpool Corporation Mortgage	200 0 0	
	£200 5½% Exchequer Bonds	201 2 0	
6,802	(Market Value as at 31st March, 1958, £6,322 5s. 0d.)		7,462 4 2
	CURRENT ASSETS		
109	Income Tax Repayment Claim	73 12 2	
200	Cash at Bank	297 12 10	
—	The British Institution of Radio Engineers Current Account	20 12 3	
			391 17 3
£7,111			£7,854 1 5

I have audited the above written Balance Sheet dated 31st March, 1958, in respect of the Benevolent Fund. I have received all the information and explanations I have required and in my opinion the Balance Sheet represents the true and accurate state of the Benevolent Fund.

42 Bedford Avenue, London, W.C.1.
19th September, 1958.

R. H. JENKINS, *Chartered Accountant,*
Honorary Auditor.

during a prolonged illness. Whilst the member is still not able to undertake full-time work, his health has improved sufficiently for him to want to take up a part-time position, and the Institution assisted through the Appointments Service. The member's son is being educated at the Royal Wolverhampton School and is now making excellent progress.

Case 242/29: Perhaps one of the most difficult cases to come before the Trustees was that involving an Associate Member who has now retired from professional life and who asked for assistance in bringing a legal action for compensation in respect of an accident. Thorough investigation into the circumstances elucidated the fact that the applicant did not have a fair claim, but legal advice was provided through the Trustees.

Case 232/24 was in connection with an Associate Member who was taken seriously ill whilst away from his home. The Trustees assisted with medical expenses until the member was sufficiently recovered to be moved to his home.

Case 743/30: An Associate Member ran into financial difficulty because of domestic affairs followed by illness. Pending his ability to undertake employment, the Trustees made a grant towards meeting his immediate expenses. Through the Institution's Appointments Service, the member is now well established in regular employment.

The above are only a few examples of the way in which the Fund gives help, and the Trustees always ensure that every applicant is fully recovered from financial difficulty before concluding the case.

Schools.—Subscribers know that one of the most important aspects of the work of the Fund is the support given to Schools having a specific interest in the education of orphaned or fatherless children.

For the benefit of new subscribers to the Fund, the Schools at present co-operating with the Trustees are Reed's School, the Royal Wolverhampton School, and the Royal Wanstead School.

Reed's School is only responsible for boys over the age of 11 years and provides a Grammar school education up to G.C.E. Advanced Level. The Trustees purchase Bursaries to cover the cost of a boy's education and maintenance throughout his time at the School. At the moment, the Trustees are not responsible for any children at this School but as stated above, it is hoped to secure the admission of the children of Case 929/26 when they are old enough.

The Royal Wolverhampton School provides education for girls and boys up to G.C.E. Advanced Level. The Trustees are responsible for a boy and a girl at this school.

For those children who are not suitable for grammar school education, the Royal Wanstead School boards and educates children at their two secondary schools. A Preparatory and Junior School are also maintained for children aged 5 to 11 years. The Trustees feel that the work done by the Governors of the Royal Wanstead School is well worthy of support and has continued to subscribe annually.

Many members have expressed appreciation of the way in which the Trustees help the important work of these schools; some have indicated their wish to make a personal contribution direct to the Schools in addition to their support of the Institution's Benevolent Fund. The Honorary Secretary will always be pleased to supply literature about all or any of the above Schools.

Balance Sheet.—The Trustees feel that the Balance Sheet of the Fund is self-explanatory and again shows a substantial increase in the Reserve Account.

Acknowledgments.—The Trustees again record their appreciation of the advice and help given during the year by Mr. R. H. Jenkins and Mr. Charles Hill in their capacities as Honorary Auditor and Honorary Solicitor respectively. The Trustees are also deeply grateful to those members who draw attention to cases of difficulties and distress and who, in some instances, visit those members or dependents on behalf of the Trustees.

The object of the Benevolent Fund is to afford assistance to necessitous members of the Institution or their families. To all those who have made fulfilment of this object possible the Trustees express thanks. Members who hesitate to subscribe because they are only able to contribute a small amount are assured that every donation is welcomed.

NEW BRITISH STANDARDS

The following is a selection of the new and revised British Standards and Codes of Practice of interest to members which have been issued during recent months. Copies may be obtained from Sales Dept., British Standards Institution, British Standards House, 2 Park Street, London, W.1.

CP. 1005. **The use of electronic valves Part 4 : 1958. Magnetrons and special quality valves.** *Price 5s.*

This new part (comprising Section 9 and 10) of CP. 1005 deals with additional recommendations for magnetrons and special quality valves. It should be read in conjunction with Section 2 of the same Code —"General recommendations for all electronic valves". Recommendations are made on ratings, installation (including mounting), operation and storage. The Section on magnetrons gives guidance on magnet design and on dangerous radiations which may be encountered in use. The Section on special quality valves emphasizes that the term "special quality" may apply to only some of the features of the valve and that for different conditions of use, different "special qualities" may be necessary. Reference is also made to the need to take account of the temperature considerations.

B.S. 2950: 1958. **Cartridge fuse-links for telecommunication and light electrical apparatus.** *Price 4s. 6d.*

The fuse-links dealt with in this new British Standard supersede the Type B fuses which were specified in B.S. 646: 1935 (now revised as B.S. 646: 1958). They have the same dimensions as the old Type B fuses, but the performance differs in two important respects. Firstly, the rated voltage varies according to the rated current being 1,000 V for the smaller currents (50 to 250 mA) down to 32 V for currents of 20 and 25 A; secondly, the breaking-capacity test is made at a prospective current that does not exceed ten times' the rated current of the fuse link. Two grades of fuse-link, A and B, are specified for rated currents of 250 mA and below, which will blow at two or three times' their rated currents respectively. A preferred range of rated currents and voltages is given with an optional colour code.

B.S. 2990: 1958. **Rationalized and unrationalized formulae in electrical engineering.** *Price 4s. 6d.*

The M.K.S. (metre-kilogramme-second) rationalized system of units is being used increasingly by engineers, but the C.G.S. (centimetre-gramme-second) systems (usually unrationalized), with which many engineers become acquainted during their education, are, however, still to be found in technical literature. In this Standard the more important relations in electrical science are given in both the rationalized and unrationalized systems as tables and explanatory notes. It includes examples of: "defining" relations, qualities unaffected by rationalization, quantities affected by rationalization, together with a large number of relations expressed in the rationalized and the unrationalized forms.

Note: B.S. 2990 supplements B.S. 1637, Memorandum on the M.K.S. system of electrical and magnetic units.

B.S. 2981: 1958. **Dimensional features of magnetic sound recording on perforated film.** *Price 4s. 6d.*

As this form of recording is mainly used in studios the section dealing with 17·5 mm. and 35 mm. perforated film is exclusively for studio application, and includes dimensional requirements for one, two, three, four and six-track recordings. Another important section deals with magnetic coatings on 16 mm. (single and double perforated) and 8 mm. film, and determines the position and width of magnetic tracks and the relative position of picture and sound records. It applies to both negative and positive film stock.

B.S. 3015: 1958. **Glossary of terms used in vibration and shock testing.** *Price 5s.*

Contains 72 definitions of interest to those concerned with the study and testing of the behaviour of equipment when subjected to shock and vibration. A few of the definitions (e.g. "isolator", "snubber") have a specialized meaning in vibration and shock testing but most of them have a wide general use; the glossary does, however, clarify their meanings for use within the field it covers. There are mathematical Appendices on "Line spectra", "Continuous spectra" and "Spectra of experimentally determined quantities".

B.S. 3040: 1958. **Radio-frequency cables for use with domestic television and v.h.f. receiving aerials.** *Price 4s. 6d.*

Specifies constructional, dimensional and performance requirements, together with methods of test, for radio-frequency coaxial and twin cables intended primarily for use with domestic television and v.h.f. receiving aerials. The coaxial cables covered have a nominal impedance of 75 ohms and nominal diameters over dielectric of 0·128 in. and 0·200 in. The balanced twin cables have a nominal impedance of 75 ohms and a nominal major dimension of 0·160 in.

B.S. 3041: 1958. **Television and v.h.f. broadcast receiving aerial feeder connectors.** *Price 4s.*

Specifies essential dimensional features of two types of connector for television and v.h.f. receiving aerial feeder cables. Types of aerial feeder cable suitable for use with the connectors are given in B.S. 3040. Radio-frequency cables for use with domestic television and v.h.f. receiving aerials. The type 1 connector is a coaxial connector for use with coaxial cables having a characteristic impedance of between 50 to 100 ohms and is suitable for use at frequencies up to, and including, Band III. The type 2 connector is a polarized 2-pin device for use with either coaxial cable or balanced twin feeders for frequencies up to, and including, Band II. The standard specifies contact-resistance requirements but not contact finishes.

A TRANSISTOR WITH THYRATRON CHARACTERISTICS AND RELATED DEVICES*

by

W. von Münch, Dr. phil. nat.†

SUMMARY

A semi-conductor device with thyratron-like input characteristic is obtained by immersing, during the alloy process, a tungsten whisker into the collector contact of an *npn*-junction transistor with high base resistivity. Details of production and electrical performance are given. The radial voltage drop which is set up in the base layer causes a restriction of carrier transport to a region of small cross-section. This permits the construction of devices with more than one output electrode. Finally a special structure for triggering by radiation and a symmetrical switching transistor have been studied.

1. Introduction

For many circuit applications semi-conductor devices are needed which can be operated under bistable conditions. The following electronic engineering fields will especially make use of such devices: counter and digital computer circuits, information storage, control techniques, pulse forming or regenerating circuits and, in the near future, electronic telephone exchange systems.

For optimum performance it is desirable to obtain a device which exhibits the following electrical properties: high impedance in the off-state, low impedance and low residual voltage drop between input and output in the conducting state, adequate power handling capacity, and short response times. As these devices will have to be employed in appreciable quantities, one must also pay attention to the production costs.

Numerous approaches have been made to establish convenient bistable semi-conductor devices. Most of these proposals, however, had to be rejected, either because of unsatisfactory electrical performance or because of economical considerations. The method of producing a switching transistor with thyratron characteristic described in this paper has the advantage of being rather easy. Hence low production costs can be expected.

* Manuscript received 5th August 1958. (Paper No. 476.)

† Fernmeldetechnisches Zentralamt, Darmstadt, Germany.

U.D.C. No. 621.382.333

In the off-state the a.c. input resistance exceeds 1 MΩ, whereas the conducting part of the characteristic has an a.c. resistance of less than 10 ohms. This ratio of impedance will be sufficient for most switching applications[1]. As the response times are in the order of magnitude of 10^{-7} sec, the switching transistors will also be useful in high-speed counter and digital computer circuits.

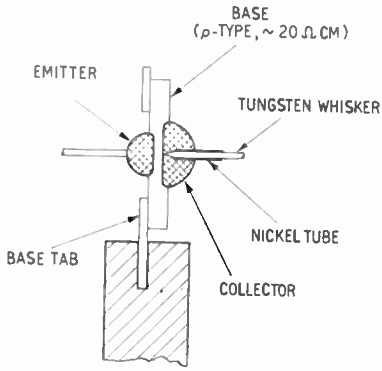
In the following sections some details of production and electrical performance will be given. Section 4 deals with the design and the applications of some closely related devices.

2. Design of Switching Transistor

Figure 1(*a*) shows the general design of the switching transistor which is very similar to that of a normal germanium *npn*-alloyed junction transistor[2]. It has been found suitable to use base material with an initial resistivity of about 35 Ωcm, which, in the course of the alloy process, usually drops to some 20 Ωcm. For the alloy contacts an eutectic mixture of lead plus 13 per cent. antimony is preferred, a lower percentage of antimony being also sufficient. Likewise, lead plus arsenic can be used. The alloy process is done in three separate steps. In the first step both the emitter and collector contacts are alloyed at a temperature of about 600°C. The second step involves the soldering of the base lead. Finally, a tungsten whisker is immersed into the collector contact at a slightly increased temperature, about 650°C. By these means the collector *pn*-junction is disturbed within a very small region which acts

D

as a source of majority carriers while the remaining junction area preserves rectifying qualities. The whisker itself only serves for piercing through the recrystallization layer. It may be carefully removed after the alloy process is finished without affecting the electrical properties of the device. Another non-alloying metal or even an insulating material, such as quartz, may be used instead of tungsten.



(*a*)

(*b*)

Fig. 1. (*a*) Switching transistor design. (*b*) Switching transistor from laboratory production.

As indicated in Fig. 1(*a*), the collector area—as in normal junction transistors—will preferably be made somewhat larger than the emitter area. There are two reasons for this: first, a better support for the tungsten whisker is achieved and, second, a large portion of injected carriers can be absorbed, even in the high-current state. A ring-shaped base tab is also suitable for switching transistors. The photograph, Fig. 1(*b*), shows a switching transistor obtained from laboratory production.

3. Electrical Properties

When the collector is biased in the reverse direction, a small majority carrier current flows from the region in which the collector junction is disturbed to the base contact. This current is not only limited by the small cross-section of the disturbed area but also by the space charge layer of the adjacent undisturbed junction. As the height of the space charge varies with the square root of the applied voltage, it is evident that the resistance in front of the tungsten whisker will also have a portion following a square root law. Thus the increasing internal collector resistance, r_c, allows the application of a relatively high collector bias without dissipating too much power in the non-conducting state of the transistor. The influence of space charge layer widening is particularly effective with high resistivity base material (see Fig. 2(*a*)).

The current originating in the centre of the collector junction causes a radial voltage drop within the base layer. The open circuit emitter will adopt the potential prevailing on the axis of symmetry just in front of the emitter junction. The area outside the centre will then be biased in the reverse direction. In order to account for the radial voltage drop between the axis of symmetry and the base contact, it is necessary to introduce an internal base resistance, r_b, into the equivalent circuit of the switching transistor. This base resistance is independent of voltage as long as the base width remains large compared with the space charge thickness. With high resistivity base material, however, a marked dependance of r_b on collector bias can be observed (see Fig. 2(*b*)).

The mechanism of electrical instability leading to a thyratron-like input characteristic is similar to that which occurs in double base diodes. When the emitter voltage is sufficiently lowered, carrier injection from the emitter junction takes place, particularly in the vicinity of the axis of symmetry. Due to the geometrical reasons and by aid of the electrical field in the base region these injected carriers will only reduce r_c, while r_b remains unaffected. This results in an increase of the base potential and hence in a further increase of the emitter current until the potential difference between emitter and collector is substantially reduced, or until current limitation is caused by an external resistance. An essential advantage of the above device is that the residual collector current in the off-state can be kept low, while in the high-current state the total collector junction area is capable of absorbing injected carriers, thus providing greater power handling capacity.

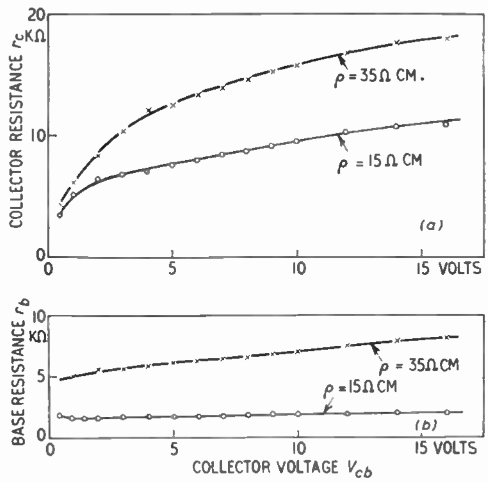


Fig. 2. Variation of internal collector resistance r_c and internal base resistance r_b with applied voltage V_{cb}.

Input characteristics for fixed collector bias (10 V) and for different external base resistances are drawn in Fig. 3. In the region of high input resistance (drawn separately with enlarged current scale) there is a reverse current in the order of magnitude of 10 μA, the a.c. input resistance exceeding 1 MΩ. The transition to the instable region occurs at a voltage

$$V_{eb} = \frac{r_b + R_{be}}{r_b + R_{be} + r_c} V_{cb}.$$

(R_{be} = external base resistance)

In order to keep this kink voltage as low as possible, a low r_b/r_c ratio should be reached. For optimum design an inhomogeneous base doping—as in high frequency transistors—would be most favourable. This will especially hold for silicon transistors. With high resistivity silicon the residual collector current can be kept very low; moreover, a considerably higher resistance is expected for the reverse input characteristic. Preliminary experiments have shown that the production process is, in principle, applicable to silicon material, too.

It can be seen from Fig. 3 that the slope of the negative resistance region is in the kilohm range. In the high-current state the residual voltage between emitter and collector is reduced to about 1 volt. There is a marked dependance of the high-current transmission properties on the base layer thickness. A decrease in base thickness will reduce the residual voltage as well as the a.c. input resistance of the high-current region. A base layer which is too thin, however, results in a high base resistance, r_b, and hence in a small difference between peak and bottoming voltage, which is undesirable for most circuit applications. As a suitable compromise, a base layer thickness of about 70 microns has been adopted. In order to obtain good high-current performance semiconductor material should be used which retains long carrier life-time, even after heat treatment.

As indicated in Fig. 3, an external base resistance R_{be} has a noticeable influence on the high-current region too. For obtaining low residual voltage and low a.c. input resistance a high external base resistance is favourable. An external circuit which exhibits a low base resistance for the non-conducting state and a high base resistance for the conducting state of the transistor may be very useful for many circuit applications[3].

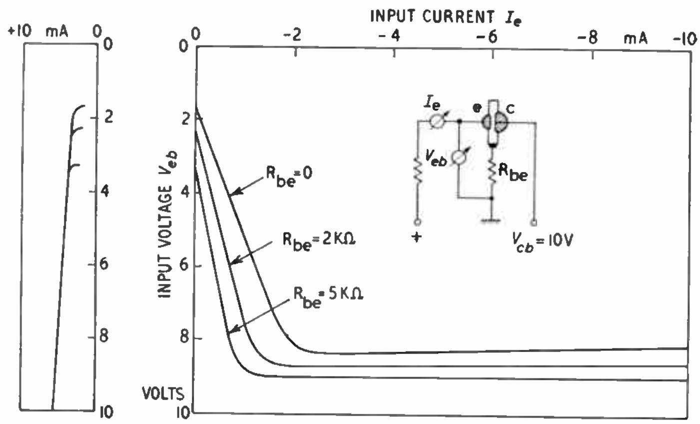
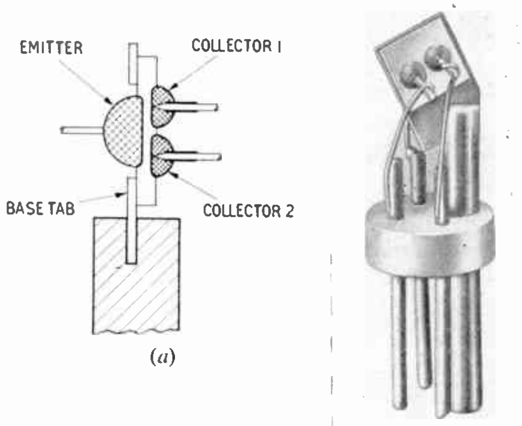


Fig. 3. Input characteristics for fixed collector voltage (V_{cb} = 10 V) and different external base resistances R_{be}. Positive voltage increasing downwards.

4. Related Devices

4.1. *Transistors with Two Collectors*

The current originating from the tungsten whisker produces an electric field between emitter and collector which leads to a high velocity of carrier transport and hence very low response times are achieved. Moreover, there is a radial voltage drop in the base region which tends to restrict carrier injection and carrier transport to the axis of symmetry. Similar effects will be obtained with other devices having current amplification greater than unity, such as point contact and hook transistors[4], whereas in normal junction transistors injection prevails near the emitter edge (Fletcher effect).



(*a*) (*b*)

Fig. 4. (*a*) Switching transistor with two collector electrodes.

(*b*) Two-collector transistor from laboratory production.

The restriction of carrier transport to a small cross-section allows the construction of switching transistors with several output electrodes in such a manner that there is no, or very little, interference between different signal paths. In Fig. 4(*a*) the design of a switching transistor with two collectors is drawn, Fig. 4(*b*) shows a sample from laboratory production. The emitter junction must be extremely homogeneous within an area sufficient to cover at least both whiskers immersed into the two opposite collector contacts. The influence of base width and resistivity is the same as in transistors with one collector.

There are numerous circuit applications for switching transistors with two collectors. At first a circuit will be considered in which both collector electrodes c_1 and c_2 are under equal bias and load conditions (see Fig. 5, inserting $V_{c1}=V_{c2}$ and $R_{c1}=R_{c2}$). When starting the transition from the off-state to the active region, a conducting path will only be built up between the emitter and one of the two collectors. The injected carriers will be completely drawn to that collector which produces the higher field in the vicinity of the emitter region. In other words: given equal bias and load conditions, the "ignition" will take place between the emitter and that collector which has the lower internal resistance, therefore producing the higher kink voltage in the input characteristic (see, for example, Fig. 6).

The single-path signal transmission can be maintained up to currents of more than 10 mA (in the case of Fig. 6). When feeding higher currents to the transistor, the radial voltage drop will be reduced and hence the mechanism of carrier transport limitation will cease to be effective. The current will then start flowing across to both collectors c_1 and c_2. The input characteristic has a break at this point, the a.c. input resistance dropping to one-half of the original value since both current paths are now connected in parallel. This break usually occurs when the base current has considerably decreased but has not yet changed its (negative) sign. (For sign convention see Fig. 5.) The

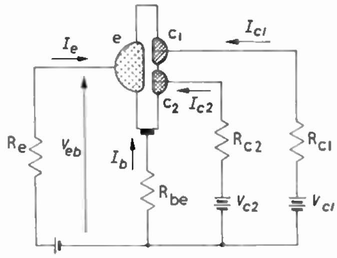


Fig. 5. General circuit for transistor with two collectors.

magnitude of the break current depends on the load resistances. A decrease of load resistances will considerably extend the range of single-path operation.

With uniformly produced collector contacts or by properly adjusting collector bias, one can obtain a circuit in which both collectors generate almost the same kink voltage in the input characteristic. It will then be possible to direct the "ignition" to a selected collector output only by applying a small additional voltage (e.g. 0·1 V) to one of the collectors. This control voltage is only needed for a very short

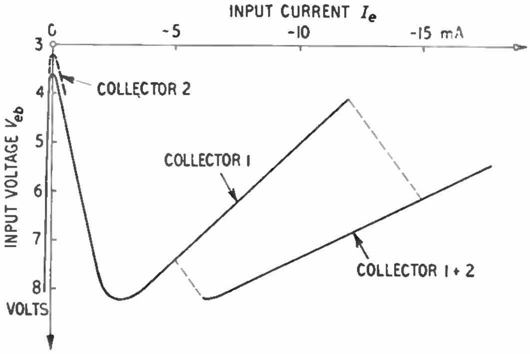
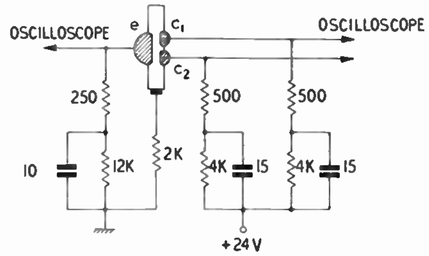


Fig. 6. Input characteristic of two-collector transistor for $R_{c1}=R_{c2}=500\Omega$, $V_{c1}=V_{c2}=14$ V.

period, namely, in the instant of firing. Triggering pulses must be taken from a high-impedance source with a rise time exceeding the response time of the transistor. A manual trigger circuit is shown in Fig. 8.

The performance of a switching transistor with two collectors is illustrated in Fig. 7. The emitter circuit includes the usual means for generating a free-running relaxation oscillation. Discharge pulses appear either on collector 1 or collector 2, depending on bias conditions in the instant of transition from the non-conducting to the conducting state. Alternating discharges are obtained if the collector bias supplies (*RC*-networks) have recovery time-constants comparable with the interval between two pulses. This situation is illustrated in Fig. 7 (*b*). If, for example, the first discharge takes place through c_2 then the bias of c_2 will not have completely recovered when the emitter voltage reaches its peak. Thus the second pulse must appear at c_1, whereas the third discharge can again pass across c_2. The upper part of Fig. 7(*b*) shows the oscilloscope display of the sawtooth-shaped emitter voltage and the pulses which alternately appear at collector 1 and collector 2. By making use of different time-constants it is possible to produce other types of pulse sequences, e.g. one pulse at c_1 followed by two pulses at c_2.

As can be seen from the preceding description, a two-collector transistor permits the connection of a signal input to a selected signal output, while only low control power is required for this operation. It should be mentioned, however, that there is always a slight interference between the two signal channels. This is due to a base current modulation and the resulting voltage drop across the common base resistance. With small base resistance and relatively low signal power (e.g. 5 mW), cross-talk attenuation of 50 decibels can be achieved.



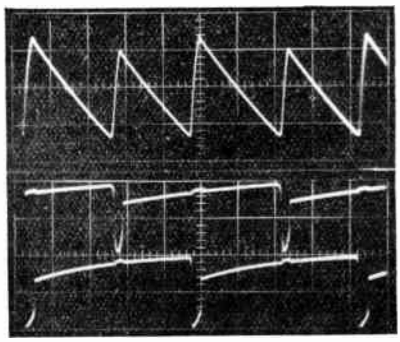
(*a*) Circuit diagram.

Note.—The values of the capacitors are given in nanofarads (1nF = 10^{-9}F)

Emitter

Collector 1

Collector 2



(*b*) Oscilloscope display.

Fig. 7. Performance of two-collector transistor.

It is evident that the number of output electrodes can be increased by connecting two-collector transistors parallel and in series. A circuit designed for four outputs is drawn in Fig. 8. All transistors are selected to ensure that a conducting path will only be built up between emitter e and collector c_1 if no signals are applied to the control inputs A and B. The circuit is fired by feeding a negative pulse to the first transistor. Resetting is done by interrupting the input current. By applying appropriate positive signals to control inputs A or B respectively, the "ignition" may be directed

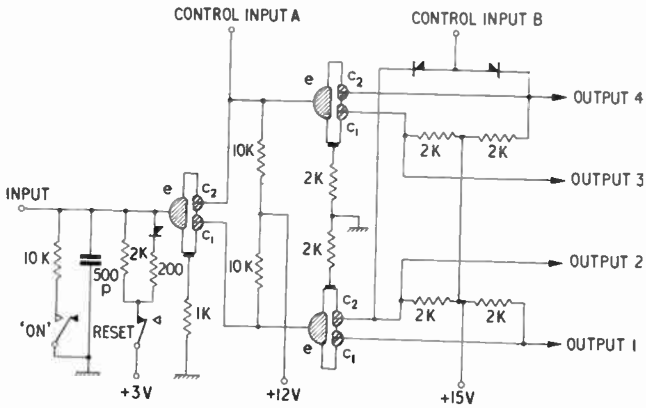


Fig. 8. Circuit designed for four outputs.

to collector c_2 instead of c_1. Thus, if no signals are fed to A and B the signal input will be connected to output No. 1. Applying a positive control signal to input B will consequently cause the connection of the input to output No. 2 when the circuit is fired. In the same way the other outputs are accessible if control signals are properly fed to A or/and B in the instant of firing the circuit. The simple circuit of Fig. 8 may be useful for many applications, as, for example, binary-to-decimal converters. For demonstrating this type of operation in a laboratory model the 2 kΩ load resistances have been replaced by electromechanical indicators of equal impedance.

Further circuit problems can be solved with a two-collector transistor operated under different bias and load conditions. Assuming, for example, $V_{c1} > V_{c2}$ and $R_{c1} > R_{c2}$, then collector c_1 will at first produce the higher potential in the emitter region. The "ignition" will therefore reach collector c_1. When through the voltage drop at R_{c1} the bias of c_1 is sufficiently decreased, the carrier transport will instantaneously be transferred from collector c_1 to collector c_2. Finally, in the high-current region, there is always a saturation state in which both collectors are connected in parallel. Fig. 9 shows an input characteristic for a switching transistor with two collectors operated with $V_{c1} > V_{c2}$ and $R_{c1} > R_{c2}$. By properly adjusting bias conditions one can obtain four stable operation points: both collectors "off", collector 1 "on", collector 2 "on", both collectors "on". The two-collector transistor may therefore be useful in counters, digital computers and logical circuits.

It is possible to extend the principle of the switching transistor to a device with more than two collectors. The "on"-state may be transferred from one collector to another, while a reset pulse may be fed to the common base contact.

4.2. *Radiation Triggered Transistors*

Switching transistors in monostable or bistable circuits are usually triggered by feeding a negative pulse to the emitter or a positive pulse to the base contact. A further method for initiating carrier injection is

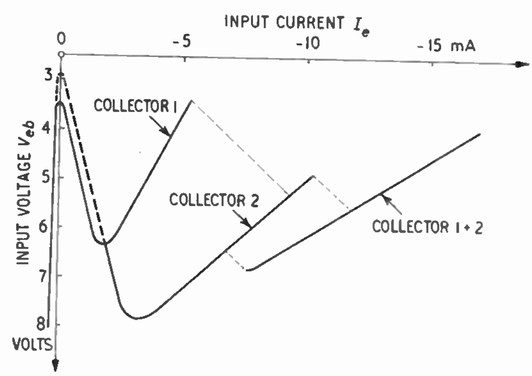


Fig. 9. Input characteristic of two-collector transistor for $R_{c1} > R_{c2}$ and $V_{c1} > V_{c2}$.

based on a shift of the potential which prevails in the base region adjacent to the emitter. For increasing this potential it is necessary to reduce the internal collector resistance r_c. This can be brought about by creating electron-hole pairs by means of an incident beam of light or charged particles, or, in the case of near-intrinsic material, also by an increase of temperature. A mechanism for triggering double-base diodes with light has been described by Granville[5]. Triggering with cathode-ray beams may be advantageous if numerous transistors are to be affected within a very short period (e.g. in the order of microseconds).

For radiation triggered switching transistors the special design shown in Fig. 10 is suitable. The base material should have high resistivity in order to obtain high relative variation of conductivity. As indicated in Fig. 10, the tungsten whisker must be immersed just opposite the edge of the emitter contact. This is necessary for procuring conductivity modulation through the carriers generated by the incident light or particle beam as well as through the carriers injected by the emitter contact. In order to obtain carrier generation in the vicinity of the whisker, the base layer should be very thin, at least at the spot of radiation incidence.

It has been verified that switching transistors as drawn in Fig. 10 can be triggered by incident light or electrons. Cathode-ray pulses of 1 μA and 1 μsec duration proved to be sufficient for initiating transitions from the non-conducting to the conducting state. The method of triggering with cathode-rays, however, is rather expensive because of the necessity to mount the switching transistors in a vacuum system. For some applications it will be suitable to convert the electron-beam energy into light energy which then will serve for triggering. Screens

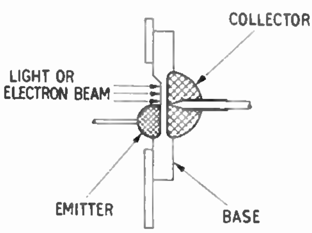


Fig. 10. Design of radiation triggered transistor.

with extremely low recovery times should be used for this purpose.

In all cases very low control energies are needed. It is evident that there are numerous circuit applications for radiation triggered switching transistors, as, for example, in control techniques, in light-relays and monitors.

4.3. *Symmetrical Switching Transistors*

For some special applications symmetrical switching transistors may be useful. As shown in Fig. 11, this type of transistor is constructed by immersing whiskers into two opposite alloy junction contacts of equal size.

This device can be operated in both directions, depending on the bias V_{c1} and V_{c2}

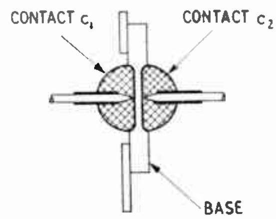


Fig. 11. Symmetrical switching transistor.

applied to c_1 and c_2 respectively. Considering, for example, collector action of contact c_2, then carrier injection will start from c_1 if V_{c1} is sufficiently lowered:

$$V_{c1} \leq \frac{r_b + R_{be}}{r_{c2} + r_b + R_{be}} V_{c2}$$

(r_{c2} = internal resistance of contact c_2, r_b = internal base resistance, R_{be} = external base resistance.) Contact c_1 is now acting as emitter and a thyratron-like input characteristic is obtained from the mechanism described in section 3. If, however, the voltage applied to c_1 considerably exceeds V_{c2}, then minority carrier transport starts from c_2 to c_1, i.e. c_2 works as an emitter. The peak voltage for initiating this process is given by:

$$V_{c1} \geq \frac{r_{c1} + r_b + R_{be}}{r_b + R_{be}} V_{c2}$$

(r_{c1} = internal resistance of contact c_1, r_b and R_{be} as defined above.)

With both contacts produced uniformly (i.e. $r_{c1} = r_{c2} = r_c$) one obtains the following simple relations:

$$V_{c1} \leq aV_{c2} \text{ : injection starting from } c_1$$

$$V_{c1} \geq \frac{1}{a} V_{c2} \text{: injection starting from } c_2.$$

The factor a, which is less than unity, can be expressed by

$$a = \frac{r_b + R_{be}}{r_c + r_b + R_{be}}$$

Fig. 12 shows the input characteristic (V_{c1} vs. I_{c1}) of a symmetrical switching transistor for a fixed bias $V_{c2}=10$ volts. In the region of high resistance (approximately 20 kΩ) the characteristic is slightly bent, due to the reasons discussed in section 3. Adjacent to this region there are two active parts in which c_1 is either acting as emitter or as collector. The two kinks depend on the external base resistance; they may be calculated from the above formulae.

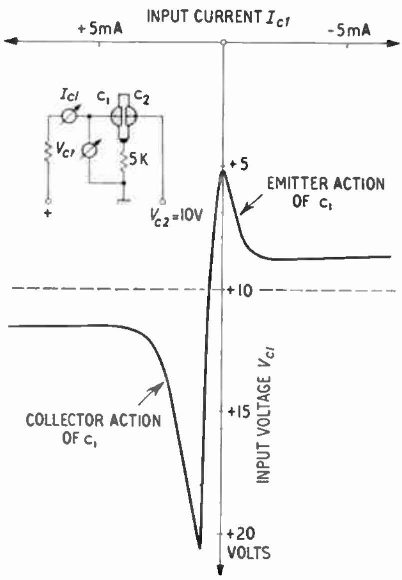


Fig. 12. Characteristic of symmetrical switching transistor.

As can be seen from the characteristic (Fig. 12), symmetrical transistors may be used in special voltage discriminator circuits. Taking, for example, $V_{c2}=10$ volts as a reference voltage, current signals will be obtained from the transistor if the input voltage V_{c1} drops to approximately 5 volts (50 per cent. of the reference voltage) or if V_{c1} exceeds 21 volts (about twice the reference voltage). Operating in an astable circuit the device will produce negative or positive pulses respectively.

5. Acknowledgments

A considerable part of this paper is based on common research with Dr. H. Salow. A comprehensive survey on this common work is given in references 6–8. Details have been adapted especially from reference 6. The author is indebted to Dr. H. Salow and Mr. A. Hähnlein for helpful suggestions.

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OSCILLOSCOPE TUBE WITH TRAVELLING WAVE DEFLECTION SYSTEM AND LARGE FIELD OF VIEW*

by

W. F. Niklas, Ph.D.† and J. Wimpffen, Dipl.Ing.†

SUMMARY

The frequency response of conventional deflection systems, i.e. the influence of the transit time, the rise time and oscillations, is discussed in a somewhat abbreviated form. It is shown that an unbalanced or balanced helix system offers great advantages for high-speed oscillography.

A new travelling-wave oscilloscope tube is described which possesses a balanced helix system as signal plates. The tube has a very large field of view (1⅜ in. by 4 in.) and an excellent frequency response (90 per cent. sensitivity at approximately 2000 Mc/s) while the sensibility is still in an acceptable range. The question of magnetic vs. electrostatic focusing in a high-speed oscilloscope tube is treated in detail. Typical operating conditions and the performance of the tube are described.

1. Introduction

The oscilloscope tubes now in general use possess electrostatic deflection systems which in principle consist of two pairs of parallel plates. The electrical contacts for these plates are normally brought out at the base. Tubes of this design are severely limited in their frequency response since with increasing frequency of the deflecting voltage the sensitivity drops sharply. Further, the display on the face of the tube is distorted with respect to the input wave form. For example, a step function is reproduced as ramp function and the resulting "overshoot" falsifies the display further.

The cause for these distortions is the low resonance frequency of the oscillatory circuit, consisting of inductance and resistance of the deflection plate leads and the inter-plate capacitance. Further, the change of the deflection voltage during the transit time of the electrons through the system cannot be neglected at high frequencies.

Various efforts have been made to improve the frequency response. Using side contacts for the deflection plates increases their resonance frequency. Lee's micro-oscillograph[1] was a substantial improvement in this direction. Further, the utilization of lumped deflection systems improved on the transit-time effects.[2]

A lumped deflection system consists essentially of several capacitors in parallel connected by resistors. The *RC* time-constant of the chain is chosen in such a way that the group velocity of the signal voltage matches the axial velocity of the electron beam. Thus the deflection voltage does not change appreciably during the passage of the electrons and transit time effects are reduced.

The lumped deflection system is essentially a lumped delay line. The logical development led from there to the application of distributed delay lines as represented by the travelling-wave (t.w.) system or helix.[3]

In this paper the frequency response of standard and t.w. systems will be outlined. Further, the design and performance of a tube, the TW-11, utilizing a helix system which has been developed and constructed in close co-operation with the U.S. Naval Research Laboratory will be described. The TW-11 represents the further development of the TW-9, which has been described elsewhere.[4]

2. Frequency Response of Deflection Systems

It is not possible within the framework of this paper to derive a detailed theory of the frequency response of deflection systems.‡ However, to assist understanding of the mode of

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‡ An excellent monographic description of this topic is contained in the book "Millimicrosecond Pulse Technique" by I. A. D. Lewis and F. H. Wells, Chapter 6. (Pergamon Press, London, 1954.)

operation, some of the most important relations of the established theory will be listed without proof.

2.1. *Transit Time Effects (Conventional Systems)*

The term "conventional systems" will be understood here and in the following sections to mean parallel deflection plates. Fringe field influences are generally neglected.

The effect of the electron transit time on the display will be illustrated in the case of a step function and a sinusoidal function on the input.

The complete integration of the step function response leads to the following relation:

$$\left.\begin{aligned} Y &= 0 && \text{for } t<\tau \\ Y &= \frac{E\,e\,S}{b\,m\,v_z}(t-\tau) && \text{for } \tau<t<(\tau+t_r) \\ Y &= \frac{E\,e\,S}{b\,m\,v_z}t_r = Y_0 && \text{for } t>(\tau+t_r) \end{aligned}\right\} \quad \ldots\ldots\ldots(1)$$

where Y = deflection on the screen.

E = deflection voltage

t_r = electron transit-time through the deflecting plates

τ = time of flight of the electrons from the plates to the screen

e = electron charge

m = electron mass

S = distance from the end of the deflecing plates to the screen

b = spacing of the deflecting plates

v_z = axial electron velocity

It can be seen that a step function is displayed as a delayed ramp function.

A sinusoidal function will be displayed with a phase shift as a sinusoidal function of somewhat distorted shape and reduced amplitude. If $Y_0(\omega)$ denotes the amplitude of the display at the circular frequency $\omega=2\pi f$ and $Y_0(0)$ denotes the amplitude at the frequency zero, we obtain the well-known relation:

$$\frac{Y_0(\omega)}{Y_0(0)} = \frac{\sin\left(\frac{1}{2}\,\omega t_r\right)}{\frac{1}{2}\,\omega t_r} \quad \ldots\ldots\ldots(2)$$

Thus, the sensitivity as a function of the frequency (being proportional to the absolute value of eqn. (2)) shows several relative maxima of successively decreasing height.

2.2. *Rise Time Effects and Oscillations (Conventional System)*

So far, the inductance and resistance of the deflection system have been neglected. Their physical presence, however, leads to a certain build-up time for the signal voltage across the plates and causes oscillations. The build-up time materializes itself in a similar manner to the transit time in a reduced slope of the leading edge as well as in a reduced sensitivity, while the oscillations cause the overshoot.

The overshoot may be minimized by a damping resistor which, however, increases the *RC* time-constant of the circuit.

Assuming a slightly under-damped circuit (4% overshoot), the rise time T_r of a displayed step function is obtained with

$$T_r = 2{\cdot}3\,CR \quad \ldots\ldots\ldots(3)$$

with C = capacitance of the plates

R = resistance of the leads

and the frequency response to a sinusoidal input function follows with

$$\frac{Y_0^*(\omega)}{Y_0^*(0)} = \left(1+\tfrac{1}{4}\omega^4 T_r^4\right)^{-\frac{1}{2}} \quad \ldots\ldots\ldots(4)$$

Thus, the deflection obtained decreases sharply with increasing frequency. Note that the *RC* time influence is more pronounced than the effect of the transit time.

The complete frequency response of the signal plates is obtained by combining eqns. (2) and (4)

$$\frac{Y_0(\omega)}{Y_0(0)} = \frac{\sin\left(\frac{1}{2}\,\omega t_r\right)}{\frac{1}{2}\,\omega t_r}\left(1+\tfrac{1}{4}\omega^4 T_r^4\right)^{-\frac{1}{2}} \ldots\ldots\ldots(5)$$

2.3. *Time-base (Conventional System)*

The effect of $T_r>0$ in the time-base system results in an initial non-linearity in the display of a linear input function. This effect is, however, generally not disturbing as the time-base frequency is for most applications essentially lower than the signal frequency. Due to the same reasoning, transit-time effects in the time-base system may be generally neglected.

2.4. *Travelling Wave System*

A travelling wave system is essentially a distributed delay line along which a pulse front proceeds with a certain speed coinciding with the axial velocity of the electron beam. The winding diameter of the helix is designed in such a way that signal and electron velocity coincide.

Two different types of helix systems are used, unbalanced and balanced.

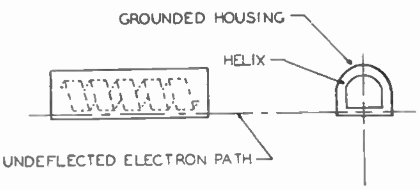

Fig. 1. Single helix enclosed in an earthed housing.

The unbalanced helix system consists fundamentally of a single helix wound of metal band, flattened on one side and enclosed in a grounded housing as shown in Fig. 1. The electron beam travels between the flattened helix and the housing. Deflection plates with asymmetric feeding are analogous in the conventional system.

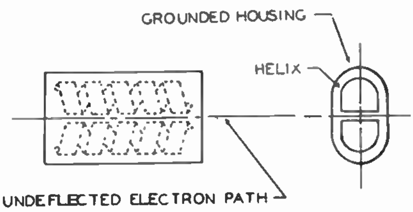

Fig. 2. Balanced helix system.

The balanced helix system consists of two flattened helices which are wound in a counter-rotating way (Fig. 2). The electron beam travels between the two helices. This system facilitates push-pull operation in the driving circuits in the same way as conventional plates, employing a centre-tap.

As mentioned above, the helix may be treated as distributed delay line. The fundamental expression for the resulting time delay is given by:

$$T_D = l\sqrt{L_0 C_0} \qquad \text{.........(6)}$$

with T_D = delay time
L_0 = inductance per unit axial length
C_0 = capacitance per unit axial length
l = axial length

The helix has to be designed in such a way that T_D equals t_r, the electron transit time through the entire helix structure. If this condition is not fulfilled, transit-time distortions will occur which are phenomenologically equal to the distortions discussed in Sect. 2.1.

The electron beam is always then deflected when it passes a winding of the helix. The effective transit time $t_{r,H}$ of the electron beam follows therefore as

$$t_{r,H} = w/v_x \qquad \text{.........(7)}$$

where w = width of a single winding
v_x = axial velocity of the electron beam

Fringe field effects and the successive transverse shift of the electron beam are neglected here. The former may be partly accounted for by substituting the pitch of the helix for the width of single winding in eqn. (7).

As the value of w is very much smaller than the length of a conventional plate system, the transit-time effects are greatly reduced.

The helix ends in coaxial side contacts in the tube-envelope which have the same impedance as the delay line to avoid reflection, which would result in display distortions. A helix system is, however, not troubled by rise-time effects (except effects due to the width of a single helix turn) and oscillations (up to the frequency where resonance occurs between the turns of the helix).

After having outlined the frequency response of standard and travelling-wave deflection systems, a practical oscilloscope tube will be described which utilizes a helix structure for the signal system.

3. The Travelling Wave Oscilloscope Tube

Rather than treating the tube as an entity, its main components will be discussed in detail and the reason outlined for the choice of certain designs.

3.1. *The Glass Envelope*

The new large field oscilloscope tube for the recording of high-speed transient phenomena is shown in the dimensional sketch of Fig. 3 and the photograph of Fig. 4. The envelope consists of glass No. 7052 (Corning) which has been chosen to accommodate the several Kovar metal side contacts. The faceplate diameter of the tube is $5\frac{1}{8}$ in., the overall length 24 in. The neck consists of two parts: the part enclosing the gun has an outside diameter of $1\frac{3}{8}$ in. while the part enclosing the deflection structure has a diameter of $2\frac{3}{4}$ in. This part carries also the side contacts for the focusing electrode, the helix system housing, the time base plates and the four coaxial connections for the two balanced helices.

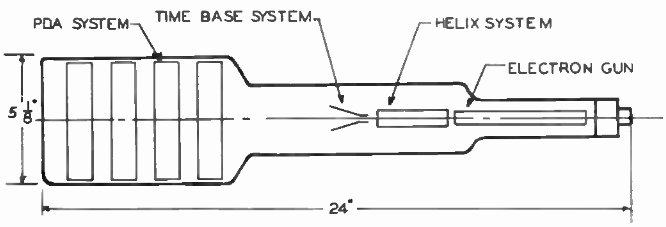

Fig. 3. Dimensional view of the TW-11.

The faceplate itself is completely flat and consists of No. 7056 glass (Corning) which has a very high optical quality.

An external conductive coating is applied to the neck part containing the deflection structure. The entire envelope including the external conductive coating is sprayed with a clear non-hygroscopic insulating lacquer. Four side contacts for the post-deflection acceleration bands are located near the screen.

3.2. *The Electron Gun*

The electron gun shown in Fig. 5 consists of a tetrode system and a decelerating electrostatic focusing lens of the two-electrode type. A tetrode system has been chosen as it permits an independent intensity and focus control.[4] Also, a variation of the second grid voltage results in the following effects: (1) the power of the lens between the second and third grid (pre-focus lens) is changed, thus leading to a changed angular magnification of the entire electron optical system; (2) altering the angular magnification leads to a changed spot-size on the screen and to a changed gun efficiency. These two effects are negatively correlated. In addition, changes in the potential configuration of the triode occur which emphasize these effects. The utilization of a tetrode system reserves, therefore, the possibility of compromising individually between spot-size and gun efficiency. As maximum writing speed and maximum sensibility (see below) require maximum gun efficiency and minimum spot-size, a change in the second grid voltage can emphasize the one or the other performance parameter which is an advantage for certain applications.

An electrostatic lens has been chosen in preference to an external magnetic lens for reasons of reduced bulkiness of the device. An

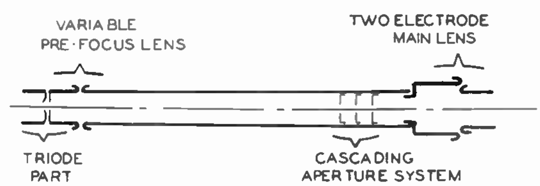

Fig. 5. The electron gun.

external magnetic lens also requires a very accurate adjustment as otherwise an astigmatically distorted spot results. This adjustment is rather cumbersome in practical application. Furthermore, rotation-free focusing units are required.

A two-electrode decelerating lens is applied, as this type of lens facilitates the utilization of

Fig. 4. Photograph of the TW-11.

a suitable electron-velocity in the deflection system at maintained stiffness of the beam over the relatively long distance from the cathode to the deflection structure, and thus shows a relatively small amount of inherent aberrations.

It may be worthwhile to elaborate somewhat on the controversial issue of magnetic vs. electrostatic focusing in high-speed oscilloscope tubes. One of the important performance parameters is the sensibility of the tube. By this term is understood the potential difference on the deflection plates required to shift a trace on the screen over a distance equal to its own width. Maximum deflection sensitivity and minimum trace width are required to obtain maximal sensibility. The sensitivity increases with increasing throw and the trace width decreases with decreasing lateral magnification. Thus, it is advantageous in principle to utilize a focusing lens between the deflection system and the screen.[5] Such a design carried out to the extreme is, however, quite impractical and the magnetic focus lens is therefore placed between the two deflection systems or at the same location as the signal system. The resulting gain in sensibility for a practical tube design is, however, not very substantial. On the other hand, the time-base sensitivity is reduced, which usually is of a second-order importance.

A decrease in trace width may also be expected due to the reduced amount of spherical aberration of the large diameter magnetic lens, provided the deflection in the lens region is restricted. In the present electrostatic lens, aberrations are greatly reduced by using a cascaded aperture system. Thus, the overall performance of the electrostatic lens approaches, in this case, the performance of the magnetic lens.

As mentioned above, a cascaded aperture system is built into the third grid cylinder. The purpose of these apertures is the interception of the marginal rays of the electron beam, thus producing a pseudo-pencil ray which results in essentially reduced spherical and chromatic aberration. In addition, deflection distortions are also decreased as the influence of the field gradient over the small beam diameter in the inhomogeneous fringe fields may be neglected for all practical purposes.

3.3. *Deflection Systems*

The TW-11 utilizes a balanced helix structure for the signal plates and conventional system for the time-base plates. This combination results in a full field of view along the time axis as a helix structure leads generally to severe shadowing. The utilization of helix structures for both systems seems to be an advantage only then when time-base and signal frequencies are of comparable magnitude. This case occurs rather seldom in practical applications.

3.3.1. Travelling-wave system (signal plates)

The balanced helix system* consists of two flattened helices wound of metal band in a counter-rotating way (see Fig. 2). The flattened sides oppose each other and the electron beam travels between them. The entire structure is enclosed in a grounded housing.

The helix structure has been selected in such a way that the resulting delay time matches the electron transit time for the entire system at a certain value of the acceleration voltage. Note that the axes of the two helices are parallel.

The sensitivity of a t.w. system is determined, among other parameters, by the total number of windings, i.e. the length of the system and the width of a single winding (or single pitch). This parameter also determines transit-time distortions while the length of the helix together with the distance helix to screen determines the field of view. A compromise had to be chosen. It was felt that a reasonably large field of view is to be preferred to a very high sensitivity as a restricted field of view of, say, $\frac{1}{2}$ inch would only create a somewhat enlarged version of Lee's micro-oscillograph.[1] Also, an improved frequency response seems to be more important than an increased sensitivity, particularly as amplifiers in the 2 kMc/s range seem now to be feasible.

The field of view could be increased even further by shaping the inside of the helix structure, according to H. Kallmann.[6] Kallmann's

* The travelling-wave deflection structure of the TW-11 (and the similar TW-9 and TW-10) was designed and perfected by Mr. R. Shifflett of the Naval Research Laboratory, Radiation Division, Nuclear Instrumentation Branch, Washington, D.C. The authors are greatly indebted to him for this contribution.

idea pertained to an unbalanced helix; the earthed housing and the helix diverge, a configuration which is achieved by successively decreasing the winding diameter of the helix.

Tilting the entire helix may be a somewhat simpler way. In this case, winding of the helix seems to be simpler and the effective width of the windings is reduced without losing sensitivity. In addition, tilting permits longer helices without shadowing. Thus, it seems feasible to increase the sensitivity and the field of view at slightly reduced transit-time effects. The effective delay time, of course, has to be re-matched to the axial electron velocity, and the impedance must be held constant throughout the length of the deflection structure.

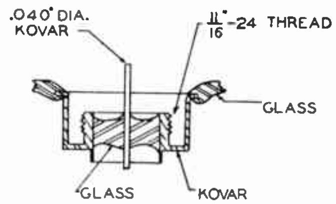

Fig. 6. Cross-section of the coaxial side contacts.

The four coaxial side contacts had to be designed to a careful match with the helices, as otherwise display distortions may occur as pointed out above. A cross-section of the contact is shown in Fig. 6. Impedance measurements carried out by means of a deflection method developed by the U.S. Naval Research Laboratory indicate that the mismatch deviates by less than 5 per cent. from the normal 125-ohms impedance assigned to the deflection structure. More detailed information concerning impedance, phase and attenuation characteristics will be the subject of further development work.

A technological difficulty had to be overcome in connection with the coaxial side contacts. Originally the threaded piece was heliarc-welded to the metal support ring. Leaks developed along the weld when the central Kovar wire was sealed in. Machining of the entire external metal part turned out to be the only remedy.

3.3.2. Time-base system

The time-base system is designed as conventional plate structure. The plates are flared to approximate the parabolic electron path. The entire system is shielded by an earthed metal housing. This shielding also reduces interaction between the two deflection systems to a large extent.

3.4. *Post-deflection Acceleration* (*p.d.a. system*)

The p.d.a. system consists of three rings and the screen. The rings are separated by chromium oxide bands (width 0·75 in., overlapping the aquadag rings by 0·125 in.) to counteract stray emission and internal breakdown.

A lumped system was used rather than a distributing spiral as the free choice of the post-acceleration voltages enables the user of the tube to find his own compromise between the variations performance parameters, like edge non-linearity, sensitivity reduction, spot-size, brightness, etc.

3.5. *Screen*

The screen material used is P-11 phosphor. This phosphor has a relative light emission maximum in the blue which is very suitable for photographic purposes. Its persistence is quite short, the brightness of a single line scan with a current load of 20 $\mu A/cm^2$ decreases to 10 per cent. of its original value after 0·2 millisec. The spectral distribution curve of P-11

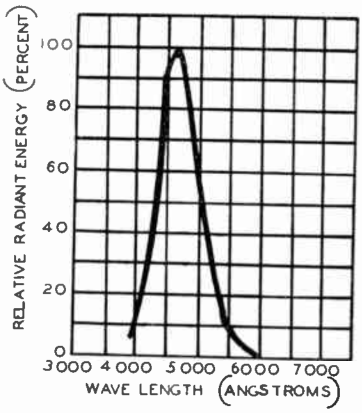

Fig. 7. Spectral distribution curve of P-11.

is shown in Fig. 7. The phosphor screen is aluminized to increase the brightness and to avoid display distortions due to local accumulation of electrostatic charges.

4. Performance of the TW-11

The performance of the tube in inherently connected with the mode of operation chosen. Thus, several performance characteristics will be listed for a typical operation mode.

4.1. *Typical Operation*

All voltages refer to earth

Cathode, – 10 kV.

Heater (one side or centre tab tied to cathode) – 10 kV.

Grid 1 voltage for visual cut-off, – 10·2 kV to – 10·4 kV.

Grid 2, – 8·5 kV.

Grid 3 (focus voltage), 15 to 17 kV.

Housing of horizontal and vertical deflection plates, 0 V.

Centre voltage of horizontal and vertical deflection system, 0 V.

First post accelerating ring, 0 V.

Second post accelerating ring, 8 kV.

Third post accelerating ring, 16 kV.

Screen, 25 kV.

4.2. *Performance of the Tube for the Above Described Typical Operation (Actual measured values)*

Vertical (t.w.) sensitivity, 0·0087 in./V.

Vertical (t.w.) sensibility, 0·46 V/trace width.

Vertical maximum vertical scan, $1\frac{3}{8}$ in.

Horizontal sensitivity, 0·005 in./V.

Horizontal sensibility, 0·80 V/trace width.

Maximum horizontal scan, 4 in.

Trace width (approx.), 0·004 in.

Characteristic helix impedance, 125 ohms each side to earth (coaxial balanced input).

Electron transit time:
vertical (t.w.) plates,* $0{\cdot}086 \times 10^{-9}$ sec (per turn);
horizontal plates, $0{\cdot}70 \times 10^{-9}$ sec.

Frequency response (approx. values):
vertical (t.w.) plates,† 2900 Mc/s, 90%;
horizontal plates, 2 Mc/s, 90%.

Maximal writing speed, $3{\cdot}5 \times 10^{11}$ trace widths/sec.

4.3. *Discussion of Tube Performance*

The frequency response and transit-time values listed in Section 4.2 have been determined theoretically. Thus, it might be justified to elaborate somewhat on practical tests carried out with this tube.

The tube has been operated with balanced signal input using ferrite inverters (developed by the U.S. Naval Research Laboratory) in the 1,000 Mc/s range. The results showed a uniform frequency response over the entire range.

Due to limitations in test equipment, the measurements could not be extended as yet to the 90 per cent. value of 2,900 Mc/s. It may, however, be anticipated that the tube will perform as practical device at frequencies even higher than 3 kMc/s. As mentioned above, the evaluation of this tube to its full capacity will be the subject of further development work.

The signal deflection system is designed for balanced input. The performance with unbalanced input is not known. Another broadband oscilloscope tube developed by the U.S. Naval Research Laboratory is designed for unbalanced signal input and may be used readily for such an application.[4] Such a type of travelling-wave tube has also been described elsewhere.[7]

4.4. *Current Distribution*

It is worthwhile to discuss the current distribution as a function of the pre-focus lens strength somewhat more in detail. As outlined in Sect. 3.2, the screen current efficiency increases with decreasing second-grid voltage. This effect is depicted in the curves of Fig. 8. This figure shows the total current and the screen current as a function of the grid drive for two values of the second-grid voltage. The current distribution has been determined under the following conditions:

Screen voltage (all p.d.a. rings connected to the screen)	+25 kV
Focus voltage	+15 kV
Deflection systems	0 V
Cathode	– 10 kV

The curves 1 and 2 show total current and screen current for – 9·695 kV on the second-grid while the curves 3 and 4 show total current and screen current for – 8·650 kV on the second-grid. It can be seen clearly that the screen current efficiency decreases with increasing second-grid voltage. As the spot-size on the

* Theoretical value: based upon pitch, rather than plate length. This assumes full fringing (most pessimistic case).

† Theoretical value: fringe field influences taken partly into account.

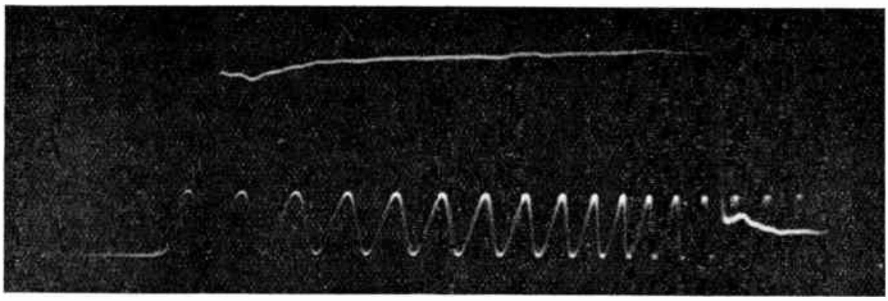

Fig. 9. Step function response of the TW-11.

screen decreases also due to the changing angular magnification, a compromise may be chosen between sensibility and writing speed. Note, however, that at high speeds only the centre part of the bell shaped-current distribution in the beam is used for writing. Thus, the effective trace width for high-speed writing is substantially smaller than for low-speed display.

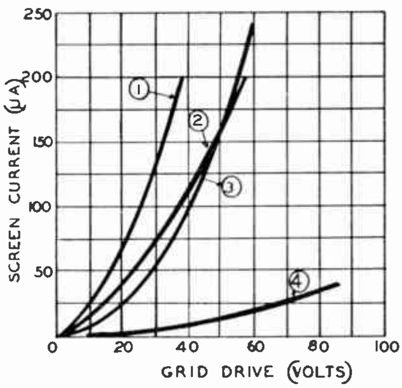

Fig. 8. Current distribution in the gun of the TW-11.

4.5. *Response to a Step Function*

The response of the TW-11 to an input step function is displayed in the photograph of Fig. 9. A timing wave of 1,000 Mc/s is shown together with the step-function response. The tube was used as described in Sect. 4.1 with the exception of the second-grid voltage which was −9 kV instead of −8·5 kV. It can be seen that the display of the step function is almost faultless.

5. Acknowledgment

It is a pleasure to acknowledge the close co-operation and assistance of many staff members of the U.S. Naval Research Laboratory, Radiation Division, Nuclear Instrumentation Branch, Washington, D.C. The authors are particularly obliged to Mr. George F. Wall of this organization for many helpful design suggestions and constructive criticism.

The release by the Naval Research Laboratory of the photograph of Fig. 9 is greatly appreciated.

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BIRTH CENTENARY OF SIR JAGADISH CHANDRA BOSE, F.R.S.

An appreciation by Dr. S. K. Mitra, F.R.S. (Member)

JAGADISH CHANDRA BOSE whose birth centenary will be celebrated in India in the last week of this month is recognized as the first Indian scientist of modern times to obtain recognition in the international world of science.* During his remarkable scientific career of more than four decades, he made notable contributions to certain borderland regions of science, e.g. those separating (1) electro-magnetic waves from light waves, (2) the living from the non-living, and (3) the life activities of plants from those of animals.

Bose began his career as one of the pre-1900 Hertzian wave investigators who had turned their attention rather to the study of the quasi-optical properties of these waves than to their application to signalling across space. In the hands of these investigators, working with waves in the centimetre range, microwave technique developed and remarkably anticipated much of what is practised today. Bose, perhaps the most prominent amongst these investigators, designed an elegant microwave spectrometer and made use of dielectric lenses, crossed gratings polarimeter, microwave absorber, hollow metal pipes for guiding the waves, and flared wave guide (electromagnetic horn). He also devised macroscopic models of molecules —twisted band of jute fibres—for producing rotation of plane of polarization, and thus established microwave analogue physics. An account of Bose's experiments is to be found in a recent article by J. F. Ramsay.†

Bose also made an extensive study of the properties of detectors made of different metals and crystals. This led him to the study of the response of many inorganic systems to the stimulus not only of electric waves, but of light, mechanical torsion, etc. The response manifested itself as a change of resistance, e.m.f. variation, or photo-voltaic effect; it was subject to fatigue, was enhanced by stimulants and depressed by poisons. It thus showed a great deal of similarity to the electrical response of living tissues. The contents of this common law of response, first postulated by Bose, have been greatly enriched in recent years by developments in electronics which have led to construction of inorganic systems with purposive controlling mechanism. Such systems have a great deal of similarity with receptor and effector activities of higher animals endowed with a central nervous system. The name *cybernetics* has been coined by Wiener (1948) for such mechanisms which emphasize "the essential unity of the set of problems centering about communication, control, and statistical mechanics, whether in the machine or in living tissue." From what has been said above, Bose's work may be considered as foreshadowing this new technique called "Cybernetics."

A hitherto unpublished portrait of Sir Jagadish Bose. His lifetime—1858-1937 covered great scientific achievements. His contributions are commemorated by an Institution Premium which bears his name.

Bose was born on 30th November, 1858. In 1885 he joined the Presidency College, Calcutta, after obtaining a B.A. degree in Natural Sciences Tripos at Cambridge. He retired from the College in 1915 and two years later founded the Bose Institute "for further investigation of the many ever-opening problems of the nascent science which includes both life and non-life." He was created a Knight Bachelor by King George V in 1917 and was elected a Fellow of the Royal Society in 1920—the very first Indian physicist to be accorded this distinction.

By his unbounded enthusiasm for science, Bose exerted an enduring influence on the development of the spirit of scientific research amongst his countrymen. He was intensely patriotic, and any success he achieved in his scientific pursuits he always regarded as a glory added to his motherland.

* *J.Brit.I.R.E.*, **13**, page 130, March 1953.

† "Microwave antenna and waveguide techniques before 1900," *Proc. Inst. Radio Engrs*, **46**, pp. 405-415, February 1958.

Section Activities . . .

SOUTH WALES

The 1958-9 session opened on October 15 at the Cardiff College of Advanced Technology, when Mr. B. R. A. Bettridge (Associate Member) gave an interesting lecture on the principles of Transistor Circuitry before an audience of more than seventy members and guests.

Mr. Bettridge opened with a summary of the characteristic features of transistor parameters, and explained the phenomena of neutralization, softening voltages, thermal effects, and the factors controlling self destruction. He followed with an account of the conditions of Class A amplification, and gave a criticism of some of the basic circuits. The lecture concluded with a detailed reference to the significance of ambient temperature, thermal dissipation, class B amplification, and pulse conditions.

C.C.E.

SOUTH-WESTERN

The inaugural meeting of this new Section was held in Bristol on October 2, and no fewer than 110 members and guests were present. The Chairman, Captain L. Hix, R.N., opened the meeting and introduced Rear-Admiral Sir Philip Clarke, K.B.E., C.B., D.S.O. (Immediate Past President). A lecture was then given on "Applications of the Modern Computer," by Dr. A. D. Booth (Member).

The first application was the calculation of the most economical time table for a forty mile electric railway having intermediate stations. The second was the re-organization of a small factory in order to obtain the maximum profit. In this case the predicted increase was 15 per cent.—when the re-arrangement had been carried out a 10 per cent. increase was achieved. Tht third example was that of time saving in the case of prolonged calculations dealing with crystal structure. Six men had completed this exercise in three years—the computer completed the task in two weeks. At the same time the plotting of the electron contour, a week's job for one man, was produced on the computer display in 15 seconds.

These three examples were followed by details of the problems and programming met in translating machines. Dr. Booth ended with a reference to the possible future development of computers to deal with the problems of human behaviour.

During the discussion which followed, Dr. Booth answered questions on bi-directional translators, direct translation from speech for computers dealing with air traffic control problems and the use of magnetic transductors to replace valves.

E.G.D.

WEST MIDLANDS

"An Introduction to Colour Television" was the subject of the paper read by Mr. T. Jacobs, B.Sc., at the first meeting of the session on October 8. Mr. Jacobs began by considering the requirements of an elementary three-channel colour system. He then described and evaluated the features of the more important display devices developed to date, namely, the trinoscope monitor, a projection system, and the Apple, Lawrence and Shadow Mask tubes. He pointed out that the elementary system had many severe drawbacks which prevented the production of stable economic receivers and which rendered the system wasteful of bandwidth and incompatible. Some alternatives had been, or were being, investigated and he made particular mention of the N.T.S.C. system, whose underlying principles were widely acknowledged to be correct, and which had been extensively tested recently by the B.B.C. in live broadcasts. The application of the N.T.S.C. system to single gun colour tubes was discussed at some length. Lastly, Mr. Jacobs considered some of the future propects of colour television and analysed the factors that tended at present to impede progress.

R.A.L.

NEW ZEALAND

During the 1958 session the Wellington Section has held a number of meetings for the reading and discussion of papers. The details are as follows:—

July 9th. A discussion on Television Standards.

July 30th. A paper by Mr. D. A. Bernon (Associate Member) entitled "An Introduction to Transistor Theory."

August 27th. A paper by Mr. G. J. Ferguson on "Carbon 14 Dating."

September 24th. Annual General Meeting followed by a paper by Mr. N. V. Ryder on "Cosmic Ray Research in New Zealand."

W.C.L.

A NOTE ON THE RADIO-FREQUENCY HEATING OF RUBBER COMPOUNDS*

by

N. H. Langton, Ph.D. (Associate Member)† and D. Matthews, F.N.C.R.T.†

SUMMARY

An investigation of the dielectric heating of a number of vulcanized and unvulcanized rubber mixes is described. The unvulcanized material is of an industrial type, whilst the vulcanized compounds contain zinc oxide of known particle size, shape, and dispersion. It is verified that the behaviour of the mixes in a dielectric heater agrees reasonably well with that predicted by theory. The heat function, α, as defined by Elvy, is calculated.

1. Introduction

In a recent paper by Elvy[1], the problem of the dielectric heating of various materials is considered. Elvy defines a function α, called the heat factor, by:

$$\alpha = \frac{k \cos \theta}{cs} \qquad \ldots\ldots\ldots(1)$$

where c = specific heat,
s = specific gravity,
k = permittivity,
and $\cos \theta$ = power factor of the material under consideration.

Elvy mentions the heating of rubber, and gives a figure of $\alpha = 8$ for hard rubber (ebonite). Hard rubber, however, is only one of the many different types of rubber mix in use, and it is the purpose of this note to indicate how the value of the heat factor may vary for different rubber compounds. There is little information available, because there are so many different types of rubber compounds in use, and the raw material itself, being a natural product, is subject to considerable variation. A knowledge of the heat factor, however, would be of use both to those concerned with the processing of the compounds, and to those whose concern is the design of radio frequency heaters for use in the rubber industry.

2. The Heat Factor

To calculate the heat factor, a knowledge of permittivity, power factor, specific heat and specific gravity of the rubber mix is required. Of these four quantities only the last is commonly measured, but the specific heat, which is difficult to measure in usual routine, can be calculated easily from the compounding formula. The manner in which c and s vary with temperature is generally not known, although for the purpose of calculating α it is sufficiently accurate to use the room temperature values and assume that the variation is negligible.

The permittivity and power factors are not quantities which are measured as routine quality checks except where rubber is being produced for electrical purposes. Whilst the permittivity is fairly easy to measure, the power factor is not, since it is often very small, so that, as a rule, the loss factor $\tan \delta = k \cos \theta$ will be an unknown quantity for most rubber mixes. It is not possible to calculate either k or $\cos \theta$ from the values of these quantities for the constituents of the mix. Whilst there are several theoretical and empirical equations which are supposed to give values of the permittivity of a two-phase mixture, and at least one for a multi-phase mixture, none of these equations in practice give accurate results for a rubber mix. This is because the resulting electrical properties of a rubber mix depend in an unknown manner upon the particle shapes and sizes of the fillers, and also upon the degree of dispersion of the particles in the rubber. The influence of this last factor has never been thoroughly investigated. The influence of particle shape, size, and degree of dispersion in the case of zinc oxide as a filler, is being investigated by the authors, and some of these results in this one case may be of interest.

* Manuscript received 17th July 1958. (Paper No. 478.)

† National College of Rubber Technology, Northern Polytechnic, Holloway, London, N.7.

U.D.C. No. 621.365.55:678

3. The Dielectric Properties of Rubber Mixes

The variation of tan δ with frequency and mix constitution has been investigated in a few cases by Waring[2]. It was found that tan δ depends upon the frequency, and may exhibit a peak value, after which it decreases with increase of frequency. This means that increasing the working frequency of a dielectric heater may not produce the increase of efficiency which would be expected from the heating equation. Waring did not, however, take into account the degree of dispersion of the filler particles in his mixes, nor does he quote information as to the particle sizes and shapes of the particulate fillers. Below are given some results obtained by measuring the rate of heating of production rubber mixes in a dielectric heater under controlled conditions, and some results from experiments to investigate the influence of dispersion and particle shape upon the permittivity of laboratory mixes when zinc oxide was used as a filler. The particle shapes and sizes, together with the degree of uniformity of dispersion were measured using an electron microscope and an ultramicrotome, and details of this technique will be given elsewhere[3].

4. Experimental Procedure

The results recorded are from two types of experiment. The first type involved the use of a radio frequency heater working at a frequency of 16 Mc/s. For these experiments, rubber mixes of an industrial type, from both the intermediate and final stages of the industrial process were used. These mixes consisted of an unvulcanized rubber mix containing small additions of resin and zinc oxide, the details of which are given in Table 1.

The second type of experiment consisted in measuring the permittivity and power factors of special mixes, using a Q-meter. The main constituent of the mix, other than the rubber, was a zinc oxide of special purity and controlled particle size. The particle sizes of the various types of oxide were measured by the manufacturers, using the porous plug method, and checked by the authors with an electron microscope. Most of the mixes were examined under the microscope, and a statistical analysis made to determine the degree of dispersion of the zinc oxide. The presence of other constituents in these mixes, which were used in the vulcanized state, may be ignored since such small amounts were used compared with the zinc oxide loadings.

5. Results

For the first type of experiment, small blocks were cut from the material, about 3 in. × 3 in. × 1 in. These were then weighed, and placed between the plates of a dielectric heater, making sure that they were entirely in the region of uniform heating, according to the criterion of Langton and Gunn[4]. The input power, as measured on the instrument wattmeter, was then adjusted to either 1 or 1·5 kW. The material was subjected to 30-second heating cycles, and the temperature reached at the end of each cycle was measured by inserting a needle thermocouple into the material, taking the average of several readings. During the temperature readings the block of material was cooling, but preliminary tests showed that the heat loss over the period of time required to measure the temperature was negligible, so that this cooling could be neglected. Tables 1 and 2 give details of these experiments. Since different masses were used, the temperatures have all been adjusted to correspond to unit mass and 1 kW input power. Some of the results are shown in graphical form in Fig. 1 and will be discussed later.

The second series of experiments involved measurements of permittivity and power factor. Some measurements were made using the low

Table 1

Description of Mixes

Mix	*Description*
A	95% rubber + 5% zinc oxide
B	95% rubber + 5% resin
C	95% mix B + 5% zinc oxide
D	70% rubber + 30% resin
E	50% rubber + 25% resin + 25% zinc oxide
F	33·3% rubber + 33·3% resin + 33·3% zinc oxide
G	Pressure sensitive adhesive, high tack
H	Pressure sensitive adhesive, low tack

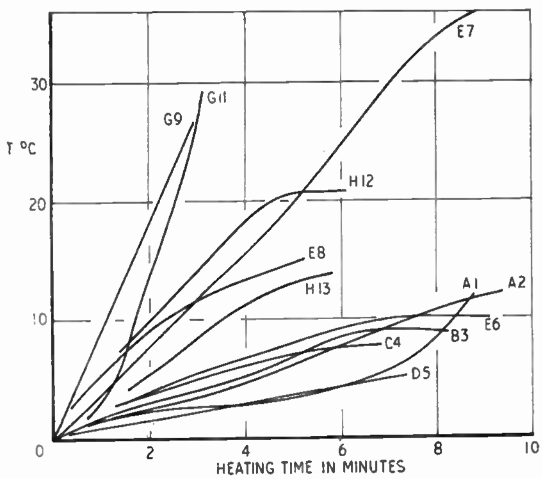

Fig. 1. Heating curves of various rubber mixes at 16 Mc/s.

tack adhesive mass, Mix H, and the results are shown in Table 3. From these figures it is possible to calculate the variation of α with frequency, as shown in the Table, and from this the theoretical heating curve can be drawn. This curve is compared with that obtained experimentally when a sample of the material was heated in the dielectric heater, as shown in Fig. 2.

Table 4 summarizes results obtained by using the Q-meter in the usual way to measure permittivity at various frequencies. This Table, and the curves of Fig. 3 show how *k* varies with frequency for various loadings of zinc oxide filler and for two types of zinc oxide. These results refer to a good dispersion, and a typical electron micrograph of a section of such a mixture is shown in Fig. 4. A statistical analysis of this mixture shows that it approximates very closely to a Normal distribution of particles.

During attempts to test Lichteneker's equation[5] for predicting the permittivity of a mix from the permittivity values of its components,

Table 2

Schedule of Experiments

Run	Mix	Heating Time (min)	Initial Temp. (°C)	Final Temp. (°C)	Power (kW)	Mass of Material (grams)
1	A	8·5	24	57	1·0	333
2	A	9·5	24	96	1·5	263
3	B	7·0	40	57	1·0	499
4	C	6·5	32	48	1·0	477
5	D	7·0	24	63	1·0	133
6	E	6·5	32	123	1·5	167
7	E	9·0	22	90	1·0	530
8	F	5·0	23	123	1·5	224
9	G	2·5	20	112	1·5	365
10	G	14·0	19	72	1·0	380
11	G	3·0	20	94	1·0	380
12	H	5·0	27	139	1·0	188
13	H	5·5	28	118	1·5	228

Notes.—Run 5, Mix D. Sample milled to form block.
Run 6, Mix E. Capacitor plates held apart distance of 4·5 cm so that there was a small air gap between the upper plate and the specimen.
Run 12, Mix H. Capacitor plates held 3·5 cm apart. Small air gap between upper plate and specimen.
Run 13, Mix H. Capacitor plates held 6·5 cm apart. Small air gap between upper plate and specimen.

Table 3
Variation of Permittivity and Loss Factor for tht Low Tack Adhesive Mass

Frequency (Mc/s)	Permittivity K	Loss Factor tan δ	α
1·0	2·6	5·9	11·8
2·5	2·9	4·6	9·2
5·0	3·0	4·8	9·6
7·5	3·0	—	—
10·0	3·0	3·5	7·0
20·0	3·0	3·3	6·6
25·0	2·9	3·0	6·0
30·0	2·8	2·8	5·6
40·0	2·9	2·7	5·4

Note.—It was assumed that $s=1{\cdot}0$ and $c=0{\cdot}5$ for this mix

it became necessary to measure k for zinc oxide, as no values for this quantity over a range of radio frequencies were available. A description of the method used and the results obtained is to be published elsewhere[6]. The interesting point relevant to this note, however, is that the permittivity of the zinc oxide varies widely according to the type. Colloidal zinc oxide has a permittivity of about 11 over a range of frequencies from about 50 kc/s to 30 Mc/s, whilst the acicular type has a permittivity of over 40 for the same frequency range.

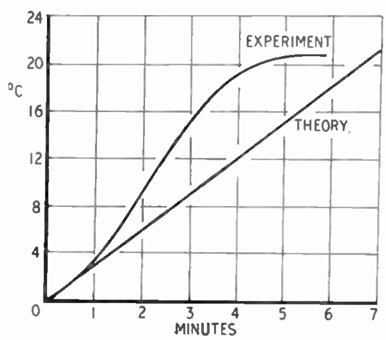

Fig. 2. Experimental and theoretical heating curves for Run H12.

The exact value of k for this type of oxide could not be measured by the authors as it was too high for the method used. The normal commercial grade of zinc oxide used by most rubber manufacturers is a mixture of various particle shapes, but does not contain much of the acicular type, generally less than 20 per cent. It therefore appears that there might be considerable advantage in certain cases from the radio-frequency point of view if the usual grade of oxide was replaced by the acicular, where this could be done without spoiling the properties of the finished product.

6. Conclusions

The curves of Fig. 1 show the temperature variation of various rubber mixes with heating

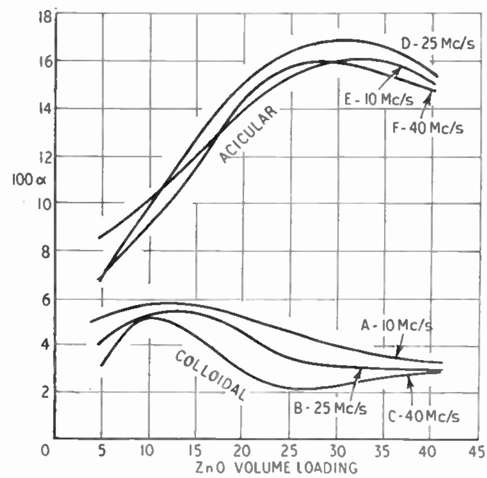

Fig. 3. Variation of heat factor α with ZnO loading for colloidal and acicular oxides.

time, reduced to unit mass (one gram), and unit power input (one watt). There is considerable variation amongst the curves, as would be expected. Whilst some of the mixes, such as D5 and C4, do not heat efficiently in a high frequency field, others, such as G9 and H12, would be very suitable for this method of heating. Most of the curves show a change of slope towards the end of the heating period. This is probably a latent heat effect due to the melting of one of the components, or else due to chemical changes starting to take place because of the onset of vulcanization. Ignoring these parts of the curves, the remaining portions are fairly linear.

By combining eqn. (1) with the usual heating equation, which can be written as

$$P=1{\cdot}41.w.R^2.\tan\delta.10^{-12}=\text{constant}.m.c.\Delta T \qquad \ldots\ldots\ldots(2)$$

Table 4

Variation of Permittivity and Loss Factor for the Special Mixes

Frequency (Mc/s)	Stock A5 K	A5 $\tan\delta$	A10 K	A10 $\tan\delta$	A20 K	A20 $\tan\delta$	C5 K	C5 $\tan\delta$	C10 K	C10 $\tan\delta$	C20 K	C20 $\tan\delta$
1·0	3·52	3·50	4·03	3·50	5·26	4·40	3·18	1·90	3·35	1·50	3·81	1·50
2·5	3·46	3·90	3·94	4·60	5·09	5·60	3·06	1·70	3·24	2·50	3·73	1·80
5·0	3·36	4·60	3·83	5·00	4·93	6·20	2·97	2·80	3·24	2·00	3·65	2·00
7·5	3·33	4·30	3·78	5·10	4·86	6·90	2·97	2·80	3·24	3·00	3·80	2·90
10·0	3·35	4·10	3·77	5·00	4·82	6·70	3·01	2·40	3·24	2·40	3·73	2·00
15·0	3·27	4·40	3·71	5·20	4·72	7·00	—	—	—	—	—	—
25·0	3·24	3·50	3·58	4·80	4·53	8·10	2·97	2·00	3·13	1·70	3·53	2·70
40·0	3·17	3·50	3·53	4·60	4·54	8·20	2·94	1·60	3·08	3·30	3·59	1·60

Note.—Stocks A and C are compounded with acicular and colloidal zinc oxides respectively. The number gives the number of volumes of zinc oxide compounded with 100 volumes of rubber; e.g. A10 contains 100 parts of rubber, by volume, and 10 parts, by volume, of acicular oxide.

where

P = power in watts entering the material,
R = the r.m.s. field strength in volts/in,
w = the pulsatance = $2\pi \times$ frequency,
$\tan\delta$ = the loss factor of the material,

then

$$\frac{\Delta T}{t} = \frac{F\,(V')^2.0{\cdot}068}{48{\cdot}7} \qquad \ldots\ldots\ldots(3)$$

where

ΔT = temperature rise in °C of the material,
t = heating time in seconds,
F = heater frequency in Mc/s,
V' = applied voltage in r.m.s. volts/0·001 in.

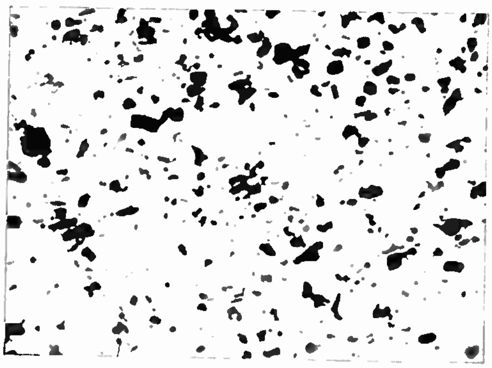

Fig. 4. Electron micrograph of colloidal ZnO in rubber. Sectioned on ultra-microtome, 20 volume loading.

In eqn. (3), the value 0·068 is the heat factor for the low tack adhesive mass taken from Table 3, so that, if V' is known, the actual heating curve may be compared with that obtained by using Elvy's eqn. (3). The voltage gradient, V' can be calculated from eqn. (2), since the capacitor plates were 3·5 cm apart in the case of run 12, and the loss factor of the material is 0·034. Hence the value of 14 kV is obtained for the value of r.m.s. voltage between the capacitor plates when separated by a distance of 3·5 cm. Equation (3) therefore becomes

$$\frac{\Delta T}{t} = 3{\cdot}1\,^\circ\text{C/min}$$

where t is now the heating time in minutes. The value found by experiment was about 5°C/minute, and the theoretical and experimental curves are shown in Fig. 2. Considering that the inevitable losses have been ignored, and that approximations made in the calculation of V' introduce errors, which are doubled since V' occurs squared, this is quite good agreement. It thus appears that the use of the heat factor leads to useful information in the case of rubber mixes as well as for other materials.

The results of Table 4 and the curves of Fig. 3 indicate how difficult it is to postulate the dielectric behaviour of rubber compounds in advance without preliminary investigations. Whereas the effect on $\tan\delta$ of varying the frequency is small, a large and previously unpredictable effect is shown when the type of zinc oxide is altered.

7. Acknowledgments

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MAGNETO-IONIC FADING IN PULSED RADIO WAVES REFLECTED AT VERTICAL INCIDENCE FROM THE IONOSPHERE*

by

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SUMMARY

The results of a fairly extensive study of magneto-ionic fading in pulsed radio waves vertically reflected from the F2-region of the ionosphere are presented. Phase paths of the two interfering magneto-ionic components are calculated on the basis of ray theory assuming a parabolic distributiou of iouization in the F2-region. The calculated frequeucies of fading are found to agree fairly well with the observed values. A method of deducing the semi-thickuess of the F2-layer from the observed frequencies of fading is presented and the results obtained by this method are also presented and discussed.

1. Introduction

Periodic fading of radio waves received after reflection from the ionosphere is a commonly observed phenomenon. This periodic fading is of many types and has different origins. Periodic fading of one type was observed by Appleton and Beynon[1] in c.w. transmissions obliquely incident on the ionosphere. They interpreted this type of fading as due to the interference of two magneto-ionically split components. Similar fading was observed subsequently by several scientific workers both in short and medium wave transmissions from distant stations. A quantitative interpretation of such fading was first attempted by M. S. Rao and B. R. Rao[2] in analysing the fading records obtained with c.w. transmissions in the medium-wave band from a distant station. They used Booker's ray treatment in calculating the phase paths of the two magneto-ionic components and calculated theoretically the frequencies of fading. The agreement between the calculated and experimentally observed values was quite good in general. They also developed an empirical approximate formula for the rapid calculation of phase paths of the ordinary and extraordinary rays in the ionosphere, assuming a parabolic distribution of ionization.

The occurrence of periodic fading of magneto-ionic origin in pulsed radio waves vertically reflected from the ionosphere was reported by S. N. Mitra[3]. Using polarized aerials, he showed that the fading was observed only when both the magneto-ionic components were present to interfere with each other. No quantitative study of such magneto-ionic fading has been attempted so far. The authors have undertaken such a study extending the method of phase path calculations used by M. S. Rao and B. R. Rao in their interpretation of c.w. fading records.

2. Preliminary Experimental Results and their Interpretation

2.1. *Experimental details*

Preliminary experiments were conducted during May 1956 to obtain periodic fading records, during the early morning hours of 0500 to 0630 hours I.S.T. This part of the day was chosen for the recording because the F2-region is least disturbed by turbulence and the ionization change is sufficiently rapid to give quick period fading. Pulsed transmissions on a frequency of 5·0 Mc/s vertically incident on the ionosphere were used. The equipment was a standard pulse sounding equipment consisting of a pulsed transmitter, communication receiver and cathode-ray oscillograph. Provision was made for increasing the pulse width up to 250 microsec at the time of recording to ensure the complete merging of the two magneto-ionic components. The operating frequency was chosen to be well below the critical frequency of F2-region at the time of recording but high enough for the two magneto-ionic components to be present in comparable strength and interfere with each other producing periodic fading.

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By increasing the frequency by about 1 Mc/s the two components were observable separately on the oscillograph, each individual echo showing little fading, random or periodic. The above observation can be taken to be an experimental confirmation of the magneto-ionic origin of the fading recorded on 5·0 Mc/s, even though no direct experimental verification of the magneto-ionic nature was attempted as was done by Mitra. Many records were obtained showing smooth periodic fading quite frequently, the frequency of fading being of the order of 2 to 6 cycles per minute. A typical record is reproduced in Fig. 2. The critical frequency of F2-layer was determined before and after each record, the time interval between recording time and critical frequency determinations being as short as possible. From the knowledge of the critical frequencies the frequency of fading for each record was calculated as outlined below.

2.2. *Method of calculation of phase paths*

The phase path of either magneto-ionic component in the ionosphere can be expressed in the form:

$$P=\int \mu \, ds \qquad \ldots\ldots\ldots(1)$$

where ds is an infinitesimally small element along the path of the wave at any point in the ionosphere and μ is the phase refractive index at the same point for propagation along the direction ds. The integration is to be carried over the entire path in the ionosphere. The evaluation of the above integral requires the knowledge of μ at each point along the path of the ray in the ionosphere as well as of the point of reflection. In the case of vertical incidence, μ can be evaluated at different heights in the ionosphere direct from Appleton-Hartree formula. As the phase propagation is vertical, ds can be replaced by dh, an infinitesimal element of height h. In the case of short waves used in the present investigation, the effect of collisions can justifiably be neglected and the Appleton-Hartree equation then reduces to the following simple quadratic form in terms of μ^2 and x:

$$\mu^2=1+[x(1-x)]/f(x) \qquad \ldots\ldots\ldots(2)$$

where

$$f(x)=x-1+\frac{y^2\cos^2\theta}{2}\pm$$

$$+\left[\frac{y^4\cos^4\theta}{4}+y^2\sin^2\theta(1-x)^2\right]^{\frac{1}{2}}$$

$$x=\frac{4\pi Ne^2}{mp^2}; \qquad p=2\pi f$$

$$y=\frac{f_H}{f}=\frac{He}{2\pi mcf}; \qquad \theta=\text{dip angle.}$$

This equation gives, for each discreet value of x, two values of μ^2, corresponding to the ordinary and extraordinary rays. The positive and negative values of μ correspond to the upgoing and downcoming rays respectively. These values of μ are found for different values of x over the range of 0 to 1 and the $\mu-x$ values are plotted as curves in Fig. 1 (*a*) and (*b*), for the

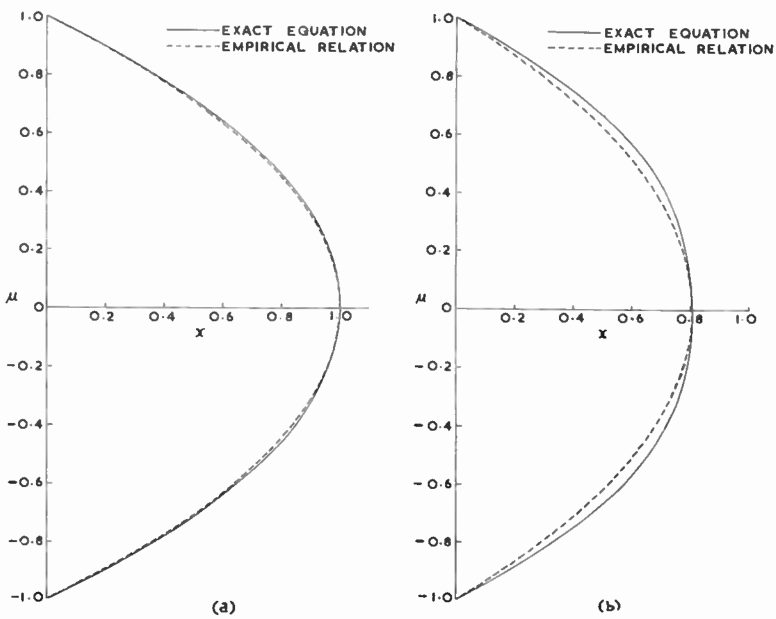

Fig. 1. Theoretical $\mu-x$ curves: (a) for the ordinary ray; (b) for the extraordinary ray.

ordinary and extraordinary rays respectively. The heights at which these values of x and μ obtain in the ionosphere are then evaluated from the well-known quadratic relating x and h for a parabolic distribution of ionization:

$$\beta h^2 - \alpha h + x = 0 \qquad \text{.........(3)}$$

where

$$\alpha = \frac{2f_0^2}{f^2 y_m} \; ; \quad \beta = \frac{f_0^2}{f^2 y_m^2}$$

f_0 = critical frequency of the ordinary ray
h = height above the bottom of the layer
y_m = semi-thickness of the layer

The upper limit of the integral (1) is determined by the limiting value of x and this is different for the two magneto-ionic components. These limiting values for this special case come out to be 1 and $1 - y$ respectively for the ordinary and extraordinary rays. The values of μ_r and h_r corresponding to these two values of x determine the upper limiting values of the integral. The total path of each magneto-ionic component in the ionosphere is given by twice the value of the integral (1). By plotting μ against h between the proper limits, the integral is evaluated graphically and the phase paths of the two magneto-ionic components are obtained for the condition of the ionosphere at the beginning and end of a short interval during which records have been taken, the critical frequencies at the two instants being determined experimentally. From the calculated values of the change in the phase path difference between the two magneto-ionic components during the interval of the record, the frequency of fading is readily obtained. The value of f_H at the F2-layer height for the present case comes out to be 0·9565 Mc/s, assuming the total field H to be 10 per cent less at the F2-layer height than that at the ground. The value of y_m for F2-layer is assumed as 140 km, following S. K. Mitra[4].

2.3. *Comparison with experimental results*

The $\mu - x$ graphs for both the magneto-ionic components are shown in Fig. 1. The results of detailed phase path calculations are summarized in Tables 1 and 2 for two records taken on two different days. From these Tables, it can be seen that the calculated and observed frequencies of fading are agreeing reasonably well. The agreement is quite good particularly for the first records taken on 22nd May 1956. The slight disagreement in the case of the second record may be due to a slight inaccuracy in the determination of critical frequency or due to the semi-thickness of the F2-layer being different from the assumed value of 140 km on that particular day. The inaccuracy in critical frequency is mainly due to the fact that they are determined manually for want of a $p' - f$ recorder. It is found that a better agreement with observed values is obtained for the second record if the semi-thickness of the F2-layer is assumed as 180 km on that particular day. This immediately suggests the possibility of determining the semi-thickness of the F2-layer using the observed frequencies of magneto-ionic fading provided, of course, the experimental errors in critical frequency values are reduced to a minimum. These preliminary experiments showed conclusively that the observed periodic fading was of magneto-ionic origin and that the method of calculations outlined above enables one to interpret such type of fading quantitatively provided the assumed values of semi-thickness are reasonably nearer the true values.

3. An Approximate Empirical Formula for Phase Paths

An empirical relation between q and x was assumed by M. S. Rao and B. R. Rao[2] in the case of oblique incidence continuous waves of standard broadcast frequencies and it was found to give values of x very close to the exact values obtainable from Booker's cubic equation[5]. Using this empirical relation they arrived at an approximate formula for the phase path of either magneto-ionic component for the case of parabolic distribution of ionization. The same empirical relation between q and x is found to hold good in the present case of short waves also, after it is suitably modified for vertical incidence case. This empirical relation between q and x reduced for the case of vertical incidence may be written as

$$\mu^2 = 1 - \Delta x \qquad \text{.........(4)}$$

where $\Delta = 1/x_r$

since the parameter q used in Booker's treatment reduces to μ for vertical incidence case. x_r is the value of x at the level of reflection and is given by unity and $1 - y$ for the ordinary and extraordinary respectively in the present case. Using this relation, $\mu - x$ values were determined both for ordinary and extraordinary and

Table 1

Results of Phase Path Calculations and Frequencies of Fading for the Record taken on 22nd May 1956

Description	By graphical integration		From empirical formula (5)	
	at 0530 hours	at 0550 hours	at 0530 hours	at 0550 hours
Critical frequency, f_0F2	6·5 Mc/s	7·5 Mc/s	6·5 Mc/s	7·5 Mc/s
Total path of ordinary	64·62 km	46·49 km	64·32 km	46·07 km
Total path of extra-ordinary	52·77 km	38·52 km	50·24 km	36·40 km
Path difference between ordinary and extra-ordinary	11·84 km	7·96 km	14·08 km	9·67 km
Change in path difference from 0530 to 0550 hours	3·87 km (64·5 wavelengths)		4·41 km (73·5 wavelengths)	
Calculated frequency of fading	3·23 cycles/min		3·67 cycles/min	
Observed frequency of fading	3·00 cycles/minute			

compared with the exact values obtained from relation (2). The broken curves in Fig. 1. represent the $\mu - x$ relation as given by the empirical formula (4). The agreement between the two sets of curves is found to be quite good especially for the ordinary ray, the maximum deviation being about 2 per cent for the ordinary and 8 per cent for the extraordinary ray. The error involved in the phase path calculations will be much less than these values as will be shown later.

Making use of this simple empirical relation between μ and x and assuming a parabolic distribution of ionization, an approximate formula can be derived for the phase paths as shown below. Combining relation (4) with integral (1) we have the expression:

$$P = 2 \int_0^{h_r} \sqrt{1 - \Delta x.}\ dh$$

for the total phase path of the ray in the ionosphere. Again substituting the value of x from relation (3) in the above integral and carrying out the integration between the limits, the following simplified expression is obtained for the phase paths of both the magneto-ionic components at vertical incidence:

$$P = y_m \left[1 + \frac{1}{2}\left(D - \frac{1}{D}\right) \log_e \frac{1+D}{1-D} \right] \quad \ldots\ldots\ldots(5)$$

where $D = \dfrac{f}{f_0} \sqrt{x_r}$

f_0 = ordinary critical frequency
f = operating frequency
x_r = value of x at the point of reflection
y_m = semi-thickness of the reflecting layer

Using the above formula, phase paths and frequencies of fading were calculated for the same two records taken on 22nd and 24th May, 1956; the results are shown in Tables 1 and 2. Comparing the phase paths obtained from the approximate formula with those obtained from the exact method of graphical integration, it was found that the two values agreed to within 1 per cent for the ordinary and to within 6 per cent for the extraordinary. The use of empirical formula is thus justified when not too accurate values are desired. The values of the fading frequencies in each case are greater by 14 per cent than those obtained from the accurate graphical method. Considering, however, the fairly good agreement between the values of phase paths obtained by the two methods the use of empirical formula is to be preferred for cases where high accuracy is not necessary as it is much easier to calculate frequencies of fading compared to the laborious method of graphical integration.

4. Determination of the Semi-thickness of the F2 layer using the Empirical Formula

4.1. *Determination of* y_m *from magneto-ionic fading records*

With a view to comparing the fading frequencies obtained by using empirical formula with the observed values, a large number of records were taken on suitable frequencies in the early morning hours during the months of October and November 1956. The frequencies of fading calculated for each record using relation (5) and assuming a semi-thickness value of 140 km for F2-layer are shown in Table 3 along with the observed values. The difference observed between the theoretical and experimental values is more than the expected error due to the inherent limitation in the empirical formula or the inaccuracy in the values of the critical frequencies which were measured with sufficient care. This discrepancy must be mainly due to the divergence of the semi-thickness of F2-layer from the assumed value of 140 km. As it has not been possible to determine semi-thickness of the F2-layer experimentally, the converse procedure has been adopted of calculating the semi-thickness of the F2-layer by assuming that the empirical formula gives reasonably correct values of fading frequencies. The y_m values thus obtained are also shown in Table 3 in the last column. These values fall in the range of 109 to 191 km, most of them, however, being less than 140 km. These values of y_m thus obtained are lower than the actual y_m values by about 10 to 14 per cent as the fading frequencies obtained from the empirical formula are higher than those obtained by the rigorous graphical method by about 10 to 14 per cent.

4.2. *A more reliable method of determining* y_m

A more exact method of measuring the semi-thickness of F2-layer and its variation was developed by the authors by using a simultaneous recording technique for magneto-ionic fading on two different operating frequencies. Two pulsed transmitters operating on two

Table 2

Results of Phase Path Calculations and Frequencies of Fading for the Record taken on 24th May 1956

Description	By graphical integration		From empirical formula (5)	
	at 0545 hours	at 0605 hours	at 0545 hours	at 0605 hours
Critical frequency, f_0F2	6·7 Mc/s	8·0 Mc/s	6·7 Mc/s	8·0 Mc/s
Total path of ordinary	60·56 km	40·32 km	59·8 km	39·91 km
Total path of extra-ordinary	49·53 km	33·43 km	46·80 km	31·65 km
Path difference between ordinary and extra-ordinary	11·03 km	6·89 km	13·0 km	8·26 km
Change in path difference from 0545 to 0605 hours	4·14 km (68·97 wavelengths)		4·75 km (79·1 wavelengths)	
Calculated frequency of fading	3·45 cycles/min		3·955 cycles/min	
Observed frequency of fading	4·5 cycles per minute			

Table 3

Results of y_m Determinations from Single Magneto-ionic Fading Records

S. No.	Date and hour of recording (I.S.T.)	Operating frequency (Mc/s)	Hours I.S.T.	f_0F2 Mc/s	Calculated frequency of fading (y_m=140 km)	Observed frequency of fading F (c/min)	y_m as determined from F
1.	12-10-'56 0645	6·4	0620 0700	9·0 11·2	1·926	1·5	109·0 km
2.	18-10-'56 0630	5·85	0605 0655	7·1 10·5	3·735	3·463	130·0 ,,
3.	28-10-'56 0640	6·4	0630 0652	9·55 11·8	2·878	3·349	163·0 ,,
4.	31-10-'56 0555	4·35	0533 0612	5·1 8·35	5·929	4·9	115·7 ,,
5.	31-10-'56 0620	5·85	0612 0647	8·35 11·0	2·542	2·197	121·0 ,,
6.	7-11-'56 0605	6·2	0545 0635	7·7 10·5	2·569	1·942	106·0 ,,
7.	11-11-'56 0615	5·6	0555 0628	8·3 10·85	2·415	3·302	191·0 ,,

different frequencies which were close to each other but less than the critical frequency of the F2-layer were used and the reflected signals, after amplification, were fed to the Y plates of a double beam oscillograph for recording purposes. A typical simultaneous record is shown in Fig. 2. The critical frequencies were determined as usual before and after each record. Using the frequencies of fading observed in the simultaneous fading records and the critical frequency data, the semi-thickness of the F2-layer was determined from each record as was done for single records. The values of y_m thus obtained from the simultaneous records are presented in Table 4 and the two values obtained from each record are compared with each other. These two values are seldom identical, the difference, however, being always less than 10 per cent. This slight difference can be attributed to the error inherent in the empirical formula. This method of simultaneous recording enabled us to reject a few of the records for which y_m values were differing widely. Table 4 also shows the mean values of y_m obtained from simultaneous records and it is found that most of these values are confined to a limited range of 140 to 150 km. On certain days, however, large departures of y_m values from the normal value are noticed and this feature is characteristic of the F2-layer at this latitude.

The method of obtaining y_m values for F2-region by simultaneous recording on two frequencies has the advantage that it is reliable, rapid and sufficiently accurate, provided the f_0F2 values are determined accurately at times close to the period of recording. Even the single record method for y_m determinations gives reasonably reliable values. This method has the disadvantage that it cannot be easily extended

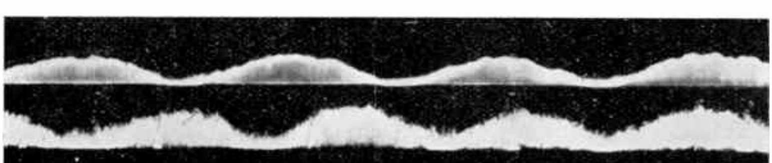

Fig. 2. A typical record of magneto-ionic fading on two frequencies. 0625 hours I.S.T., 4th December, 1956.

Table 4

Results of y_m Determinations from Simultaneous Records of Magneto-ionic Fading

S. No.	Date and hour of recording (I.S.T.)	Operating frequency (Mc/s)	Hours I.S.T.	f_0F2 Mc/s	Observed frequency of fading F (c/min)	y_m as determined from F	Mean value of y_m
1.	14-10-'56	6·4	0635	9·5	3·0	138 km	142 km
	0645	5·85	0655	11·5	2·49	147 ,,	
2.	17-10-'56	6·4	0620	8·1	2·564	127 ,,	147 ,,
	0700	5·85	0710	11·0	2·492	166 ,,	
3.	19-10-'56	6·12	0627	8·5	2·35	148 ,,	152 ,,
	0644	5·85	0707	10·8	2·05	158 ,,	
4.	24-10-'56	6·12	0620	9·3	2·236	164 ,,	174 ,,
	0502	5·85	0655	11·8	2·194	184 ,,	
5.	1-11-'56	3·4	0439	6·3	1·122	99 ,,	107 ,,
	0502	3·0	0510	5·275	0·959	116 ,,	
6.	2-11-'56	4·35	0553	6·85	3·292	156 ,,	141 ,,
	0600	4·14	0610	8·25	2·317	126 ,,	
7.	4-11-'56	4·15	0537	5·55	2·228	68 ,,	70 ,,
	0555	4·35	0600	7·25	2·786	73 ,,	
8.	4-12-'56	4·7	0605	6·05	3·4	109 ,,	108 ,,
	0625	4·5	0640	8·8	2·773	107 ,,	

to daylight hours as the periodic fading of magneto-ionic origin is lesser in amplitude and easily obscured by random fading. This investigation can be extended easily for the study of magneto-ionic fading at other hours during night time.

5. References

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# of current interest . . .

British Centre for Rocket and Satellite Data

A World Data Centre for Rockets and Satellites is now operating at the Radio Research Station of the Department of Scientific and Industrial Research at Ditton Park, Slough, Bucks. This is the third of three centres established under the International Geophysical Year arrangements for centralization of this type of information. Previously there have been rocket and satellite data centres only in Moscow and Washington and it was agreed at the recent Moscow meeting of the Special Committee for the International Geophysical Year to accept a British offer of a third rocket and satellite centre.

The Radio Research Station is an appropriate location for the rocket and satellite data centre because many of the satellite experiments are concerned with studies of the ionosphere. Research workers at the Radio Research Station and its Singapore sub-station are engaged in such studies, in association with other research establishments.

Other British satellite studies include radio and radar observations of satellites made at the Jodrell Bank Experimental Station, University of Manchester. Telemetry information from U.S. earth satellites is recorded on equipment lent by the Jet Propulsion Laboratory, California Institute of Technology, to the University College of Ibadan in Nigeria and the Radio Research sub-station, Singapore. The B.B.C. Receiving Station at Tatsfield receives telemetry signals also from U.S.S.R. satellites.

Data from all these British investigations will be collected by the Slough Data Centre and exchanged with the other Data Centres in the U.S.A. and U.S.S.R. Information on I.G.Y. rocket flights and the published reports of investigations will also be collected.

The Use of Semi-conductor Devices

The rapidly increasing application of all sorts of semi-conductor device has made it desirable to provide some authoritative information on their use. The principal manufacturers of semi-conductors in Great Britain have contributed to the preparation of a booklet—published on their behalf by the British Radio Valve Manufacturers' Association (the B.V.A.)—which it is hoped, will prove of use in this direction.

The book is primarily intended to assist equipment designers to secure optimum performance and life from semi-conductor devices. A number of problems arising in the design of equipment which are relevant to the application of semi-conductors are dealt with and recommendations for suitable operating conditions are made.

The book is divided into four sections, the first dealing with general properties of semi-conductors, the second with diodes, the third with junction transistors and the last section with photo-sensitive semi-conductor devices. It is proposed that the contents will be revised and expanded from time to time to keep abreast with current techniques.

Copies may be obtained from the B.V.A., 16 Jermyn Street, London, S.W.1.

E.M.I. College of Electronics

Over the past few years E.M.I. Electronics Ltd. has found an increasing necessity to meet the training requirements of its technical staff, and has increased the training facilities within its own organization at Hayes and elsewhere.

For these reasons the Board of Directors of Electric and Musical Industries Ltd. has decided to close the E.M.I. College of Electronics with effect from July, 1959.

Canadian Trials of Decca Navigator

Evaluation tests into the value to shipping of the Decca Navigator system have been carried out for more than a year on Canada's eastern seaboard by the Canadian Department of Transport. The result of the tests are now being studied by officials of the Telecommunications Branch of the Department and the results will determine the government's decision.

The system has been evaluated by a large cross-section of shipping including fishing boats, coastal vessels and ocean liners and freighters. Four chains of land-based stations were set up for the evaluation tests, each consisting of a master transmitting station and three slave stations, located as follows: south coast of Newfoundland, east coast of Newfoundland, Nova Scotia and Eastern Quebec.

ELECTROMAGNETIC WAVE PROPAGATION IN CYLINDRICAL WAVEGUIDES CONTAINING GYROMAGNETIC MEDIA*

by

R. A. Waldron, B.A. (Cantab.) (Associate Member)†

PART 2*

7. A Study of Cut-offs

7.1. *Introduction*

Equation (34) may be solved for the normalized phase constant $\bar{\beta}$ for given values of the parameters a/λ_0, b/λ_0, ε, μ, and α. A value must be assigned to p, and there may be more than one value of $\bar{\beta}$ to satisfy eqn. (34). Let us fix our attention on the qth solution, the first being that with the highest value of $\bar{\beta}$. The mode corresponding to this solution may be designated the (p, q) mode. We shall not keep to this notation in the future, but it will serve for the time being until some understanding of the mode structure is obtained. For a given set of values of a, b, ε, μ, and α, we may vary the frequency, starting at zero and working upwards. Then $\bar{\beta}_{pq}$, the value of $\bar{\beta}$ appropriate to the (p, q) mode, will move first along the imaginary axis from infinity to zero, then out along the real axis from zero to infinity. The frequency f_0, at which $\bar{\beta}_{pq}=0$, divides the frequency axis into two regions; in that below f_0 there is heavy attenuation, and the guide is said to be cut off, while for frequencies above f_0 the (p, q) mode propagates freely in the guide. Similarly, for any of the other parameters, if its value when $\bar{\beta}_{pq}=0$ is known, we may say that to one side of this value propagation takes place, while to the other it does not (but see the next paragraph but one).

In the five-dimensional space with dimensions a/λ_0, b/a, ε, μ, and α, if a given set of these values satisfies the cut-off equations, the set will be referred to as a cut-off point. It is not necessary to take the frequency as a sixth dimension, since the normalization used makes this superfluous. In the following, this five-dimensional space will be called β-space. In β-space, a/λ_0 and ε are limited to positive values, and b/a to the range from 0 to 1. μ and α may take any values. Only real values of these quantities will be considered.

It is evident that a study of the relations between the parameters when $\bar{\beta}$ is zero, for all modes, will yield valuable information about the mode spectrum. For given values of the parameters, it will tell us which modes are able to propagate. Also, if values are assigned to a/λ_0, ε, μ, and α, we can find the value of b/a for which $\bar{\beta}$ is zero for, say, the (p, q) mode. It may then be expected that as b/a increases from this critical value $\bar{\beta}$ will increase monotonically from zero; this gives some indication of where to look for solutions of the characteristic equation. Actually, in some cases, this is not quite what happens, as will be seen from the results of Section 8; however, in the calculations of phase constants this picture has been a useful guide.

The value of a study of cut-offs is apparent; indeed, the calculations of phase constant would have been virtually impossible without this preliminary study. Further, the study will be found to yield a method of relating the normal modes in the guide containing ferrite to those in the guide homogeneously filled with an isotropic medium, and hence to give a method of designating the modes. It will also be possible to demonstrate that all the possible modes have been accounted for, and to make some comments on the H_{p0} and E_{p0} modes, which do not occur in the homogeneous isotropic case but do occur trivially in the case of the guide containing ferrite.

* The first part of this paper was published in the October issue of the *Journal* (page 597-612).

U.D.C. No. 621.372.852.22

7.2. *The Cut-off Equations*

We start by putting $\bar{\beta}$ equal to 0 in eqn. (34). We thus obtain for the determinant of eqn. (34) a product of two factors and the reduced characteristic equation is satisfied when either of these factors vanishes. The two equations so yielded are:

$$J_p(B\chi).\Delta_1 - \left\{ PJ_p'(B\chi) - \frac{pQ}{B}.J_p(B\chi) \right\}.\Delta_2 = 0 \qquad \ldots\ldots\ldots(52)$$

and $$J_p(B\sqrt{\varepsilon}).\Delta_3 - \frac{J_p'(B\sqrt{\varepsilon})}{\sqrt{\varepsilon}}.\Delta_4 = 0 \qquad \ldots\ldots\ldots(53)$$

where

$$\Delta_1 = \begin{vmatrix} J_p(A) & Y_p(A) \\ J_p'(B) & Y_p'(B) \end{vmatrix} \qquad \Delta_2 = \begin{vmatrix} J_p(A) & Y_p(A) \\ J_p(B) & Y_p(B) \end{vmatrix}$$

$$\Delta_3 = \begin{vmatrix} J_p'(A) & Y_p'(A) \\ J_p'(B) & Y_p'(B) \end{vmatrix} \qquad \Delta_4 = \begin{vmatrix} J_p'(A) & Y_p'(A) \\ J_p(B) & Y_p(B) \end{vmatrix}$$

$$A = 2\pi a/\lambda_0 \qquad B = 2\pi b/\lambda_0$$

$$P = \sqrt{\frac{\varepsilon}{\mu(1-\alpha^2/\mu^2)}} \qquad Q = \frac{\alpha}{\mu^2(1-\alpha^2/\mu^2)}$$

$$\chi = \sqrt{\varepsilon\mu(1-\alpha^2/\mu^2)}$$

Owing to the way in which the functions P and χ arise, it is clear that when they are real they take the same sign, and when imaginary, opposite signs. It is convenient to take χ as positive, so that the arguments of the Bessel functions are positive. P may then be taken as real and positive or imaginary and negative, as the case may be. Reversal of the signs merely changes the sign of the left-hand side of eqn. (52), and so does not affect the solutions. There is no danger of obtaining spurious solutions if the wrong sign combinations are chosen; there are then no solutions.

Equations (52) and (53) give the loci of points in β-space satisfying the condition $\bar{\beta}=0$, and these loci divide β-space into regions in which, for a given mode, propagation does or does not take place. It is impossible to reach a non-propagation region from a propagation region without crossing the locus appropriate to the mode in question. Thus if we trace a solution of eqn. (52) or eqn. (53), as the parameters vary, we can define the region of β-space in which propagation takes place for a given mode. If we trace all possible solutions of eqns. (52) and (53), we shall define the propagation regions of β-space for all the normal modes, and we can then find a system of nomenclature for the normal modes.

The only way in which a propagating mode could be missed by this technique is that it does not cut off—i.e. $\bar{\beta}$ is always greater than zero throughout the whole of β-space. But by analogy with the isotropic homogeneous case, we may expect that such a mode would require the presence of a second conductor, and so we reject the possibility. We therefore expect that our study will enable us to discover all the normal modes.

7.3. *The Normal Modes*

We can consider the normal modes to be divided into two sets, according as the condition $\bar{\beta}=0$ is satisfied by a solution of eqn. (52) or of eqn. (53). In due course it will be seen that these sets of modes may be related to the E-modes and H-modes, respectively, of the guide with homogeneous isotropic filling.

Let us assume that values are assigned to a/λ_0, μ, and α. Also, let us consider a specific mode, which means that p is given. Eqns. (52) and (53) then give the radius ratio b/a as a function of ε, and curves may be plotted in the ε, b/a plane which are loci of points which satisfy the condition $\bar{\beta}=0$. Since our attention will be confined to a single mode, one of these curves is chosen; to consider more than one would contradict what we understand by a mode.

We start by reducing α continuously to zero. There are two cases to consider—firstly, $|\alpha|>|\mu|$, in which case we pass through the critical condition $|\alpha|=|\mu|$, and secondly $|\alpha|<|\mu|$, in which case there is no critical condition. The first case will not be considered further at present; it is dealt with in Section 7.4. In the second case, the curve under consideration degenerates smoothly to that appropriate to $\alpha=0$. We next change μ smoothly to unity, and the curve degenerates further to that appropriate to a guide containing a dielectric rod. Next, the radius of the rod is increased until b/a becomes unity; thus we move along the curve in the b/a, ε plane till we reach the value of ε for which the filled guide is in the critical condition $\bar{\beta}=0$. This value of ε is unique. The result of these changes is to reduce eqns. (52) and (53) respectively to

$$J_p(A\sqrt{\varepsilon})=0 \qquad \text{.........(54)}$$

and

$$J_p'(A\sqrt{\varepsilon}=0 \qquad \text{.........(55)}$$

For a guide filled with dielectric, operating in an E mode, the characteristic equation is

$$J_p(A\sqrt{\varepsilon-\bar{\beta}^2})=0 \qquad \text{.........(56)}$$

and if $\bar{\beta}$ is put equal to 0, this reduces to eqn. (54). In the case of an H-mode the characteristic equation reduces to eqn. (55) on putting $\bar{\beta}=0$.

The value of ε which satisfies eqn. (54) or (55) may thus be approached in either of two ways. We may think of a guide filled with dielectric, and imagine ε to be varied until β becomes zero, or we may start with a guide containing a ferrite rod, and reduce the parameters as described above. It is thus evident that a normal mode in a guide containing ferrite can always be related to a normal mode in the isotropic homogeneous case. The question remains, whether this a 1–1 correspondence. It would be tedious to give a rigorous affirmative answer to this question, but in view of the number of numerical solutions which have been obtained to eqns. (52) and (53), it is extremely unlikely that any multiplicity of solutions could have escaped unnoticed.

By virtue of the reduction of eqn. (52) to eqn. (54), and of eqn. (53) to eqn. (55), it is possible to relate those modes given by eqn. (52) to E-modes and those given by eqn. (53) to H-modes. They may be designated E_{pq} modes and H_{pq} modes, where q refers to the qth zero of eqn. (54) or (55). These modes are not true E or H modes, as has been demonstrated by Kales[8]; however, this is a useful nomenclature as long as the point is borne in mind.

It should be noted that p may take any integral value, including 0. The solutions of eqns. (34) and (52) depend on the sign of α, and may be related to right-handed or left-handed helical modes according as α is a negative or positive, respectively. The solutions for opposite signs of α degenerate to a single solution in the homogeneous isotropic case, and also at the value of b/a for which β is zero in the case of H-modes, since eqn. (53) is independent of the sign of α. If we remember that the normal modes in the isotropic homogeneous case are degenerate, then we are correct in our deduction above that there is a 1-1 correspondence.

7.4. *Primary and Secondary Solutions of the Cut-off Equation*

Suhl and Walker[7] have pointed out that the characteristic equation for the filled guide is satisfied by $\bar{\beta}=0$, $|\mu|=|\alpha|$, for all ε, α, and a/λ_0. Seidel has studied in some detail the question of propagation in the filled guide for $|\mu|<|\alpha|$; however, he adopts a restricted viewpoint which makes the subject unnecessarily difficult. We shall see that the existence of modes of propagation for $|\mu|<|\alpha|$ is predicted by the cut-off equations, and that this approach enables us to elicit the mode structure in this case, although we shall not study the question in detail.

In order to obtain a starting-point for all cut-off curves, we consider first the filled guide. Then in eqns. (52) and (53), Δ_2 and Δ_3 vanish, while Δ_1 and Δ_4 both reduce to the Wronskian and so have no zeros. These equations therefore reduce, respectively, to

$$J_p(A\chi)=0 \qquad \text{.........(57)}$$

and

$$J_p'(A\sqrt{\varepsilon})=0 \qquad \text{.........(58)}$$

It is evident that for H-modes ε is given as a function of a/λ_0, independent of μ and α. Thus only one type of solution is obtainable, and H-modes will not be considered further at present. For E-modes, let C_{pq} be the qth zero of the Bessel function of order p. Then

$$A\chi=C_{pq} \qquad \text{.........(59)}$$

Squaring both sides and substituting for χ, we obtain a quadratic equation in μ whose solutions are

$$\mu=\frac{1}{2}\left\{\frac{C^2_{pq}}{\varepsilon A^2}\pm\sqrt{\frac{C^4_{pq}}{\varepsilon^2A^4}+4\alpha^2}\right\} \qquad \text{.........(60)}$$

There are thus always two and only two real values of μ for a given E-mode which satisfy the cut-off equation in the filled guide. One of these lies in the range $(C^2_{pq}/\varepsilon A^2)\leqslant\mu\leqslant(C^2_{pq}/\varepsilon A^2)+\alpha$, and this is the one for which $|\mu|>|\alpha|$. We shall call this the primary solution; it is the one that we shall be mainly concerned with in this paper. The other solution of eqn. (60) lies in the range $-|\alpha|\leqslant\mu\leqslant0$, and it may be seen from Figs. 1 (*a*), (*b*), (*c*) and (*d*), that this solution will apply for values of polarizing field, σ, lying between 1 and some value between 0 and 1. This solution will be called the secondary solution.

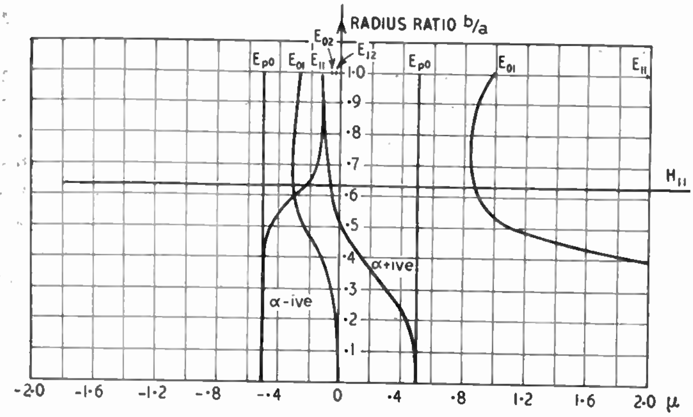


Fig. 2. Cut-off curves in the b/a, μ, plane for $a/\lambda_0 = 0{\cdot}2$, $\varepsilon = 5$, $\alpha = \pm 0{\cdot}5$. The E_{0q} curves are independent of the sign of α. The H_{11} mode, which is the only H mode able to propagate for these values of ε and a/λ_0 has a cut-off value which is independent of μ and α.

Figure 2 illustrates some typical values of μ for some of the lower modes. The computations have been carried out for $\varepsilon = 5$, $\alpha = \pm 0{\cdot}5$, $a/\lambda_0 = 0{\cdot}2$. Table 1* gives more values of cut-off points in the filled guide.

It may be noted that there is a solution of eqn. (60) when $C_{pq} = 0$, corresponding to the E_{p0} modes, which do not exist in the empty guide. This does not apply if $p = 0$, because $J_0(0) \neq 0$, but it does apply to all other values of p. These modes will be discussed in Section 7.5. We also note that an H_{p0} mode ($|p| \geqslant 2$) can exist if $\varepsilon = 0$, and that then eqn. (53) is satisfied for all values of b/a. This is a trivial case, however, as $\bar{\beta}$ becomes imaginary as soon as ε departs from zero.

7.5. E_{p0} *Modes*

In deriving eqn. (52) from the characteristic equation, a factor $(1 - \alpha^2/\mu^2)$ was cancelled. If this is restored, it is readily seen that eqn. (52) is satisfied by $\chi = 0$, $|p| \geqslant 1$, for all values of b/a. Thus an E_{p0} cut-off curve exists for all p except $p = 0$, and this curve takes the form of the two lines $\mu = \pm|\alpha|$. As with the E_{pq} modes, there are two branches for either positive or negative values of p. Further, there is no other solution, so that an E_{p0} mode only occurs for the trivial case $\mu = \pm|\alpha|$, with zero phase constant. These are the solutions which Suhl and Walker[7] discovered in the case of the filled guide. They appear to be of no physical interest.

It has been shown in Section 7.4 that an E_{00} mode does not exist for the filled guide. It may also be shown that if p is put equal to zero in eqn. (52) there is no solution for small χ. Further, in the computations that have been performed for the E_{01} mode, no root was discovered that could be attributed to an E_{00} mode. It thus appears likely that the E_{00} mode does not exist, not even in the primitive form of the other E_{p0} modes.

7.6. *Secondary* E_{0q} *Modes*

If we put p equal to 0 in eqn. (52), we obtain

$$J_0(B\chi).\Delta_1 - PJ_1(B\chi).\Delta_2 = 0 \qquad \ldots\ldots\ldots(61)$$

where Δ_1 now takes the form

$$\begin{vmatrix} J_0(A) & Y_0(A) \\ J_1(B) & Y_1(B) \end{vmatrix}$$

and Δ_2 the form

$$\begin{vmatrix} J_0(A) & Y_0(A) \\ J_0(B) & Y_0(B) \end{vmatrix}$$

In this equation α occurs only to an even power, so that the solutions are independent of the direction of the polarizing field. The value of μ in the filled guide, for given a/λ_0, ε, α, can be obtained from eqn. (60), and this is illustrated for a special case in Fig. 2. Both primary and secondary curves of b/a against μ for the E_{01} mode are drawn. The primary curve is similar in form to the curves of b/a against ε in Figs. 3 to 14.

For the secondary E_{01} cut-off curve, if we take B and μ to be small in eqn. (61), we obtain

$$(1/B).J_0(B\chi) + PJ_1(B\chi).\log_e B = 0$$

which is satisfied by $B = 0$, $\mu = 0$, if χ approaches

* Tables 1, 2 and 3 were reproduced on pp. 609-12 of the October issue of the *Journal.*

infinity more rapidly than B approaches zero, i.e. if B and μ approach zero in such a way that $B \gg \mu$. This is seen to be the case for the curve drawn in Fig. 2.

It may also be noted that for all values of B eqn. (61) is satisfied by $\mu=0$. Then $B\chi$ becomes infinite, and both $J_0(B\chi)$ and $J_1(B\chi)$ are zero. Thus the line $\mu=0$ is part of the locus of points satisfying eqn. (61). We may therefore say that the values of μ for which the secondary E_{0q} mode propagates lie between the curve and the line $\mu=0$. The solution $\mu=0$ of eqn. (61) is not indicated by eqn. (60), and represents a special case.

It seems fairly certain that as q increases, the secondary cut-off curve will lie closer and closer to the line $\mu=0$, and that the E_{01} mode is therefore the lowest of the E_{0q} modes. For all values of μ for which the E_{01} mode can propagate, except $\mu=0$, it may be expected that there will be a range of values of b/a for which no other E_{0q} mode can propagate.

7.7. *Secondary* E_{pq} *Modes*

It has been shown in Section 7.4 that there is always a solution of eqn. (52) when $B=A$, for some value of μ in the range $-|\alpha|<\mu<0$, and we may expect that there is a curve in the b/a, μ plane which starts from this point and connects values of b/a and μ for which the condition (52) is obeyed. Such curves are shown in Fig. 2 for the E_{11} mode both for positive and negative α. If we take b/a to be small, and expand the left-hand side of eqn. (52) about $B=0$, we obtain

$$\left.\begin{aligned} \lim_{B\to 0}\mu &= \pm\alpha \\ \text{or} \quad \lim_{B\to 0}\mu &= -(1\pm\alpha) \end{aligned}\right\} \quad \ldots\ldots\ldots(62)$$

the + or − sign to be taken according as p is positive or negative. From the values that have been computed, it appears probable that the second of these solutions is without physical significance, and that the curves approach the point $b/a=0$, $\mu=\pm\alpha$, as shown in Fig. 2.

The question now arises, which side of the cut-off curve is the region in which propagation can take place? We know the region to the right (as drawn in Fig. 2) of the primary cut-off curve to be a propagation region, while to the left is a non-propagation region. Also, in general, while the real part of $\bar{\beta}$ is zero in the empty guide, the imaginary part takes a finite value, so that it would seem unlikely that propagation could take place in the region where b/a is smaller than the value given by the secondary cut-off curve. It may be expected that as b/a increases from zero to this value, the imaginary value of $\bar{\beta}$ decreases from a finite value to zero, and that the secondary propagation region is above the cut-off curve. It is necessary, therefore, to locate a boundary between this propagation region and the non-propagation region to the left of the primary curve for positive α, and some other boundary, containing the point $b/a=0$, $\mu=-|\alpha|$, for negative α.

Attempts to locate such a boundary by numerical solution of the cut-off equation have failed; it therefore seems certain that it does not lie outside the region $-|\alpha| \leqslant \mu \leqslant |\alpha|$. For values of μ within this range there are an infinite number of solutions for b/a for any given value of p, since all modes are represented, so that it would be difficult to identify a single curve, if one existed. Intuitively, however, it seems not unlikely that the lines $\mu=\pm|\alpha|$ form the required boundaries. Attempts to prove this fail; if we take μ to be nearly equal to $\pm|\alpha|$, we find $B=0$, corresponding to the curve already obtained, while if we put μ actually equal to $\pm|\alpha|$, eqn. (52) is satisfied but the solution is appropriate to the E_{p0} mode.

We shall not investigate this problem further here, but content ourselves with having pointed out the difficulty.

7.8. *Primary Solutions of the Cut-off Equations*

In this section we shall discuss solutions of the cut-off curves subject to the condition $|\mu| > |\alpha|$, with μ positive. It is for this case that we shall undertake extensive investigations in Section 8 of the normalized phase constant β as a function of the quantities a/λ_0, b/a, ε, μ, and α.

Before considering the actual solutions of eqns. (52) and (53), there are certain general features that may be profitably discussed. We notice first that μ and α occur neither explicitly nor implicitly in eqn. (53), which means that the curves of b/a against ε for H-modes depend only on a/λ_0 and p. In

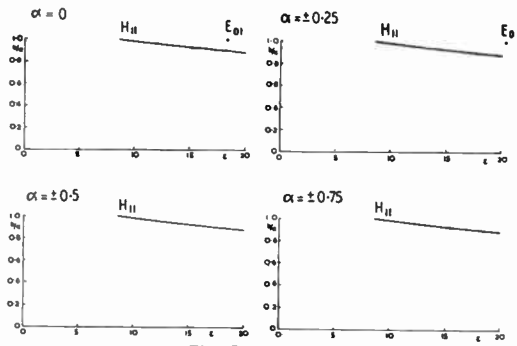


Fig. 3 - $a/\lambda_0 = 0{\cdot}1$, $\mu = 0{\cdot}8$

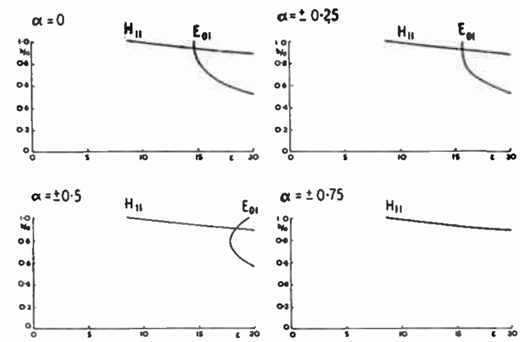


Fig 4 - $a/\lambda_0 = 0{\cdot}1$, $\mu = 1$

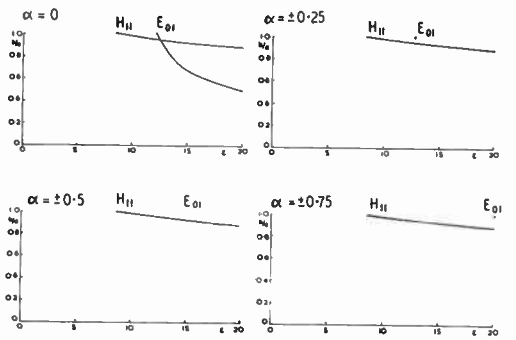


Fig. 5 - $a/\lambda_0 = 0{\cdot}1$, $\mu = 1{\cdot}2$

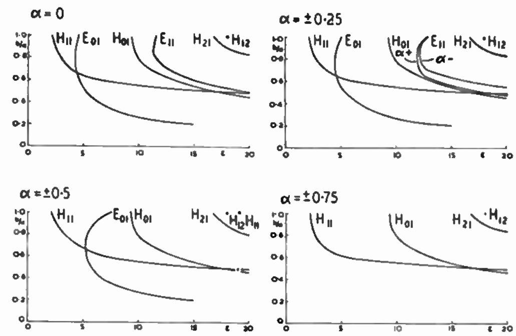


Fig. 6 - $a/\lambda_0 = 0{\cdot}2$ $\mu = 0{\cdot}8$

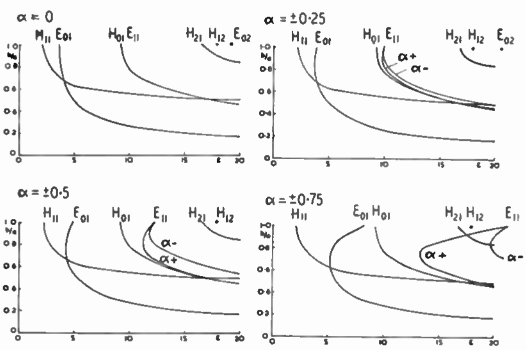


Fig. 7 - $a/\lambda_0 = 0{\cdot}2$, $\mu = 1$

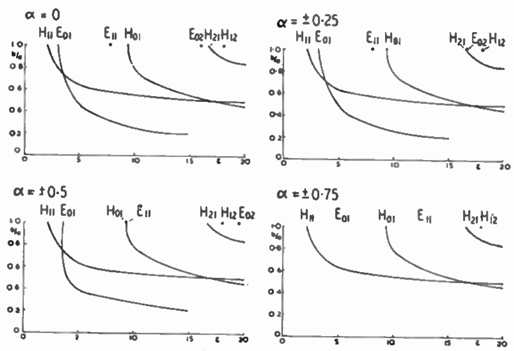


Fig. 8 - $a/\lambda_0 = 0{\cdot}2$, $\mu = 1{\cdot}2$

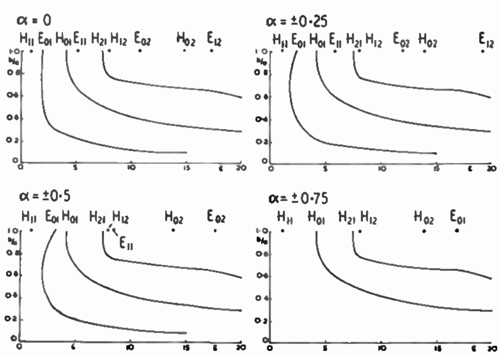


Fig. 9 - $a/\lambda_0 = 0{\cdot}3$, $\mu = 0{\cdot}8$

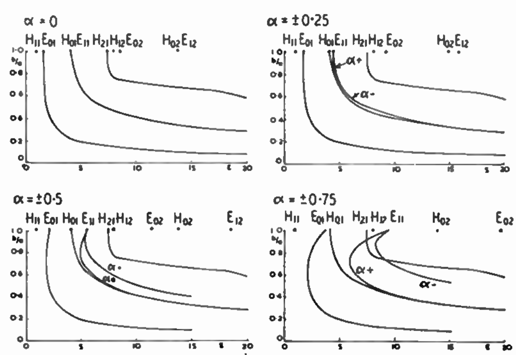
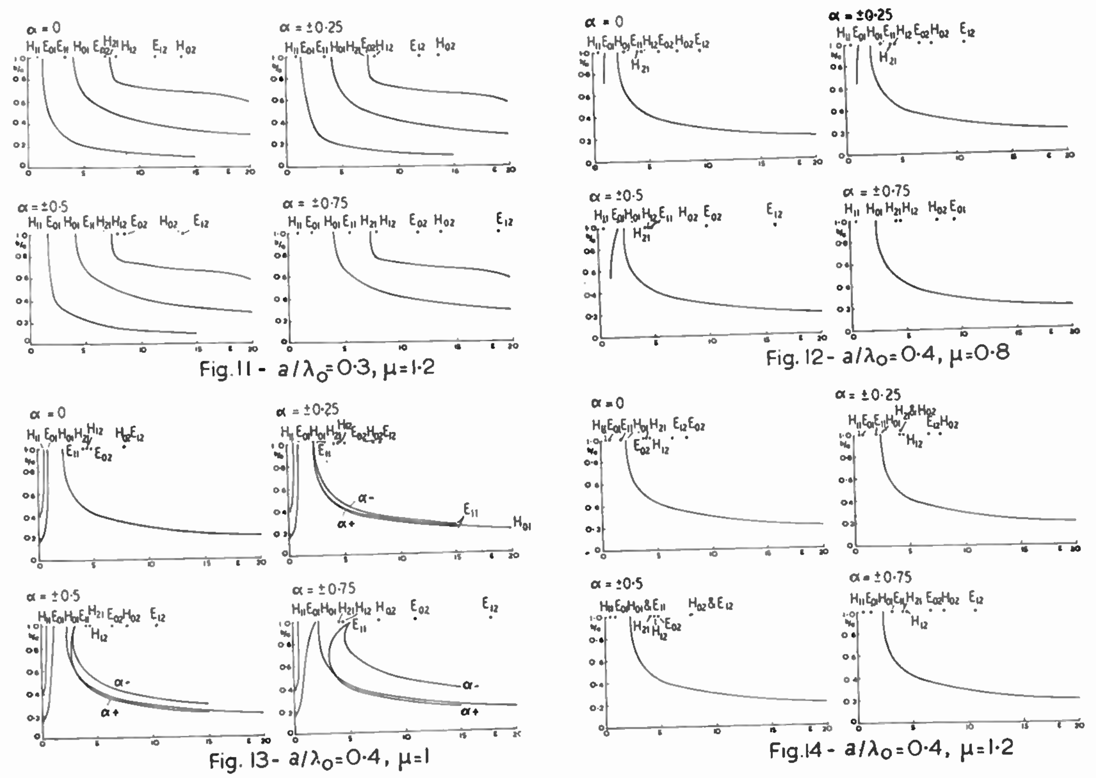


Fig. 10 - $a/\lambda_0 = 0{\cdot}3$, $\mu = 1$



Figs. 3-14. Cut-off curves.

eqn. (52), the term involving Q vanishes if p is zero. p occurs only as the order of a Bessel function and in the term involving Q. The effect of a change in sign of α is to change the sign of the term in Q in eqn. (52). The cut-off curves for the E_{0q} modes are therefore degenerate, but those for the E_{pq} modes ($p \neq 0$) occur in pairs, one curve for positive α and another curve for negative α. If b/a is put equal to unity, eqn. (52) reduces to

$$J_p(A\chi) = 0 \qquad \text{.........(63)}$$

and it is evident that the solutions of this equation are independent of the sign of α, so that the two cut-off curves, for opposite signs of α, obtained for an E_{pq} mode will meet when $b/a = 1$. A final point to notice is that if in eqn. (52) the substitutions $\alpha = 0$, $\mu = 1$, $p = 1$ are made, an equation is obtained which is identical with that obtained from eqn. (53) by putting $p = 0$.

The method of solution of eqns. (52) and (53) is to assign values to the parameters a/λ_0, ε, μ, α, and p. The left-hand sides can then be evaluated for particular values of b/a, and by an iterative process the value of b/a can be obtained for which the left-hand side in question vanishes. The procedure is tedious, but sufficiently simple to be carried out without recourse to an electronic computer. The results are given here both graphically in Figs. 3–14 and numerically in Tables 2 and 3*. These two presentations are complementary, since neither method gives, by itself, all the information that has been obtained. The tables give accurate values of points on the graphs, and indicate the accuracy of values, but the values are not in themselves sufficient to enable all the graphs to be drawn. Curves have sometimes been drawn by reference to other, accurately-drawn, curves, with enough calculated points to determine their positions but not to show clearly their shape. Also, a minimum value of ε has often been inferred from the shape of

* See Part 1.

the curve of the left-hand side of eqn. (52) against b/a. For example, in Fig. 9, with $\alpha = -0{\cdot}5$, values of b/a were calculated for the E_{01} mode for $\varepsilon = 2{\cdot}5$. When the left-hand side of eqn. (52) was plotted against b/a for $\varepsilon = 2{\cdot}0$, a minimum value was found which just failed to cross the zero, from which it was inferred that the cut-off curve fails to reach the value $\varepsilon = 2{\cdot}0$, but that the minimum value of ε that is reached is only slightly above 2·0. In this sort of way, minimum values of ε are indicated in the graphs, but there is not sufficient information in the tables to enable the graphs to be drawn in the neighbourhood of the lowest values of ε. The accuracy of the minimum values of ε in the E-mode curves is better than $\pm 0{\cdot}5$ in ε.

It might be expected that the value of ε in the filled guide would be a minimum, and that for values of b/a decreasing from unity the values of ε would increase monotonically. This is found to be the case for H-modes, but not, in general, for E-modes. For sufficiently small values of μ and sufficiently large values of $|\alpha|$ the cut-off curves for E-modes exhibit a bulge, so that ε takes values smaller than its value in the filled guide. Over the range of values for ε for which this effect occurs, b/a is double valued, i.e. there are two values of b/a for which $\bar{\beta}$ is zero. It may thus be expected that under these conditions the curve of $\bar{\beta}$ against b/a will increase from zero, reach a maximum, and return again to zero. There must also be intermediate cases in which the value of $\bar{\beta}$ rises to a maximum as b/a increases, then starts to fall, but has not yet reached zero when b/a reaches unity. These expectations are fulfilled by the results of Section 8 (see, e.g., Table 5(*d*), for $\alpha = \pm 0{\cdot}25$, and Table 6(*e*), for $\alpha = \pm 0{\cdot}5$).*

In many cases it has not been thought worth while to plot complete curves of b/a against ε, and only the value of ε for $b/a = 1$ is indicated. For $a/\lambda_0 = 0{\cdot}1$ (Figs. 3, 4 and 5) and $a/\lambda_0 = 0{\cdot}2$ (Figs. 6, 7 and 8), all modes which can occur for $\varepsilon < 20$ are indicated. For $a/\lambda_0 = 0{\cdot}3$ (Figs. 9, 10 and 11) and $a/\lambda_0 = 0{\cdot}4$ (Figs. 12, 13 and 14), not all modes are indicated, but any modes not indicated will have a value of ε in the filled guide at least as great as the value for the highest indicated mode. Disregarding the H_{0q} and E_{0q} modes, it is clear that the second mode is the E_{11} mode. Where this mode occurs for values of ε less than 20, the cut-off curves are given for $\mu = 1$, and for $\mu = 0{\cdot}8$ in the case of $a/\lambda_0 = 0{\cdot}2$. A fair estimate of their positions for $\mu = 0{\cdot}8$, $a/\lambda_0 = 0{\cdot}3$ and 0·4, and for $\mu = 1{\cdot}2$, can be made from these data and the given values of ε for $b/a = 1$.

For sufficiently large values of a/λ_0, the H_{11} mode propagates in the empty guide. In this case, a value of ε less than unity is found for $b/a = 1$. On tracing the cut-off curve, it is found that as b/a decreases, the value of ε also decreases, reaching zero for some value of b/a. This is illustrated for the case $a/\lambda_0 = 0{\cdot}4$, $\mu = 1$ (Fig. 13). It would be possible to create a situation with ε less than 1 in practice by surrounding the ferrite with a dielectric of higher permittivity, so that the case $\varepsilon < 1$ is not without practical interest. But the condition $\varepsilon \sim 0$ is one that is not likely to be imitated; a substance would only be found with a dielectric constant which showed a zero in the case of anomalous dispersion, and we may therefore expect the phenomenon to be accompanied by heavy losses. Since we are specifically treating the lossless case, the results for ε near zero are not reliable.

The cut-off curves divide the b/a, ε plane into two regions; to the right of the curve, propagation can take place in the appropriate mode; to the left, propagation cannot take place. When $\varepsilon = 1$, $\mu = 1$, and $\alpha = 0$, the conditions are those of the empty guide, and if propagation takes place for $b/a = 0$ it is to be expected that the cut-off curve will not cross the line $\varepsilon = 1$, nor reach the value $b/a = 0$. This is seen to be the case for the H_{11} mode (Fig. 13).

It is also possible for the E_{01} mode to propagate in the empty guide when a/λ_0 is sufficiently large. When $\mu = 1$ and $\alpha = 0$, the cut-off curves behave similarly to those for the H_{11} mode, but when μ and α take different values different curves are obtained, and in particular the value of ε for $b/a = 1$ depends on μ and α. As α gets further from zero, or as μ decreases below unity, this value of ε increases, and can take values above unity. Under these conditions it is found that the cut-off curves cross the line $\varepsilon = 1$ and

* Tables 4—7 are reproduced at the end of this Part.

reach the value $\varepsilon=0$ for some value of b/a (see Fig. 13). This is not surprising; when μ differs from unity or α from zero, the condition $\varepsilon=1$ is not equivalent to the empty guide, so that the above argument for the cut-off curve not passing through the value $\varepsilon=1$ no longer applies. Rather, if $\alpha=0$, we may expect that it is the condition $\varepsilon\mu=1$ instead of $\varepsilon=1$ that is critical, and we may notice in Figs. 12, 13 and 14 that for $\alpha=0$ the value of ε in the filled guide is in each case such as to give the same value for $\varepsilon\mu$; this value is less than 1. The evaluation of a critical value of ε will be more complicated when α differs from zero; we shall not go into this question in the present paper.

There is some academic interest in discussing the behaviour of the cut-off curves in the neighbourhood of $\varepsilon=0$. For the H_{11} mode, eqn. (53) reduces to the approximate form

$$B\varepsilon \begin{vmatrix} J_1'(A) & Y_1'(A) \\ J_1'(B) & Y_1'(B) \end{vmatrix} - \begin{vmatrix} J_1'(A) & Y_1'(A) \\ J_1(B) & Y_1(B) \end{vmatrix} = 0 \quad \text{.........(64)}$$

When ε is zero, the value of b/a which satisfies eqn. (53) is given (exactly) by

$$\begin{vmatrix} J_1'(A) & Y_1'(A) \\ J_1(B) & Y_1(B) \end{vmatrix} = 0 \quad \text{.........(65)}$$

and so is independent of the properties of the ferrite. For the E_{11} mode, eqn. (52) reduces to the approximate form

$$\begin{vmatrix} J_0(A) & Y_0(A) \\ J_1(B) & Y_1(B) \end{vmatrix} - \frac{B\varepsilon}{2} \begin{vmatrix} J_0(A) & Y_0(A) \\ J_0(B) & Y_0(B) \end{vmatrix} = 0 \quad \text{.........(66)}$$

from which it is seen that for small ε the cut-off curves are independent of μ and α, and the value of b/a for $\varepsilon=0$, given (exactly) by

$$\begin{vmatrix} J_0(A) & Y_0(A) \\ J_1(B) & Y_1(B) \end{vmatrix} = 0, \quad \text{.........(67)}$$

is thus independent of the properties of the ferrite.

Let us now consider the behaviour of an H-mode cut-off curve when a/λ_0 is of such a value that $\bar{\beta}=0$ (both real and imaginary parts vanish) in the empty guide, i.e. the empty guide is working at its cut-off frequency. When a/λ_0 is below this critical value, a curve will be obtained starting, for $b/a=1$, with $\varepsilon > 1$, and as ε approaches infinity this curve will approach the value $b/a=0$. For a value of a/λ_0 sufficiently close to the critical value, but still below it, a value of ε can be found, exceeding unity by an arbitrarily small amount, together with an arbitrarily small value of b/a, such that propagation can take place. Thus in the limit as a/λ_0 approaches the critical value, it may be expected that the cut-off curve will approach the pair of straight lines $\varepsilon=1$, $b/a=0$, the latter being taken over the range $\varepsilon>1$; at the critical value of a/λ_0 we may say that the propagation region is the b/a, ε plane to the right of the line $\varepsilon=1$. Similarly, as a/λ_0 approaches the critical value from above, we may expect that the cut-off curve will approach the pair of straight lines $\varepsilon=1$, $b/a=0$, the latter being taken over the range $\varepsilon<1$, so marking out the region of the b/a, ε plane to the left of the line $\varepsilon=1$ as the non-propagation region. This discussion applies equally to E-modes when $\alpha=0$, if the line $\varepsilon=1/\mu$ is substituted for the line $\varepsilon=1$. If α is not zero, similar arguments will apply, but the limit of the cut-off curve as a/λ_0 approaches its critical value will perhaps be more complicated in form, and it is not certain without carrying out some analysis just how it will behave. This point will not be discussed further in the present paper.

An interesting feature of the E_{pq} modes, when p is not zero, is that, by virtue of the splitting of the cut-off curves, when α is different from zero, according to the sign of α, there is a substantial region of the b/a, ε plane, especially for large values of α, over which one helically-polarized mode propagates and not the other. With a positive polarizing field, it is the left-handed mode that can propagate in the absence of the right-handed mode, and on changing the direction of the polarizing field the situation is reversed. It is doubtful whether this phenomenon is of any value as a method of generating helically-polarized waves, because the behaviour of a physical system designed to exhibit it would be complicated by the presence of the H_{11} mode.

7.9. *Cut-off Curves for Large Values of a/λ_0*

The curves drawn in Fig. 2 are for the case $a/\lambda_0=0{\cdot}2$, when no propagation takes place in the absence of ferrite. Let us now consider what happens when a/λ_0 increases until propa-

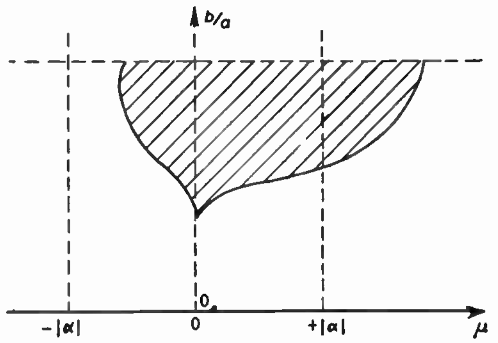


Fig. 15. Form of the cut-off curve for E_{0q} modes when the guide is sufficiently large to support the mode when empty. The shaded region is that in which the propagation does not take place.

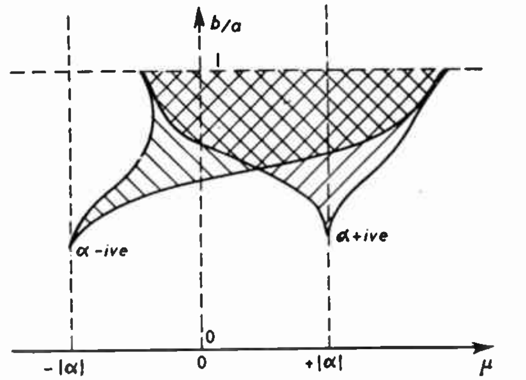


Fig. 16. Form of the cut-off curves for an E_{0q} mode ($p \neq 0$) when the guide is sufficiently large to support the mode when empty. The shaded regions indicate that no propagation can take place; the two types of shading indicate the two senses of circular polarization.

These curves are only roughly sketched.

gation does take place in the absence of ferrite. Firstly, as a/λ_0 increases, horizontal lines, corresponding to H-modes, will move down the plane of Fig. 2 from $b/a=1$ to $b/a=0$; after such a line reaches $b/a=0$, the value of $\bar{\beta}$ in the guide with no ferrite will be finite and, of course, independent of the properties of the ferrite. If b/a is allowed to increase from zero, the way in which $\bar{\beta}$ varies will depend on the values of ε, μ, and α; in some cases it will increase, in others decrease. Fig. 13 for example, indicates that for a sufficiently small value of ε there will be a cut-off line b/a=constant for the H_{11} mode, so that the value of $\bar{\beta}$ will decrease from its value at $b/a=0$ to zero at this cut-off value. The existence or non-existence of this cut-off is independent of μ or α, but except at cut-off it is to be expected that the value of $\bar{\beta}$ will depend, in general, on μ and α.

Let us now consider the behaviour of an E-mode cut-off curve when a/λ_0 is sufficiently large for propagation to take place in the absence of ferrite. The general behaviour will be the same for all modes, except that the line $\mu=0$ plays the same part for the E_{0q} modes as the lines $\mu=\pm|\alpha|$ for the E_{pq} modes ($p\neq 0$). We shall therefore limit the present discussion to the E_{01} mode. Referring to eqn. (60), it is apparent that whatever the value of a/λ_0 there are always solutions for μ in the filled guide, and always the primary solution has μ positive and greater than $|\alpha|$, while the secondary solution has μ negative and $|\mu|<|\alpha|$. The curves which emanate from the points corresponding to the filled guide solutions do not reach the line $b/a=0$. A little consideration shows that the primary curve cannot behave as in Fig. 2; it must move not to the right but to the left as b/a becomes smaller. If we refer to Figs. 12, 13 and 14, for the case $\alpha=-0{\cdot}5$, it is apparent that for a given value of ε, say unity, the value of b/a on the cut-off curve decreases as μ decreases; we shall prefer to say that μ decreases as b/a decreases. Also, for given values of ε and μ, there is only one value of b/a on the cut-off curve, so that having started to move leftwards in the b/a, μ plane as b/a decreases, the curve does not change direction later and move to the right. This behaviour is different from that illustrated in Fig. 2 for $a/\lambda_0=0{\cdot}2$, where propagation does not take place for $b/a=0$. We may also remark that it is the region below the primary cut-off curve in which propagation takes place.

If eqn. (61) is examined, for large A, it is seen that there is a value of B, smaller than A, for which the determinant

$$\begin{vmatrix} J_0(A) & Y_0(A) \\ J_0(B) & Y_0(B) \end{vmatrix}$$

vanishes. For this value of B, the equation reduces to

$$J_0(B\chi)=0 \qquad \text{.........(68)}$$

and this equation holds for both the primary and secondary curves. It is satisfied by $\mu=0$, when χ becomes infinite, for all E_{0q} modes. It may therefore be expected that the primary and secondary curves meet at $\mu=0$, although without going more deeply into the analysis it cannot be said whether they join smoothly or form a cusp. This, however, is immaterial for a qualitative discussion. The main point to notice is that the curves mark off a region in the b/a, μ plane for which propagation does not take place. On the assumption that the two curves meet in a cusp, a rough sketch is given in Fig. 15. The shaded region is that for which propagation does not take place in this mode. Fig. 16 shows similar curves for an E_{pq} mode ($p\neq0$).

7.10. *Effect of Varying the Polarizing Field*

Figure 1* shows the dependence of μ and α on the polarizing field. σ is the normalized field, and p is the normalized saturation magnetization. This p should not be confused with the p that expresses the θ-dependence of electromagnetic fields. These curves are drawn according to Polder's equations[1]. For small polarizing fields, $\mu\sim1$, and provided magnetic saturation has been reached α has some value below zero. Certain of the lowest modes are then able to propagate; which these are can be decided by referring to Figs. 3 to 14.

As the polarizing field is increased, μ falls, $|\alpha|$ increases, and eventually a point is reached at which $\mu=|\alpha|$. All E-modes for which propagation does not take place in the absence of ferrite have now ceased to propagate. When the point is reached at which $\mu=|\alpha|$, all these E-modes, except E_{0q} modes, suddenly start to propagate with one sense of helical polarization —right-handed if the polarizing field is in the negative z direction, i.e. in the opposite sense to the direction of propagation. As σ increases further, these modes cease to propagate one by one as the secondary cut-off curves are crossed.

* Fig. 1. was reproduced in Part 1.

μ eventually falls below zero, and suddenly at $\mu=0$ all those E_{0q} modes which do not propagate when there is no ferrite in the guide start to propagate. These cease to propagate one by one as μ falls further, and the E_{pq} modes ($p\neq0$) start to propagate one by one, with the opposite sense of helical polarization to that which they had when μ was positive and less than $|\alpha|$. μ can never reach the value $-|\alpha|$; as σ passes through the value unity, μ and α change quickly to high positive values, and also μ is now greater than $|\alpha|$. The effects described above are suddenly reversed, the changes being compressed into a narrow range of values of σ near unity. As σ increases still further, μ and α decrease; as they approach unity and zero, respectively, the E-modes which are liable to propagate are as indicated by Figs. 3 to 14.

For an E-mode which propagate in the empty guide, the behaviour will be different. If b/a is sufficiently small, propagation will take place for all values of σ. If b/a is higher, there will be a range of values of σ for which the mode does not propagate; this range of values is that for which μ and α take such values as to give rise to regions in the b/a, μ plane, for given α, such as those shaded in Figs. 15 and 16.

For H-modes, since the cut-off curves are independent of μ and α, propagation will or will not take place for all values of σ according as it does or does not take place when σ is zero.

It should be noted that the interpretation of the cut-off curves in Section 7.7 is open to some doubt. The descriptions given in the present Section depend on the correctness of the assumptions made in Section 7.7.

References (Part 2)

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The third and final part of this paper will be published in the December issue.

The following tables will also be discussed in Part 3 of the paper.

Table 4: Phase Constants $a/\lambda_0=0{\cdot}1$

(a) H_{11} Mode, $\mu = 1$

$\bar\beta$	Values of b/a, ε = 10, α = −0.5	α = 0	α = +0.5
0	0.978	0.978	0.978
0.125	0.978	0.977	0.977
0.375	0.982	0.980	0.979
0.625	0.989	0.984	0.982
0.875		0.990	0.986
0.880	1		
1.125		0.998	0.992
1.189		1	
1.375			0.998
1.411			1

$\bar\beta$	Values of b/a, ε = 15, α = −0.5	α = 0	α = +0.5
0	0.931	0.931	0.931
0.125	0.930	0.930	0.930
0.375	0.934	0.931	0.930
0.625	0.941	0.935	0.931
0.875	0.952	0.940	0.934
1.125	0.964	0.947	0.937
1.375	0.977	0.955	0.941
1.625	0.989	0.965	0.948
1.875		0.975	0.956
1.881	1		
2.125		0.986	0.965
2.375		0.995	0.976
2.532		1	
2.625			0.986
2.875			0.995
3.017			1

Table 5: Phase Constants, $a/\lambda_0=0{\cdot}2$, $\mu=0{\cdot}8$

(a) H_{11} Mode, ε = 5

b/a	Values of $\bar\beta$: α = −0.5	α = −0.25	α = 0	α = +0.25	α = +0.5
0.632	0	0	0	0	0
0.634				0.125	0.125
0.65	0.196	0.232	0.274	0.326	0.388
0.7	0.383	0.461	0.552	0.662	0.789
0.75	0.507	0.620	0.748	0.895	1.057
0.8	0.610	0.755	0.911	1.083	1.261
0.85	0.703	0.880	1.057	1.241	1.427
0.9	0.793	1.002	1.194	1.383	1.570
0.95	0.885	1.132	1.336	1.525	1.707
1	0.987	1.291	1.510	1.696	1.868

(b) H_{11} Mode, ε = 10

α = −0.5		α = −0.25		α = 0		α = +0.25		α = +0.5	
b/a	$\bar\beta$	b/a	$\bar\beta$	b/a	$\bar\beta$	b/a	$\bar\beta$	b/a	
0.546	0	0.546	0	0.546	0	0.546	0	0.546	0
0.550	0.125	0.548	0.125	0.546	0.125	0.545	0.125	0.544	0.125
0.589	0.375	0.571	0.375	0.556	0.375	0.544	0.375	0.537	0.375
0.6	0.420	0.6	0.570	0.571	0.625	0.547	0.625	0.533	0.625
0.65	0.594	0.65	0.847	0.592	0.875	0.555	0.875	0.534	0.875
0.7	0.740	0.7	1.076	0.620	1.125	0.569	1.125	0.541	1.125
0.75	0.873	0.75	1.265	0.657	1.375	0.591	1.375	0.554	1.375
0.8	1.000	0.8	1.421	0.710	1.625	0.6	1.455	0.573	1.625
				0.787	1.875	0.65	1.801	0.6	1.865
						0.7	2.033	0.65	2.185
						0.75	2.202	0.7	2.407
						0.8	2.332	0.75	2.571
								0.8	2.697

(c) H_{11} Mode, ε = 15

α = −0.5		α = −0.25		α = 0		α = +0.25		α = +0.5	
b/a	$\bar\beta$	b/a	$\bar\beta$	b/a	$\bar\beta$	b/a	$\bar\beta$	b/a	
0.514	0	0.514	0	0.514	0	0.514	0	0.514	0
0.517	0.125	0.515	0.125	0.511	0.125	0.507	0.125	0.506	0.125
0.547	0.375	0.524	0.375	0.500	0.375	0.485	0.375	0.479	0.375
0.55	0.387	0.538	0.625	0.495	0.625	0.472	0.625	0.460	0.625
0.6	0.628	0.55	0.797	0.497	0.875	0.467	0.875	0.451	0.875
0.65	0.830	0.6	1.298	0.505	1.125	0.469	1.125	0.449	1.125
		0.65	1.602	0.519	1.375	0.475	1.375	0.452	1.375
				0.539	1.625	0.487	1.625	0.459	1.625
				0.567	1.875	0.503	1.875	0.469	1.875
				0.607	2.125	0.525	2.125	0.483	2.125
				0.663	2.375	0.55	2.336	0.502	2.375
						0.6	2.648	0.527	2.625
						0.65	2.865	0.55	2.802
								0.560	2.875
								0.6	3.101
								0.65	3.314

(d) E_{01} Mode, ε = 5

b/a	Values of $\bar\beta$: α = 0	α = ± 0.25
0.52	0	
0.54		0
0.55	0.201	0.102
0.6	0.319	0.255
0.65	0.389	0.326
0.7	0.438	0.368
0.75	0.474	0.393
0.8	0.501	0.401
0.85	0.523	0.391
0.9	0.540	0.355
0.95	0.558	0.257
0.99		0
1	0.581	

(e) E_{01} Mode, ε = 10

b/a	Values of $\bar\beta$: α = 0	α = ±0.25	α = ±0.5
0.26	0		
0.27		0	0
0.3	0.362	0.344	0.283
0.35	0.536	0.520	0.472
0.4	0.639	0.622	0.573
0.45	0.711	0.694	0.641
0.5	0.769	0.750	0.690
0.55	0.819	0.797	0.731
0.6	0.867	0.843	0.769
0.65	0.916	0.890	0.811
0.7	0.971	0.947	0.870
0.75	1.036	1.021	0.972
0.8	1.119	1.121	1.129

Table 6: Phase Constants $a/\lambda_0=0{\cdot}2$, $\mu=1$

(a) H_{11} Mode, ε = 3

b/a	Values of $\bar\beta$: α = −0.75	α = −0.5	α = −0.25	α = 0	α = +0.25	α = +0.5	α = +0.75
0.75	0	0	0	0	0	0	0
0.8	0.171	0.210	0.244	0.277	0.310	0.344	0.378
0.85	0.298	0.372	0.436	0.495	0.553	0.611	0.670
0.9	0.381	0.488	0.575	0.653	0.726	0.798	0.866
0.95	0.445	0.589	0.698	0.790	0.874	0.954	1.032
1	0.496	0.684	0.818	0.923	1.014	1.098	1.179

(b) H_{11} Mode, ε = 5

b/a	Values of $\bar\beta$: α = −0.75	α = −0.5	α = −0.25	α = 0	α = +0.25	α = +0.5	α = +0.75
0.632	0	0	0	0	0	0	0
0.632						0.125	0.125
0.632						0.375	
0.634				0.125			
0.640							0.375
0.65	0.189	0.225	0.265	0.315	0.379	0.459	0.556
0.7	0.369	0.445	0.533	0.639	0.769	0.917	1.071
0.75	0.487	0.598	0.721	0.865	1.029	1.202	1.371
0.8	0.583	0.728	0.880	1.048	1.228	1.410	1.585
0.85	0.669	0.849	1.023	1.204	1.390	1.574	1.750
0.9	0.751	0.969	1.161	1.348	1.533	1.714	1.887
0.95	0.831	1.099	1.309	1.496	1.676	1.849	2.017
1	0.915	1.259	1.498	1.689	1.858	2.018	2.173

Table 6 (*cont.*)

(c) H_{11} Mode, $\epsilon = 10$

b/a	Values of $\bar{\beta}$						
	α = −0.75	α = −0.5	α = −0.25	α = 0	α = +0.25	α = +0.5	α = +0.75
0.546	0	0	0	0	0	0	0
0.545				0.125			
0.544				0.375			
0.543					0.125		
0.542						0.125	0.125
0.534					0.375		
0.529						0.375	
0.528					0.625		
0.526							0.375
0.517						0.625	
0.513						0.875	
0.512							0.625
0.504							0.875
0.504							1.125
0.508							1.375
0.516						1.125	
0.518							1.625
0.524						1.375	
0.529					0.875		
0.533							1.875
0.536					1.125		
0.538						1.625	
0.547			0.125	0.625			
0.548		0.125					
0.550	0.125				1.375		
0.554							2.125
0.555				0.875			
0.558			0.375				
0.559						1.875	
0.571				1.125	1.625		
0.574		0.375					
0.576			0.625				
0.581							2.375
0.587						2.125	
0.592	0.375						
0.594				1.375			
0.6	0.402	0.529	0.872	1.425	1.869	2.219	2.510
0.65	0.565	0.777	1.247	1.758	2.166	2.503	2.794
0.7	0.701	0.989	1.499	1.980	2.373	2.706	2.998
0.75	0.824	1.169	1.680	2.142	2.526	2.858	3.153
0.8	0.942	1.324	1.820	2.266	2.644	2.975	3.272
0.85	1.062	1.463	1.935	2.365	2.737	3.068	3.366
0.9		1.603	2.042	2.452	2.817	3.144	
0.95		1.775	2.171	2.549	2.898	3.216	
1			2.499	2.802	3.091	3.371	

(d) H_{11} Mode, $\epsilon = 15$

b/a	Values of $\bar{\beta}$						
	α = −0.75	α = −0.5	α = −0.25	α = 0	α = +0.25	α = +0.5	α = +0.75
0.514	0	0	0	0	0	0	0
0.511			0.125				
0.504				0.125			
0.501			0.375				0.125
0.498					0.125		
0.497			0.625				
0.479				0.375			
0.467				0.625	0.375		
0.464							0.375
0.463				0.875		0.375	
0.450					0.625		
0.442					0.875	0.625	
0.440							0.625
0.431						0.875	
0.428						1.125	
0.427							0.875
0.421							1.125
0.419							1.375
0.422							1.625
0.427							1.875
0.428						1.375	
0.433						1.625	
0.435							2.125
0.440						1.875	
0.441					1.125		
0.445					1.375		2.375
0.451						2.125	
0.452					1.625		
0.459							2.625
0.464					1.875		
0.466				1.125		2.375	
0.473				1.375			
0.476							2.875
0.479					2.125		
0.484						2.625	
0.486				1.625			
0.498							3.125
0.500					2.375		
0.501			0.875				
0.504				1.875			
0.508						2.875	
0.510			1.125				
0.515		0.125					
0.518	0.125						
0.526			1.375				3.375
0.527					2.625		
0.528		0.375		2.125			
0.539						3.125	
0.55	0.365	0.645	1.635	2.301	2.791	3.194	3.544
0.6	0.584	1.126	1.996	2.597	3.068	3.468	3.822
0.65	0.762	1.441	2.232	2.804	3.268	3.668	4.026
0.7	0.928	1.658	2.401	2.957	3.470	3.819	4.181

(e) E_{01} Mode, $\epsilon = 5$

b/a	Values of $\bar{\beta}$		
	α = 0	α = ±0.25	α = ±0.5
0.486	0		
0.495		0	
0.5	0.171		
0.534			0
0.55	0.347	0.309	0.146
0.6	0.448	0.412	0.281
0.65	0.524	0.486	0.352
0.7	0.589	0.547	0.399
0.75	0.649	0.601	0.430
0.8	0.711	0.656	0.449
0.85	0.780	0.715	0.457
0.9	0.866	0.787	0.451
0.95	0.980	0.884	0.421
1.0	1.157	1.035	0.334

(f) E_{01} Mode, $\epsilon = 10$

b/a	Values of $\bar{\beta}$			
	α = 0	α = ±0.25	α = ±0.5	α = ±0.75
0.261	0			
0.263		0		
0.269			0	
0.280				0
0.3	0.407	0.394	0.351	0.269
0.35	0.576	0.564	0.527	0.462
0.4	0.681	0.668	0.629	0.563
0.45	0.760	0.745	0.702	0.630
0.5	0.825	0.809	0.760	0.679
0.55	0.887	0.868	0.812	0.720
0.6	0.949	0.928	0.865	0.759
0.65	1.017	0.994	0.926	0.808
0.7	1.097	1.076	1.011	0.892
0.75	1.197	1.183	1.142	1.067
0.8	1.323	1.324	1.329	1.338
0.85	1.483	1.499	1.545	
0.9	1.686	1.708	1.767	
0.95	1.960	1.974	2.015	
1	2.517	2.501	2.464	

(g) E_{01} Mode, $\epsilon = 15$

b/a	Values of $\bar{\beta}$	
	α = 0	α = ±0.5
0.195	0	
0.199		0
0.25	0.547	0.510
0.3	0.695	0.658
0.35	0.799	0.748
0.4	0.861	0.813
0.45	0.923	0.868
0.5	0.985	0.926
0.55	1.052	1.030
0.6	1.134	
0.65	1.242	
0.7	1.389	

Table 6 (*cont.*)

(h) H_{01} Mode, ϵ = 10

b/a	Values of $\bar{\beta}$			
	a = 0	a = ±0.25	a = ±0.5	a = ±0.75
0.781	0	0	0	0
0.8	0.384	0.375	0.344	0.280
0.85	0.668	0.643	0.564	0.414
0.9	0.787	0.753	0.644	0.423
0.95	0.831	0.796	0.674	
1	0.838	0.807	0.684	0.30

(i) E_{11} Mode, ϵ = 10

b/a	Values of $\bar{\beta}$		
	a = −0.25	a = 0	a = +0.25
0.781		0	
0.8		0.178	
0.819			0
0.85		0.346	0.156
0.860		0.375	
0.877	0		
0.9	0.169	0.470	0.229
0.95	0.265	0.603	0.260
1	0.283	0.838	0.283

(j) E_{11} Mode, ϵ = 15

b/a	Values of $\bar{\beta}$		
	a = −0.25	a = 0	a = +0.25
0.537			0
0.546		0	
0.582	0		
0.625		0.375	
0.633			0.375
0.638	0.375		
0.703		0.625	
0.705	0.625		
0.726			0.625
0.772	0.875		
0.779		0.875	
0.820			0.875
0.832	1.125		
0.848		1.125	
0.887	1.375		
0.899			1.125
0.906		1.375	
0.946			1.375
0.947		1.625	
0.972			1.625
0.974		1.875	
0.987			1.875
0.989		2.125	
0.996			2.125

Table 7: Phase Constants, a/λ_0, $\mu = 1{\cdot}2$

(a) H_{11} Mode, ϵ = 5

b/a	Values of $\bar{\beta}$				
	a = −0.5	a = −0.25	a = 0	a = +0.25	a = +0.5
0.632	0	0	0	0	0
0.65	0.257	0.304	0.367	0.452	0.563
0.7	0.514	0.616	0.746	0.900	1.068
0.75	0.695	0.834	0.999	1.178	1.358
0.8	0.849	1.013	1.193	1.380	1.562
0.85	0.990	1.168	1.353	1.540	1.720
0.9	1.128	1.313	1.497	1.678	1.854
0.95	1.279	1.468	1.646	1.818	1.985
1	1.478	1.680	1.850	2.006	2.157

(b) H_{11} Mode, ϵ = 10

b/a	Values of $\bar{\beta}$				
	a = −0.5	a = −0.25	a = 0	a = +0.25	a = +0.5
0.546	0	0	0	0	0
0.545		0.125			
0.543			0.125		
0.541				0.125	0.125
0.532			0.375		
0.526			0.625		
0.524				0.375	
0.520					0.375
0.511				0.625	
0.507				0.875	
0.503					0.625
0.495					0.875
0.495					1.125
0.501					1.375
0.510				1.125	
0.511					1.625
0.519				1.375	
0.527			0.875		1.875
0.534				1.625	
0.535			1.125		
0.545		0.375			
0.547	0.125				
0.549		0.625			2.125
0.550			1.375		
0.556				1.875	
0.559		0.875			
0.560	0.375				
0.572			1.625		
0.576		1.125			
0.578					2.375
0.582	0.625				
0.586				2.125	
0.6	0.786	1.365		2.218	2.524
0.604			1.875		
0.648			2.125		
0.65	1.150	1.696		2.485	2.786
0.7	1.402	1.915		2.676	2.977
0.713			2.375		
0.75	1.585	2.074		2.819	3.121
0.8	1.726	2.194		2.929	3.232
0.819			2.625		

(c) H_{11} Mode, ϵ = 15

Values of b/a					$\bar{\beta}$
a = −0.5	a = −0.25	a = 0	a = +0.25	a = +0.5	
0.514	0.514	0.514	0.514	0.514	0
0.511	0.501	0.488	0.482	0.484	0.125
0.504	0.477	0.459	0.450	0.447	0.375
0.503	0.466	0.444	0.432	0.426	0.625
0.508	0.463	0.437	0.423	0.415	0.875
0.519	0.467	0.437	0.420	0.410	1.125
0.537	0.475	0.442	0.422	0.410	1.375
0.55					1.508
	0.489	0.450	0.427	0.413	1.625
	0.508	0.462	0.435	0.419	1.875
0.6					1.882
0.65					2.124
	0.534	0.479	0.447	0.427	2.125
	0.55				2.240
		0.501	0.462	0.438	2.375
	0.6				2.531
		0.530	0.482	0.453	2.625
	0.65				2.734
		0.55			2.813
		0.569	0.507	0.471	2.875
		0.6			3.025
		0.624	0.541	0.495	3.125
			0.55		3.179
		0.65			3.215
			0.6		3.437
				0.55	3.539
			0.65		3.625
				0.6	3.798
				0.65	3.989

(d) E_{01} Mode, ϵ = 5

b/a	Values of $\bar{\beta}$		
	a = 0	a = ±0.25	a = ±0.5
0.46	0		
0.47		0	
0.49			0
0.5	0.312	0.281	0.163
0.55	0.453	0.428	0.343
0.6	0.554	0.529	0.446
0.65	0.639	0.611	0.523
0.7	0.717	0.687	0.589
0.75	0.797	0.763	0.652
0.8	0.885	0.846	0.718
0.85	0.986	0.942	0.793
0.9	1.111	1.061	0.887
0.95	1.277	1.220	1.015
1	1.528	1.461	1.214

(e) E_{01} Mode, ϵ = 10

b/a	Values of $\bar{\beta}$		
	a = 0	a = ±0.25	a = ±0.5
0.25	0		
0.26		0	
0.27			0
0.3	0.449	0.439	0.406
0.35	0.615	0.605	0.575
0.4	0.724	0.713	0.680
0.45	0.809	0.796	0.760
0.5	0.884	0.870	0.827
0.55	0.958	0.941	0.892
0.6	1.037	1.018	0.961
0.65	1.129	1.108	1.045
0.7	1.241	1.221	1.161
0.75	1.281	1.369	1.331
0.8	1.554	1.554	1.556

. . . Radio Engineering Overseas

A selection of abstracts from European and Commonwealth journals received in the Library of the Institution. Members who wish to borrow any of these journals should apply to the Librarian, stating full bibliographical details, i.e. title, author, journal and date, of the paper required. All papers are in the language of the country of origin of the Journal unless otherwise stated. The Institution regrets that translations cannot be supplied.

523.164.3:621.371.095.1:621.3.029.62

The polarization of solar radio emission at a frequency of 200 Mc/s. F. R. Neubauer and A. D. Fokker. *Het P.T.T.-bedrijf,* **8**, No. 4, pp. 177-194, September 1958.

Since the end of 1955 observations concerning the state of polarization of solar radio emission at a frequency of 200 Mc/s have been made by the Ionosphere and Radio Astronomy Section of Netherlands P.T.T. at the receiving station N.E.R.A. Enhanced solar radio emission generally is circularly polarized. All values of the degree of polarization between 0 and 1 do occur. From August 1957 on the observations were made with a receiver which is designed as to make possible a complete measurement of the state of polarization, including a linearly polarized component, if present. Although the calibration of the linear polarimeter still meets some difficulties, the circular part of the polarimeter nevertheless yields reliable and interesting results.

523.164.32.029.64

Impulsive and long-enduring sudden enhancements of solar radio emission at 10 centimetre wavelength. A. E. Covington and G. A. Harvey. *The Journal of the Royal Astronomical Society of Canada,* **52**, pp. 161-166, April 1958.

The two basic types of simple 10-cm enhancements of solar radio emission are described and related to suggested non-thermal mechanisms of emission.

536.52:621.383:621.314.7:621.385.1

An experimental pyrometer using a phototransistor and designed for radio-tube inspection. F. H. R. Almer and P. G. van Zanten. *Philips' Technical Review,* **20**, No. 4, pp. 89-93, October 1958.

The radiation-sensitive element in the pyrometer described here is a photo-transistor, the radiation sensitivity of which has a maximum at a wavelength of 1·55 microns. A lens projects an image of the same size as the object on to a diaphragm mounted in front of the transistor. The opening in the diaphragm has a diameter of only 0·6 mm., thus permitting very localized measurements of the temperature at points on the object. A rotating disc chops the beam 175 times per second. The variations in the current through the transistor undergo linear amplification in a narrow-band amplifier covering frequencies only between 165 and 183 c/s. The lowest apparent temperature that can be measured is determined by the noise arising in the transistor, and is about 200°C. The apparatus is capable of an accuracy of about 1°C. It is possible to measure the temperature of objects behind glass. In the range between 500 and 1000°K the pyrometer may be regarded as sensitive only to radiation of wavelength 1·51 microns.

538.221

The magnetic fields of a ferrite ellipsoid. R. A. Hurd. *Canadian Journal of Physics,* **36**, pp. 1072-1083, 1958.

Approximate expressions are found for the internal and the adjacent external magnetic fields of a small ferrite ellipsoid under plane wave excitation. Consideration is given to the variation of apparent susceptibility with the size of the ferrite.

538.221

Scattering from a small anisotropic ellipsoid. R. A. Hurd. *Canadian Journal of Physics,* **36**, pp. 1058-1071, 1958.

Scattering of an electromagnetic wave by a small ellipsoid having tensor permeability and dielectric properties is dealt with by expanding the fields as power series in λ^{-1}. Consideration has been given to the first three terms of the expansion.

621.315.616.98:621.319.42

A comparison of wool wax and petroleum jelly as impregnants for paper capacitors. J. S. Dryden and R. J. Meakins. *Proceedings of the Institution of Radio Engineers Australia,* **19**, No. 10, pp. 551-553, October 1958.

Impregnation of capacitators with wool wax instead of petroleum jelly increases the capacitance by about 10 per cent. without any serious loss in performance as regards dielectric loss, insulation resistance or dielectric breakdown.

621.371

Observations of multi-path propagation on the short-wave link Osaka-Frankfurt-a-Main. B. Beckmann and K. Vogt. *Nachrichtentechnische Zeitschrift,* **11**, pp. 519-523, October 1958.

The amplitudes and delays on propagation paths of pulse transmission from the short-wave station Osaka are measured at Frankfurt for the direct path and the backward path; the backward scatter of a pulse transmitter at Rugby has been also investigated. The results have been evaluated and related to ionospheric conditions.

621.373.42

Investigation into two-valve oscillators with pi network feedback. Eberhard Frisch. *Archiv der Elektrischen Übertragung,* **12**, pp. 401-406, September 1958.

The paper investigates two-tube oscillator circuits with feedback via a pi network; two types of such oscillator circuits of practical interest are devised. One of these relates to variable-frequency oscillators offering the advantage of the frequency being independent of the input impedance of the applied load. As an example an oscillator is devised that has this property and simultaneously offers the advantage that with actuation of a variable capacitor it can cover an extremely wide range of frequencies. The other type of connection relates to oscillators that behave much like differential-bridge oscillators, but require no transformer and need less gain for their operation.

621.374.32:621.382.3

Fast transistor circuits. M. Combier and J. Mey. *L'Onde Electrique*, **38**, pp. 629-632, August-September 1958.

The authors describe two fast transistor pulse counting circuits. The first is a decade using commercially available h.f. junction transistors. It is capable of counting rate up to 1·6 Mc/s. The second is a flip-flop employing surface-barrier transistors. Its intrinsic resolving time is 0·02 microsec and it can be used periodic counting up to 20 Mc/s.

621.374.44

Delay line frequency dividers and their application to arithmetic. Y. Amran, H. Guillon and B. Ollivier. *L'Onde Electrique*, **38**, pp. 633-640, August-September 1958.

The authors describe the principle of a delay line frequency divider working on pulses, and gives practical examples which have been produced by making a judicious choice of delay lines and electronic tubes. The input frequency can be many tens of Mc/s. One of the main applications envisaged is the rapid numerical coding of a variety of variables, particularly time. An experimental apparatus working on a clock frequency of 20 Mc/s and having a capacity of 120 is described.

621.375.126.018.424.029.4:621.397.6

On the low-frequency behaviour of video-amplifiers. A. P. Bolle. *Het P.T.T.-bedrijf*, **8**, No. 3, pp. 131-141, July 1958.

In this article the low frequency behaviour of video amplifiers is discussed. Special attention has been paid to the so-called "bumping-effect" in the output signal, when the unit-step is applied. The author also deals with the response to a 50 c/s square-wave signal. He indicates designing methods for various circuits in order to obtain a limited bumping percentage.

621.385.38:621.365.5

An experimental induction-heating generator using hydrogen thyratrons. H. L. van der Horst and P. H. G. van Vlodrop. *Philips' Technical Review*, **20**, No. 4, pp. 101-107, October 1958.

Damped oscillations suitable for induction can be generated with a frequency of up to 10 kc/s using a circuit similar in principle to the spark-gap oscillator but with the spark-gap replaced by a hydrogen thyratron. The power can be controlled by varying the repetition frequency of the pulses that ignite the thyratron. A description is given of a control circuit for generating these pulses and for automatically varying the frequency and power. The generator is easier to operate than the types employing a transmitting tube. Other advantages compared with the latter types of generator are that the thyratron requires no forced cooling and that the efficiency is higher.

621.385.831

A very short light pulse generator used for testing photomultipliers. P. Cachon and A. Sarazin. *L'Onde Electrique*, **38**, pp. 617-621, August-September 1958.

A very short light pulse generator. obtained by electronic excitation of the screen of cathode ray tube is used for testing photomultipliers. The shape and position stability of these pulses permit an accurate measurement of transit time and fluctuations. The first results of this study are given.

621.396.677.43

Studies on a rhombic antenna with cylindrical helices as the arms. Ashoke Kumar Sen. *Indian Journal of Physics*, **32**, No. 7, pp. 303-316, July 1958.

The input impedance and the directivity of a rhombic antenna with arms in the form of cylindrical helices of constant pitch angle have been studied. On the basis of certain plausible assumptions, theoretical expressions have been derived to obtain the input impedance and the directivity of the antenna. The results have been compared with experimentally observed values.

621.396.69

Casting lossy microwave parts in resin aids design work. A. Staniforth and K. A. Steele. *Canadian Electronics Engineering*, pp. 16-22, May 1958.

Describes a relatively simple and inexpensive method of producing lossy materials for use in experimental microwave work. Tests using iron powder filler in some of the casting resins have been carried out at the National Research Council Laboratories. The results of these tests are discussed, along with information on the properties of the materials used. Applications of the lossy microwave components in various types of transmission line are then considered.

621.397.132

Gradation correction in colour television. J. Kaashoek. *Nachrichtentechnische Zeitschrift*, **11**, pp. 515-518, October 1958.

The gamma correction method used in black and white television can be applied to colour television only for the purpose of obtaining a linear transmission but not for gamma adjustments because colour distortions will occur in this case. A new circuit is described for obtaining variable gamma corrections which depend on luminance and are free from colour distortion. Any gamma value between 1 and 0·4 can be chosen for the overall system transfer characteristic. The correction can be chosen to be also dependent on colour thus producing a greater relative increase in brightness for picture areas of a chosen colour without any colour change.

621.398:621.396.933

Radio links for the control of aeronautical air-ground-air equipment. W. S. McGuire. *Proceedings of the Institution of Radio Engineers*, **19**, No. 10, pp. 541-550, October 1958.

A multichannel radiotelephone link system is described over which aeronautical air-ground-air transmitters and receivers situated in isolated areas can be controlled. The link equipment is frequency modulated and operates in the 160 and 450 Mc/s bands. The equipment is duplicated and operates in conjunction with an automatic change-over system and alarm circuits. The automatic change-over system functions by means of a circulating pilot tone which locks the working system ON, switches OFF the out-of-service equipment and continuously monitors the system. Dialling facilities are incorporated enabling an Area Control Officer to change-over the air-ground-air equipment by remote control; up to fifty functions may be switched at each station in the chain. Indicator display panels are provided at the airport control centre, and on each rack of equipment to indicate the status of the remote equipment.