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(FOUNDED IN 1925 - INCORPORATED IN 1932)

*"To promote the advancement of radio, electronics and kindred subjects
by the exchange of information in these branches of engineering."*

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30th ANNUAL REPORT OF THE COUNCIL OF THE INSTITUTION

The Council has pleasure in presenting the 30th Annual Report of the Institution which reviews the proceedings for the twelve months ended 31st March, 1956. The Annual General Meeting will be held on Wednesday, October 31st, 1956, at the London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, London, W.C.1.

INTRODUCTION

The year has been noteworthy in the field of technological education. All over the world there has been a tremendous surge of interest in the need to train more engineers and scientific workers in various branches of technology. The *Journal* and meetings of the Institution have served to emphasize the widening scope of radio and electronic engineering; concurrently, the Education Committee of the Institution has devoted much time to reviewing the Graduateship examination syllabus and its relation to the knowledge required by the younger entrant to the profession.

Revision of the Graduateship examination syllabus has been a major task but nevertheless pleasantly rewarded by the favourable comment of technical colleges. Indeed, the increasing number of teaching establishments providing courses covering the syllabus of the examination, or a recognized exempting qualification, augurs well for the future development of the Institution's membership.

As forecast in the last two Annual Reports, the Council has now established a central committee in India with an administrative office in Bangalore. This is a major step toward greater understanding and co-operation between all members of the Institution wherever they may be situated. It is hoped that this enterprise will make a worthy pattern for an extension of such activities.

Due to the burden of increasing costs, many Institutions have experienced financial difficulties during the past year. In a growing organization some uplift in administrative costs must be expected but, in addition to *anticipated* expenditure, rises in postage rates, and further increases in printing and paper charges, placed an added burden on the income of the Institution. The effect of the Rating and Valuation Act, 1955, also threatened an additional cost to the Institution. The section of this report dealing with Institution finances is therefore of particular importance.

Standing Committees have given valuable aid to the Council through their various contributions to Institution activities. The information provided by all the Standing Committees deserves careful study in order to appreciate the indebtedness which the Institution as a whole owes to the many members who give their time to serving on Committees or by representing the Institution on Committees of other bodies.

Finally, the Council is pleased to record that in February last a Grant of Arms was made to the Institution. The Council was especially pleased to approve the design of a shield alluding to the pioneers of the science of radio and electronic engineering. A detailed explanation of the Armorial Bearings will appear in the January, 1957, issue of *J.Brit.I.R.E.*

PROFESSIONAL PURPOSES COMMITTEE

The Institution has always been fortunate in its choice of President, and the Committee feels that the retiring President is particularly deserving of tribute for the time and energy he has devoted to continuing the Institution's efforts to secure harmonious relationship with kindred bodies. Much of this work cannot be related in an Annual Report, but the long term effect of such endeavours will be of benefit to the entire radio engineering profession.

Good relations with other bodies already extend beyond Great Britain, but the Committee has particularly borne in mind the interests of members emigrating to other countries and of members already resident or working overseas. Often the progress of such negotiations is based on the Institution's status within Great Britain itself. On this score a great deal has been accomplished, although there remains some difficulty in obtaining from the Ministry of Labour full recognition of the *independent* status of the radio and electronics engineer.

The Officers of the Institution have, therefore, continued to press the case for a revision of the Technical and Scientific Register. The Institution's viewpoint has been supported by other bodies and by representation within the Scientific Civil Service. Meanwhile, the Appointments Service of the Institution continues to meet adequately the needs of members.

Building Appeal.—The Committee has been responsible for the present Building Appeal and wishes to record its grateful appreciation for the support now being given by many Companies in the British radio industry to the project of acquiring a building in keeping with the dignity and requirements of the Institution. The Accounts do not show, of course, the total value of donations being made by deed of covenant, but including those payments the Appeal has now secured over £20,000. This is less than half the amount needed but with the continuing support of members and the further contributions promised by industry, it is hoped a suitable building will be acquired within the next five years.

To this end, the Council has appointed a permanent Committee who will now be responsible for extending the Appeal and for handling negotiations, when the time comes, for the

acquisition of a suitable building. The principal and urgent requirements are for a lecture theatre, additional library accommodation, and Committee rooms. In addition, adequate space for the machinery and printing equipment necessary to the efficient and economic handling of the Institution's administrative work is essential. All this will take time to organize, but elimination of the use of services outside the scope of the present building will permit of economies and thus strengthen the Institution's finances. A more suitable building will, therefore, be of benefit to the entire membership.

Rating and Valuation Act, 1955.—Under the Scientific Societies Act, 1843, exemption from payment of local rates is granted to "any society instituted for purposes of science, literature, or the fine arts exclusively". During the year, several institutions, notably the Institute of Fuel, made an appeal for exemption under the Act. One difficulty in interpreting the Act is the view of the Lands Tribunal that membership of an Institution is of professional benefit to the member. In the case of the Institute of Fuel, the House of Lords disagreed with the Lands Tribunal on the grounds that if an institution is to pursue efficiently its scientific purpose, it is necessary that its members should attain standards of knowledge and experience which an institution could approve.

The Parliamentary and Scientific Committee has been examining the effect of increased rating on scientific organizations. A representative of the Institution is serving on a special sub-committee appointed for this purpose.

Pending any possible amendment to the Scientific Societies Act, 1843, the Council expresses thanks to the Holborn Borough Council for granting a measure of relief under Section 8 of the Rating and Valuation (Miscellaneous Provisions) Act, 1955.

Publication of Abstracts.—The Committee reviewed the general position and availability of abstracts of published papers of value to the professional radio engineer. The Committee recommended that the Institution should continue to publish, as occasion demanded, abstracts of papers which had been published in the Institution's *Journal* and to extend publication in the *Journal* of other abstracts, particularly of papers published in other languages.

is believed that this service will be especially appreciated by members requiring information rarer than is usually available, and by those members not having ready access to any other published abstracts.

List of Members and Library Catalogue.—High printing costs do not allow frequent publication of a List of Members and Library Catalogue, but arrangements have been made for the publication of a revised List of Members by the late autumn of 1956.

Radio Trades Examination Board.—For some years the annual report has included a reference to the Institution's support of the Radio Trades Examination Board. The formation of the R.T.E.B. was sponsored by the Institution in 1942 as a contribution to the problem of securing the recruitment and technical training of mechanics and technicians. In this and other ways, the Board can provide a useful service for mechanics and technicians who are not, of course, eligible for membership of the Institution and are not catered for in the same way as the professional engineer.

As shown elsewhere in this report, the Board's activities continue to increase and provide an ever growing pool of suitably trained mechanics and technicians. It is therefore a matter of great satisfaction to the Institution that in December last the Board secured incorporation under the Companies Act, 1948.

Extension of Institution Activities.—The Committee has considered several proposals for increasing the services available to members. In particular, there is support for the proposition of establishing Committees or arranging meetings to deal with various specialised aspects of radio and electronic engineering, e.g. industrial electronics. The implementation of such proposals is hindered by the strain that would be placed upon the present staff of the Institution, and lack of accommodation. In addition, any extension of Institution activities is very largely governed by financial considerations; the separate report of the Finance Committee shows the necessity of keeping a tight rein on all expenditure. Nevertheless, in order to provide the services which members already receive, and are entitled to expect, it is not possible to cut expenditure further. Indeed, at a time when there is so

much valuable work for the Institution to do, expenditure is bound to increase.

Many other engineering Institutions have already increased their subscriptions and whilst the Council has for some time resisted proposals for an increase in subscriptions, it is now agreed that some increase is inevitable. For this purpose an Extraordinary General Meeting will be convened, but meanwhile a note of the proposed increases is given in the Finance Section of this report.

Indian Advisory Committee.—Previous reports have indicated the endeavours of the Council to initiate a policy which will provide overseas members with facilities similar to those enjoyed by members living in Great Britain.

In the interest of Indian members, the Council has been pleased to have the assistance of Brigadier B. D. Kapur, who has attended some Council meetings.

In consequence, an agreement was made whereby the Council authorised the formation of an Indian Advisory Committee, with offices in Bangalore. The terms of reference agreed were that the Indian Advisory Committee should comprise a Chairman, nominated by the General Council of the Institution, and the Chairman of the five local Sections of the Institution in India. This Committee may appoint its own Honorary Secretary and the general terms of reference are:—

“To support and assist the Council of the Institution in every way possible in the attainment of its objects as set out in the Institution's Memorandum and Articles of Association and especially to be of service to members resident in India, and to make such reports to the Council of the Institution as are from time to time deemed necessary.”

In pursuance of these agreed terms of reference the Advisory Committee is now responsible for dealing with correspondence from candidates in India wishing to secure membership of the Institution. The final decision on the recommendations for election still rests with the Membership Committee, but the Advisory Committee is responsible for the printing in India of the regulations governing membership and examination, as approved by the Council of the Institution, as well as issuing forms of application and proposal. Similar

assistance is given in making examination arrangements.

The scheme has already worked well in connection with arrangements for holding the Graduateship Examination in India. It is now possible to publish the results of the examinations held in India almost at the same time as the results of candidates writing the examination in Great Britain.

The Indian Advisory Committee is also helping all the Indian Sections to maintain a regular programme of meetings. After a full year's working it is believed that the activities of this Committee will be of marked benefit to all members resident in India.

Honorary Membership.—The Committee last made a recommendation for election to Honorary Membership in 1953. During the year under review the Council unanimously approved the proposal of the Scottish Section that Professor G. W. O. Howe be elected an Honorary Member of the Institution in recognition of his contributions to the advancement of radio science, and in particular for his long series of notable editorial articles in *Wireless Engineer*.

Professor Howe becomes the fifteenth Honorary Member of the Institution and only the fourth to be elected since the end of the second world war.

Honours and Awards to Members.—It is gratifying to note the inclusion of Institution members in the New Year and Birthday Honours List. Mention of such members has already been made in the January and February 1956 *Journals*.

In addition, the Council records with pleasure that two corporate members of the Institution qualified for the new City and Guilds of London Institute Industrial Award (C.G.I.A.) of which mention was made in the May and September 1955 *Journals*.

Grant of Arms.—It is with particular pleasure that the Committee reports that the President received Letters Patent under the hands and seals of Garter, Clarenceux, and Norroy and Ulster Kings of Arms dated 10th February, 1956, by which the Institution was granted Armorial Bearings and Supporters.

In order that all members may be in possession of a coloured copy of the Grant of Arms,

a special supplement will be included in the January 1957 issue of the *Journal*. This will be accompanied by a heraldic description of the Coat of Arms. Meanwhile, it will be of interest to members to note that the Council has been permitted to use Supporters of personal significance and that similarly the shield alludes to the pioneers of radio science in preference to an endeavour to make a direct allusion to the science itself. Thus, there is reference to Clerk Maxwell and Heinrich Hertz, to the Duke of Devonshire, who endowed the Cavendish Laboratory, and to Admiral the Earl Mountbatten of Burma in recognition of his work in the founding of the Institution and his subsequent Presidency.

It was also felt that the Institution might now replace the motto *Pace omnes terras tegemus* and the Coat of Arms shows the Institution's new motto as *Scientia pro hominibus*.

Officers of the Institution and members of Council assisted in much of the detail work, but special thanks are due to Mr. Anthony R. Wagner, C.V.O., Richmond Herald, for his expert advice and assistance.

Institution's Seal.—Consequent upon the grant of a Coat of Arms, the Council has authorised a new Seal to be struck incorporating the Arms of the Institution. Work is also in progress on a new design for the Institution's Certificate of membership.

MEMBERSHIP COMMITTEE

An outstanding feature of the Committee's work during the year has been the examination of 1,066 proposals for election, transfer or reinstatement to the various grades of membership. Although this is a record for the Institution, it is regretted that there has been a decrease in the number of applications for Studentship Registration. Since there has not been any change in the educational requirement for Studentship Registration—broadly that of the General Certificate of Education with appropriate subjects—it is to be hoped that the lower number of applications is incidental and not indicative of any loss in recruitment to the profession.

Table 1 shows the elections and transfers to the various grades of membership which were approved during the year. Those for direct election and transfer to the corporate grades

show an increase on the previous year, but there has been a slight drop in the number of proposals approved for direct election as Associates. This is probably due to the desire of most applicants to secure election as Graduates or Associate Members which requires success in the examination or the possession of alternative qualifications.

Table 2 indicates the increasing growth of membership over the last five years:—

Table 2

Membership Growth over the Last Five Years

<i>As at March 31st</i>	<i>Total Membership</i>	<i>Annual Increase</i>
1952 ...	4,018 ...	384
1953 ...	4,383 ...	365
1954 ...	4,750 ...	367
1955 ...	5,082 ...	332
1956 ...	5,392 ...	310

[The total excludes members who, for various reasons, were suspended as at March 31st.]

Losses.—The losses during 1955-56 were higher than usual but are largely concentrated in the Student grade. This is in accordance with the policy of removing all Students from the Register who fail to qualify for transfer within the specified period of five years. This has the result of maintaining a lively Student membership which is so desirable when it is realised that subscriptions paid by Students do not cover the cost of services rendered.

Since there are now more members approaching the age of retirement, it should be noted that special provision for continuing membership is made by Bye-Law 10, namely:

“Any corporate member or Associate who has reached the age of 60 and has retired from professional practice may apply to the Council to remit his future annual subscription provided that his membership of the Institution has been continuous for at least 20 years. If he desires to continue to receive the *Journal* he can do so on payment of 10s. 6d. per annum.”

Table 1

Statement of Elections and Transfers for the Year Ended March 31st, 1956

	<i>Total considered</i>	Elections and transfers approved						Total
		Member	Associate Member	Com- panion	Associate	Graduate	Student	
Direct elections	711	9	58		37	98	456	658
Proposals for Transfer	330	12	94		31	114		251
Proposals for reinstatement	25		2		4	2	14	22
<i>Totals</i>	1,066	21	154		72	214	470	931

Losses During the Year

Loss by resignation, removal and decease	5	20	2	31	19	293	370
Transfer to other grades		12		27	52	160	251
<i>Totals</i>	5	32	2	58	71	453	621
Net gain in membership	16	122	-2	14	143	17	310

[All the above figures include applicants who accepted an alternative grade of membership to that for which they originally applied. Proposals for re-instatement are also considered in relation to the requirements of the *present* regulations.]

Interest in Membership.—In previous Annual Reports information has been given on the number of enquiries for details of qualifications for membership. The most valuable figure in this regard is of course the number of entries to the Institution's examinations.

In the initial stages of membership, however, an increasing amount of work is being done by Local Section Secretaries. Moreover, the work of attending to enquiries in India is now entirely taken over by the office set up by the Indian Advisory Committee in Bangalore. In addition to all this work now done in India and by Local Sections in Great Britain and overseas, the head office of the Institution has directly received nearly 2,200 enquiries during the 12 months under review, an increase of 400 over the preceding year.

Appointments Register.—Employers are making increasing use of the Institution's Appointments Service and the demand for Graduate and other qualified members cannot nearly be met. Nevertheless, directly through the Register, 259 introductions were made which compares with 217 effected last year.

During the year the Institution has developed the system of circulating to firms on request details of the qualifications and experience of members who have asked to be placed on the registers. This service has been appreciated by members and employers.

Reference has been made in earlier Annual Reports and in editorials to the number of members who have emigrated to Canada, the United States of America and Australia. This emigration has in fact increased and is fostered by the intensive recruiting campaigns which have been conducted by overseas organizations during the last two years.

The assistance of members.—The Committee wishes to thank all those members who have acted as proposers and seconders and who have otherwise rendered valuable assistance in the completion of reference forms and the checking of information submitted by candidates for election.

Mr. H. E. Drew (*Member*) retired from Chairmanship of the Committee in July 1955 and the Council wishes to record its appreciation of his services to the Committee during the last seven years.

EDUCATION AND EXAMINATIONS COMMITTEE

The last examination based on the old syllabus was held in May 1956. This report therefore virtually marks the end of the examination scheme which was first introduced in 1943 and which, apart from the introduction of mathematics as a compulsory subject, has remained sensibly constant for twelve years. As with most professional examinations there has been throughout that time a steady increase in the standard required, but basically the pattern of the examination has remained the same.

The new syllabus and regulations constitute a first step towards the policy of holding the examination in two sections, all parts of each section being taken at one sitting with an opportunity to refer candidates who just fail to reach the standard in any *one* subject. Recommendations at present before Council also provide for the subject of Mathematics being introduced into both Sections A and B instead of only in Section A as at present. This will mean an increase in the standard of mathematical knowledge required, which will not, however, exceed the standard of the exempting qualifications, e.g. B.Sc. Engineering Mathematics and fifth year Higher National Certificate Mathematics.

Exemptions.—The revision of the scheme of the examination has also involved some amendment to the list of qualifications recognised for whole or part exemption from the examination. Full details are given in the 23rd edition of the Regulations now available from the Institution.

During the year, and under the earlier Regulations, 985 applications for exemption were received, of which 128 were granted exemption from the entire examination and 441 were granted partial exemption.

Theses.—There has been an increase in the number of applicants anxious to submit a thesis in lieu of writing the examination. Very few such proposals progressed beyond the stage of submitting a synopsis and most candidates who submitted theses provided disappointing material. Help is given to potential authors, particularly in the form of an Institution leaflet "Notes for the Guidance of Authors". Even so, the majority of candidates failed to appreciate that, in order to be acceptable, a thesis must

describe original work and must *not* be a survey, however good, of some branch of engineering development.

Examination Entries.—The May and November 1955 examinations attracted a record entry of 1,217 candidates, and by March 31st, 1956, there was a total of 761 entries for the May 1956 examination.

This increased number of entries may be partly due to candidates wishing to sit the examination under the old syllabus. It must be emphasized, however, that students who have already engaged on a course to cover the old syllabus will still be covering the bulk of the new syllabus. The main additional requirement in Section A is a more comprehensive study of Physics, which need not materially delay any student who intended taking the examination during the next eighteen months.

The Council accepts the view that in Great Britain especially the number of candidates writing the Institution's Graduateship Examination may lessen with increased facilities for taking alternative qualifications; in particular more university degrees are reaching the required standard in radio and electronic

engineering. Furthermore, there are now more colleges in Great Britain able to submit schemes which permit of the Institution giving exemption to candidates who have completed an appropriate full time or "sandwich" scheme course. These courses must terminate in an examination of a standard broadly equivalent to the Graduateship Examination.

Examination Results.—The past year has continued to show that only approximately 10 per cent. of the candidates writing the examination succeed in wholly satisfying the Institution's requirements. One of the most important reasons for this low percentage is that many candidates who fail in one or more subjects of the examination do not continue their studies.

It may be that this attitude has been partly encouraged by present day opportunities of employment. On an individual subject basis, there has been an improvement in examination results, the percentage of candidates succeeding in the compulsory subjects of mathematics, physics, and radio technology being as high as 40 per cent. As shown in Table 3, many candidates have failed to complete the entire examination and this has resulted in the

Table 3
Summary of Graduateship Examination Results
May 1951 - November 1955

Examination	Entries received	Candidates sitting			Qualifying for Graduateship		
		U.K.	Overseas	Total	U.K.	Overseas	Total
May, 1951	360	109	137	246	30	15	45
Nov., 1951	439	106	156	262	16	11	27
May, 1952	516	134	191	325	20	24	44
Nov., 1952	522	138	191	329	19	14	33
May, 1953	570	139	266	405	17	25	42
Nov., 1953	581	111	303	414	17	13	30
May, 1954	645	135	304	439	20	20	40
Nov., 1954	553	115	281	396	21	19	40
May, 1955	597	147	273	420	25	17	42
Nov., 1955	620	180	269	449	23	23	46

apparently low percentage of only 10 per cent. of candidates completely qualifying.

Examination Prizes.—Council has approved the award of prizes for 1955 to the following:

President's Prize: to A. C. Dev (Student).

S. R. Walker Prize: to G. R. Tyler (now a Graduate).

Audio Frequency Engineering Prize: to N. G. Lolayekar (now an Associate Member).

Electronic Measurements Prize: K. K. Nambiar (Student).

No candidate qualified for the award of the Mountbatten Medal.

The new examination scheme has necessitated revisions to the terms of reference governing the award of the President's Prize, the S. R. Walker Prize and the Mountbatten Medal. The President's Prize will in future be awarded to the candidate first in order of merit of those passing the whole of Section B, and the S. R. Walker Prize will be awarded to the candidate first in order of merit of those who pass the whole of Section A. The candidate who obtains the highest marks in either Section A or B and is serving in the Royal Navy, the Army, or the Royal Air Force at the time of his examination will be eligible for the award of the Mountbatten Medal.

Examiners.—The Council takes this opportunity of recording thanks to the following members of the Institution who, notwithstanding the increasing number of candidates, have enabled the Council to keep to the dates set for the publication of pass lists:—

F. Butler, B.Sc.(Hons.), Member.

D. A. Crowther, B.Sc., Associate Member.

K. W. Cunningham, B.Sc., Associate Member.

K. E. Everett, B.Sc., M.Sc.(Eng.), Associate Member.

D. Fotheringham, B.Sc., Associate Member.

T. D. Humphreys, Member.

J. A. Hutton, B.Sc., Associate Member.

S. Kelly, Member.

K. R. McLachlan, Associate Member.

W. J. Perkins, Associate Member.

E. T. A. Rapson, M.Sc., Member.

H. V. Sims, Associate Member.

P. O. Wymer, B.Sc., Associate Member.

Examination Centres.—Many universities and technical colleges throughout the world now

offer facilities as regular centres for the Graduateship Examination. Considerable assistance has also been given by various Service establishments and the British Council in providing accommodation for candidates not having reasonable access to regular examination centres.

Council expresses thanks to the many authorities concerned for the facilities and accommodation provided.

Careers Guidance and Aids to Training.—

The Committee has proposed the publication of an Institution report on "Visual Aids to the Teaching of Technical Subjects." This will be based on a most useful and well attended discussion meeting held in London during the 1955-56 session. In accordance with a Council recommendation, some Sections also held special meetings to discuss the education and training of the radio engineer. Accounts of two discussion meetings, held in South Wales and London, have been published in the *Journal*.

Numerous enquiries continue to be received from teachers, parents and boys and girls regarding careers in radio engineering. In particular, the Institution has been asked to supply material suitable for display at local careers guidance exhibitions. Accordingly, a poster has been prepared giving a diagrammatic presentation of the training needed for progress in the radio engineering profession and is accompanied by a diagram showing the various fields of work in radio and electronic engineering.

Radio Trades Examination Board.—The Education and Examinations Committee has indirectly assisted in the work of the Radio Trades Examination Board by nominating representatives to the Board's Committees, suggesting examiners, and more particularly, preparing a report on the possible extension of the Board's activities so as to provide specialized examinations in electronic techniques, in addition to the present examinations in radio and television servicing.

The incorporation of the Board in December 1955 and the appropriate licence to omit the word "Limited," recognize the non-profit-making and educational work of the Board. The principal objects stated in the Board's Articles of Association are:—

- (a) The promotion of a high standard of skill and efficiency in the technique and work of persons employed or otherwise engaged as radio mechanics, technicians and tradesmen in the radio and allied trades.
- (b) To organize, hold and conduct from time to time either alone or through or in conjunction with any appropriate body, such trade tests and examinations as to the Association may be deemed necessary or expedient to test or determine the skill and efficiency of such persons in such work.

The Education Committee of the Institution has recommended to the Board that an examination for technicians engaged in electronics should be established on similar lines to the two existing examinations. There will be an increasing need for mechanics or technicians trained in light current theory and for maintenance and installation work in fields other than domestic radio and television equipment.

The financial subsidy required by the Board is still equally shared by the Radio Industry Council, the Radio and Television Retailers' Association, the Scottish Radio Retailers' Association, and the Institution. In addition, there is an arrangement whereby the Institution provides the necessary secretarial and record facilities.

Note from the General Council

The foregoing report of the Education and Examinations Committee gives some indication of the volume of work which has been undertaken in recent years. The revision of the examination syllabus has in itself been a major task and the Council records its special thanks to the Committee as a whole, the invigilators, and the body of examiners who have been drawn into the Committee's work and who have rendered valuable service to the Institution.

PROGRAMME AND PAPERS COMMITTEE

The size of the 1955 volume of the *Journal* shows that the content continues to increase, and the Council has authorised the adoption of a larger format. This will probably be put into effect in 1957, and will have the particular advantage of improving the presentation of diagrams and mathematical formulae.

Publication in the *Journal* of the 1954 Convention papers was completed during the early part of 1955, and the volume also included several notable survey papers, reports of discussion meetings, and reports issued by the Technical Committee. Throughout Volume 15 a fair balance has been maintained between the various branches of radio and electronic engineering.

In response to suggestions made by members, the number of articles of general and current interest has been increased. A new feature commenced during the latter part of the year is the publication of abstracts of papers selected from various Commonwealth and European journals. A calendar of conferences and exhibitions, of interest to radio engineers, is another widely appreciated feature.

Premiums.—The Council congratulates the following recipients of Institution Premiums awarded for papers published in the *Journal* during 1955:

THE CLERK MAXWELL PREMIUM: E. M. Bradley, B.Sc., and D. H. Pringle, Ph.D., on "The Theory and Design of Gas-discharge Microwave Attenuators." (Published in January 1955.)

THE HEINRICH HERTZ PREMIUM: R. Filipowsky, Dr. Ing. (Member), on "Electrical Pulse Communication Systems." (September and October.)

THE LOUIS STERLING PREMIUM: D. R. Coleman, D. Allanson and B. A. Horlock (Associate Member), on "The Development and Design of an Underwater Television Camera." (December.)

THE MARCONI PREMIUM: S. P. Fan, M.S., Ph.D., on "The Magnetron Beam Switching Tube: Its Operation and Circuit Design Criteria." (July.)

THE LESLIE MCMICHAEL PREMIUM: D. J. Fewings, B.Sc., and S. L. Fife (Associate Member), on "A Survey of Tuner Designs for Multi-channel Television Reception." (August.)

No papers qualified for award of the Sir J. C. Bose Premium, the Brabazon Premium, the A. F. Bulgin Premium and the Norman Partridge Memorial Award.

Consideration of Papers.—The number of papers submitted during the year was slightly lower than the total for 1954, when a large number of Convention papers were included. The overall standard of papers has also not been quite so high; 42 per cent. were accepted for publication without the necessity for extensive revision, compared with 48 per cent. in the previous year. On the other hand, however, the number of papers considered to be worth revision increased from 28 per cent. in 1954 to 35 per cent. during 1955.

The Committee has generally found that extensive revision to papers is due to the fact that either the author has not given enough background information and assumes that all his readers are specialists in the same subject, or the style and presentation is poor. The remedy for the first of these faults can usually be conveyed to the author in specific terms, but improvement in style and readability is more difficult to obtain. Probably the best course is for a prospective author to seek frank criticism from his colleagues before submitting a paper, as informal discussion of obscure points enables them to be elucidated and re-stated more clearly.

The Committee considered a number of papers published in the journals of overseas organizations with whom the Institution has agreements for reprinting. Six papers from these sources were selected as being of special interest for reprinting in the *Journal*.

Several papers published during 1955 were contributed by authors not resident in the British Isles. The Committee was very pleased to receive these original papers, as in conjunction with the reprinting of papers already mentioned, they emphasize the international character and interests of the Institution. These various papers have been submitted from Australia, France, Germany, India, the Netherlands, U.S.A., and the West Indies. Since members of the Institution are to be found in most countries of the world, the Committee hopes that more overseas members will submit papers for consideration, whether describing techniques of general application, or problems peculiar to their own countries.

A rather disturbing feature during recent years has been the reluctance of engineers to write papers on completed projects, because of pressure of new work. Often, of course, patent and security considerations arise; the

securing of patents is, however, often strengthened by publication of material and it cannot be over-emphasized that the development of any branch of science very largely depends on the wide dissemination of knowledge through experience.

Very often a programme of work is carried out before the discovery that it has, in fact, already been done elsewhere; it is therefore incumbent upon every engineer, in the interests of his profession, to ensure the accessible documentation of his achievements; an indication of *unsuccessful* methods of approach can also be of value to other engineers.

From a material or commercial point of view, nothing but good can result from the publication of an organization's achievements.

Meetings.—There has been a steady consolidation of the Institution's Section activities. In Great Britain meetings have been held regularly by seven Sections, London, South Wales, Wolverhampton, Liverpool, Manchester, Newcastle-upon-Tyne, Glasgow, and Edinburgh, and at the end of the year proposals were being considered for the establishment of an eighth Section which would hold meetings in Cheltenham and Malvern; this section has been approved by Council since the end of the period covered by this Report, and it is expected that a full programme of meetings will be held during the 1956-7 session.

Eleven meetings of the Institution were held in London during the 1955-6 session. For two of these meetings the lecture theatre was filled to capacity, and it has been decided that in future any non-members wishing to attend will be required to obtain tickets through members of the Institution, in order to ensure the accommodation of members. The other Sections in the British Isles held over 40 meetings, and the Committee has been particularly pleased to note the enterprise of the Scottish Section in holding a three-day symposium of papers on various aspects of electronics, from 22nd to 24th March, 1956. The meetings on the first two days were held in Glasgow, and on the third day in Edinburgh; the programme of papers was mainly biased toward industrial applications of electronics and was supplemented by visits to factories and other installations.

The Sections in India, Pakistan, South Africa and New Zealand have continued to hold

meetings at irregular intervals. The main difficulty of these Sections has been to obtain a sufficiently wide range of papers suitable for presentation and discussion at meetings. The Auckland Section in New Zealand arranged a more regular programme and it is hoped that through the assistance of the Indian Advisory Committee the forthcoming session will result in all five Indian Sections holding regular meetings and presenting papers suitable for publication in the *Journal*.

Increased "Journal" Circulation.—One of the most satisfying features of the year has been the increasing circulation of the *Journal*. The Institution is one of very few professional bodies that secures certified figures from the Audit Bureau of Circulation. For the period July to December 1955 the certified circulation was 6,106 copies per month, an increase of nearly 400 per issue over the previous year. During the first half of 1956 the circulation has continued to rise; it now includes well over one thousand non-member subscribers, such as universities, other reference libraries, and Government organizations.

The certified circulation does not include the sale of bound volumes, back numbers of the *Journal*, and reprints of Convention and other papers. These demands indicate the growing esteem in which the *Journal* is held as a source of reference for engineers.

The advertising pages of the *Journal* represent an important source of revenue, and any increase in their number helps to off-set the rising costs of printing and paper. During 1955 the number of pages of advertising was 15 per cent. higher than in 1954.

Acknowledgments.—The Council gratefully acknowledges the facilities which authorities of the universities, colleges, etc., have provided for holding meetings of Sections of the Institution in Great Britain and overseas. The Council is also grateful to all authors of papers, particularly those who have read them at one or more Section meetings, and to firms who have co-operated in the provision of demonstration and other equipment.

Thanks are due to the Council of the Institution of Radio Engineers, Australia, the Administration of the Netherlands Postal and Telecommunications Services, and the Editorial Board of *Archiv der Elektrischen Übertragung*

for permission to reprint papers from their respective publications.

The publication of notices of Institution meetings in the technical and scientific press is greatly appreciated, and the Council thanks the Editors concerned for their co-operation.

The Committee regretted losing the services of Lt.-Col. J. P. A. Martindale, B.A., B.Sc. (Associate Member), and Mr. E. G. Hamer, B.Sc.(Eng.) (Member), because of their taking appointments overseas. The Council also acknowledges the help given by other members, as well as certain specialists outside the Institution, in submitting reports on the suitability of manuscripts for publication in the *Journal*.

LIBRARY COMMITTEE

In addition to the purchase of new books, Library expenditure has been mainly concerned with refurbishing the Library. This has had the advantage of securing a better display for both lending and reference books, which now total 1,726. In addition 115 periodicals are regularly received either by subscription or an exchange arrangement with the Institution's *Journal*.

Many of the periodicals are received from other countries and the new service provided by the Library—"Radio Engineering Overseas"—has been greatly appreciated by many members. This service provides for publication each month in the Institution's *Journal* of a selection of abstracts from overseas journals much earlier than through the normal abstracting services. The Committee is grateful to all members who have assisted in the translation of abstracts for this service; it is regretted, however, that owing to the great variety it is not possible to supply translations of complete papers.

A further useful service has been that of providing up-to-date bibliographies on a variety of subjects including "Recording and Reproduction Systems," "Stabilized Power Supplies," "Ferrite Rod Aerials," and "R.F. Heating."

The accumulation of references and abstracts on specialized subjects is a development of Library services which it is hoped to extend and possibly publish in handy reference form.

Whilst in the main the Library can accede to most requests for books or reference material, the Institution endeavours to provide for every contingency by continuing to subscribe to the lending facilities provided by the Science

Library, ASLIB, and other scientific libraries.

Excluding the books obtained from those sources, the Lending Library handled a total of 881 loans.

Gifts.—Gifts to the Library are always most acceptable and in this connection thanks are expressed to Mr. L. W. Meyer and Lt.-Col. J.P.A. Martindale (Members). The Committee has also much appreciated the continuing co-operation of a number of publishing houses who provide their publications in return for the Institution's *Journal*.

Library Catalogue.—It has not been possible to complete arrangements for printing a revised Library Catalogue owing to the extremely high printing costs which would be involved. A number of alternative methods of publication have been examined and work has continued on compilation.

The Council is shortly to review the cost of publishing and every effort will be made to have a Library Catalogue available within the next 12 months.

TECHNICAL COMMITTEE

The main work of the Committee has continued to be in connection with the reviews on material used in radio and electronic engineering. Two sections, covering ceramics and plastics, were published in the October 1955 and May 1956 *Journals* respectively. Two further sections dealing with Magnetic Materials, and Electrodeposition of Metals, are nearing completion and it is hoped that both these sections will be published during the current year.

The first draft of such reports is always of importance and in this connection Mr. F. G. Diver and Mr. C. S. Fowler rendered invaluable assistance to the Committee during the past year. All members of the Committee subsequently assisted in the preparation of these reports and the Committee must also express appreciation to the many manufacturers and other experts for their help in ensuring the authenticity of the contents.

British Standards Institution. The Committee has continued to co-operate with the various Committees of the British Standards Institution. It must be remembered that the work and the preparation of standards is a slow and tedious procedure and it is made all the more

difficult when controversy is aroused. An example of this is the supplement to B.S. 531 Graphical Symbols for Telecommunications which has been in course of preparation for several years and was on the point of publication when it was decided to amend the graphical symbols for transistors. The Institution supported the view that the American symbols which had been used for a number of years and which were now accepted as current practice should be the ones adopted. These, it is understood, have been given as the main symbols with permissible variations as a second choice.

Codes of Performance Practice.—The Committee has considered proposals made by members advocating the publication of suggested standards of presenting specifications, particularly of instrument characteristics. Throughout the world there is undoubtedly a very wide variation in the method of presenting performance details in such a manner as to make clear the varied functions, and perhaps limits, of equipment, including instruments.

The Committee is reviewing the problem with a view to co-operating with various manufacturers and industry bodies. As a result, it may be possible to publish recommended codes of performance practice and the Committee will be commenting further on this subject in the next Annual Report.

Institution services in arbitration.—During the past 12 months, the Institution has been invited to nominate members to serve as arbitrators on matters of technical dispute. In such cases, the Technical Committee considers the qualifications required of an arbitrator and recommends certain members to the President, who makes the appropriate nomination.

One organization has now included in its terms of contract a clause stating that in cases of technical dispute the President of the Institution be invited to nominate an arbitrator.

International Awards.—As reported in the February 1956 *Journal*, the President was asked to make a recommendation to the City of Genoa for the 1955 award of the Christopher Columbus Prize for International Telecommunications. He was advised in the matter by the Technical Committee, who considered that the recipients should be the engineers responsible for the Transatlantic telephone cable project, to whom the award was eventually made.

1957 Convention.—The Council asked the Committee to give preliminary consideration to the subject matter of the next Institution Convention. The Council has now confirmed that the Convention will be held from 27th June—1st July, 1957, at King's College, Cambridge, and that the theme of the Convention will be "Electronics in Automation."

The arrangements will follow the customary pattern of Brit.I.R.E. Conventions, and will be divided into various sessions. Although responsibility for Convention arrangements has now been undertaken by a specially appointed Committee, under the Chairmanship of Mr. L. H. Bedford, C.B.E., M.A. (Past President), the Technical Committee will continue to assist in compiling the programme for the Convention.

FINANCE COMMITTEE

The Accounts for the year ended 31st March, 1956, are appended to this report. They also show the figures for the previous year for easy comparison.

Income and Expenditure Account.—A continuing feature of Institution Accounts is the increase in all normal items of income. This provides most satisfactory evidence of the general growth of the Institution.

Building Appeal donations are not regarded as *normal* income, and excluding this item all other revenue shows a net increase of £3,600 over the previous year.

Expenditure has only increased by £2,400. Unfortunately the economies effected were offset in the latter part of the year by rising costs, particularly in connection with printing, postage, etc. This is reflected in the cost of printing and publishing the *Journal*, which shows an increase of nearly £1,100, notwithstanding increases in advertising revenue, and paid circulation. The full effect of increases in printing, paper, telephone and postal rates will be felt during the next twelve months and it is estimated that the total increase on these charges alone will be about £2,000 in a complete year. Examination expenses and Section meeting expenses, also including printing costs, show an all round increase, and here again the full effect of increased charges was not experienced during 1955/56.

Expenditure must necessarily increase as the Institution grows; whilst the Finance Committee has always kept a tight rein on expenditure,

inflation in the form of increased costs makes it virtually impossible to cut expenditure any further. Moreover, at the present time there is much vital work for the Institution to do in order to strengthen its justification to become a Chartered body.

It has already been stressed that contributions towards the Building Appeal cannot be regarded as a normal or regular source of income. For this reason it is necessary that a review of Institution finances is related to annual income and expenditure; for the present therefore the Committee does not take into account the benefits which will ultimately derive from the acquisition of a capital asset purchased exclusively by the response to the Building Appeal.

The Committee has, therefore, reported to the Council that based on the existing membership and services, income must be raised by at least £4,000. It is believed that all members will support the Council in its endeavours to continue increasing the status of the Institution and the value of membership and will, therefore, support the recommendations of the Council in its proposed revision of subscriptions. These recommendations are shown in Table 4.

Table 4
Summary of Recommendations

	United Kingdom		Overseas	
	£	s. d.	£	s. d.
Members	6	10 0	6	0 0
Associate Members ...	5	0 0	4	10 0
Associates	5	0 0	4	10 0
Graduates over 35 years ...	5	0 0	4	10 0
" 25-35 years ...	4	0 0	4	0 0
" under 25 years ...	3	0 0	3	0 0
Students over 25 years ...	3	0 0	3	0 0
" under 25 years ...	2	0 0	2	0 0
" under 21 years ...	1	10 0	1	10 0

Balance Sheet.—An examination of Balance Sheets over the post-war years shows the difficulties encountered in building up the assets required for immediate membership services and for providing a reserve to finance future development and to meet other contingencies.

Modern taxation has eliminated the benefit of private endowment which did so much to strengthen the financial position of scientific

societies founded in earlier generations. Until the establishment of the Building Appeal, the Institution had never enjoyed capital endowment. The Building Appeal is, therefore, doing much, and will do even more, towards stabilizing the Institution's financial position. The membership has made a fair contribution towards this capital endowment, but organisations within the British radio and electronics industry have made the main contribution, for which the Council is especially grateful.

Several companies are contributing to the Appeal under deeds of covenant, two of which are for £5,000 each, and the payments still to be received under covenant will increase the amount standing to the credit of the Building Appeal by a further £9,388. For convenience in showing the accumulation of donations to the Building Appeal, the Balance Sheet for the last two years has indicated the total investments and cash at Bank held in the Building Appeal account.

Once this goal has been achieved, there will, of course, be a considerable benefit to the membership because there will be a reduction in some items of expenditure. This, coupled with increased revenue from revised subscription rates, plus the benefit of normal Institution growth in membership, will ultimately secure a satisfactory reserve account position.

Apart from the monies earmarked for the

Building Appeal, the Fixed and Current assets of the Institution are self-explanatory. The reduction of £500 in stationery and similar stock reflects some of the economies made and already commented upon.

The Balance Sheet for 1955/56 is, therefore satisfactory in that it shows the trend which must be followed in providing the Institution with adequate reserves.

CONCLUSION

The aim of these reports is to give some indication of the Institution's work during the past twelve months. During that time the meetings of the General Council and the Standing Committees totalled 58. Members will appreciate that the implementation of the decisions taken at those various meetings involves a considerable amount of work for the administrative staff in addition to their normal duties.

The general difficulty of staff recruitment has also been felt by the Institution during the past year. The Council therefore especially appreciates the loyal co-operation of the few who form the nucleus of the permanent staff.

Every Standing Committee has been involved in more work during the year and their efforts enable the Council to take pleasure in presenting this 30th Annual Report to the entire membership.

BALANCE SHEET

1955		£	s.	d.	£	s.	d.
	<i>RESERVE ACCOUNT</i>						
	Excess of Income over Expenditure for year 1955/56	2,927	19	5			
	Less Debit Balance as at 1.4.1955	2,723	8	10			
						204	10 7
	<i>CURRENT LIABILITIES</i>						
3,682	Sundry Creditors	4,171	16	11			
2,446	Subscriptions and Examination Fees in Advance	2,600	18	6			
16,885	Bank Overdraft	16,415	16	6			
						23,188	11 11

NOTE: (i) The Balance on Reserve Account, viz., £204 10s. 7d. is after credit has been taken for Building Appeal Donations and Interest on Investments.

Signed { J. L. THOMPSON (*Chairman, Finance Committee*)
 G. A. TAYLOR (*Honorary Treasurer*)
 G. D. CLIFFORD (*General Secretary*)

£23,013

£23,393 2 6

REPORT OF THE AUDITORS TO THE MEMBERS

We have obtained all the information and explanations which to the best of our knowledge and belief were necessary for the purposes of our audit. In our opinion proper books of account have been kept by the Institution so far as appears from our examination of those books and proper Returns adequate for the purpose of our audit have been received from the Sections Overseas.

We have examined the above Balance Sheet and annexed Income and Expenditure Account which are in Agreement.

23rd August, 1956.
 42 Bedford Avenue, London, W.C.2.

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, OCTOBER 31st, 1956, at the London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, London, W.C.1. The meeting will commence at 7 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 26th October, 1955. (Reported on page 595, Volume 14, of the *Journal*, dated December, 1955.)
2. To receive the Annual Report of the Trustees. (Published on pages 483-5 of this *Journal*.)
3. To receive the Income and Expenditure Account and the Balance Sheet of the Benevolent Fund for the year ended 31st March, 1956. (Published on page 484.)
4. To elect the Trustees for the year 1956-57.

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

The present Trustees are:—

The President of the Institution.

The Chairman of the General Council.

E. J. Emery (*Member*).

A. H. Whiteley, M.B.E. (*Companion*).

G. A. Taylor (*Member*). (Honorary Treasurer).

4. To appoint Honorary Solicitors.
The Trustees recommend the re-appointment of:—
Braund & Hill, 6 Gray's Inn Square, W.C.1.
5. 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.
6. 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 on pages 18 and 19 of the 1954 List of Members.)

Brit.I.R.E. BENEVOLENT FUND

Annual Report of the Trustees for the year 1955-56

The Trustees of the Benevolent Fund have pleasure in submitting the following report on the working of the Fund during the year ended 31st March, 1956. In doing so they extend their sincere thanks to those who have generously given it their financial support, thereby enabling the Trustees to meet all reasonable applications for assistance.

Although there was a slight decrease in the number of subscribers during the year under review—902 compared with 920 in 1954—the Trustees are able to report a successful year, both from the viewpoint of income and the services and help given to beneficiaries.

The three supporters of the Fund outside the membership—Electric and Musical Industries Limited, the Radio Industries Club of London, and the Radio Industries Club of Manchester—again made generous donations and their continued help is especially appreciated.

In comparing the income shown in the attached Accounts with the income for the previous year, allowance must be made for the large donation of £1,000 received from Sir Louis Sterling last year. A true comparison, therefore, must be made with the income from normal donations and a small increase of £124 is shown. Compared with the growth of the Institution, however, the progress of the Benevolent Fund is still slow; indeed, only 17 per cent. of the membership supports the Fund and the Trustees extend an earnest appeal

to *all members* to make at least a small donation.

Since there have been slightly fewer subscribers, appreciation is all the more deserving to those members who have maintained their donations. Very many of those subscribers now make an annual contribution by means of a banker's order and it is hoped that even more members will follow the procedure of not only arranging for an annual donation, but covenanting to make such donations for a minimum period of seven years.

Income Tax and Annual Donations.—The additional income which is received from covenanted donations by way of refund of income tax merits consideration by all members of the Institution who have not yet arranged for a regular annual contribution. The only condition is that the subscriber pays income tax at the full rate on some part of his income, and the following table shows the benefits which can be derived by the Fund, with income tax at the present rate of 8s. 6d.

Amount Covenanted and to be paid annually	Tax Reclaimed Annually	Gross amount for one year	Estimated Gross amount over 7 years
1 0 0	14 9	1 14 9	12 3 3
1 1 0	15 6	1 16 6	12 15 6
1 10 0	1 2 2	2 12 2	18 5 2
1 11 6	1 3 3	2 14 9	19 3 3
2 0 0	1 9 7	3 9 7	24 7 1
2 2 0	1 11 0	3 13 0	25 11 0
3 0 0	2 4 4	5 4 4	36 10 4
3 3 0	2 6 7	5 9 7	38 7 1
4 4 0	3 2 1	7 6 1	51 2 7
5 5 0	3 17 7	9 2 7	63 18 1

The subscription actually paid by the subscriber is the amount stated in the first column and this is the net sum which should be inserted in the deed of covenant.

The Trustees ask all regular subscribers to allow them to take advantage of this provision of the Finance Act and an approved form is available from the offices of the Institution. The covenant is terminated automatically by death and no continuing liability falls on the estate of a subscriber.

Grants.—Once again the Trustees main concern has been to ensure the continued education and welfare of those children for whom the Fund has undertaken responsibility. This aspect of the Trustees' endeavours could not be accomplished without the willing help and co-operation given by the authorities of Reed's School, the Royal Wolverhampton School, and the Royal Wanstead School. These schools, which are quite independent of State aid, are experiencing great difficulties in meeting the ever increasing costs of educating and boarding their pupils.

Nevertheless, the governors continue to maintain the high standards of education and welfare laid down by the founders of the Schools; the Trustees feel, therefore, that subscribers will wish to show their appreciation of the Schools' work by giving approval to the yearly grants made by the Trustees for the purchase of Bursaries.

Two such Bursaries have already been purchased and used at Reed's School, and the two beneficiaries of those Bursaries are now successfully launched on their chosen careers. During the year the Trustees have not been required to sponsor the admission of any other children to Reed's School, but a further grant was made towards the purchase of a third Bursary.

The two girls transferred to the Royal Wolverhampton School consequent upon the closing of Reed's Girls' School have settled down happily and are making good progress.

Previous Annual Reports have cited the case of a widow with three very young children. The family were living in a remote district with no opportunities for the mother to obtain employment, or for the children to take up a career when their school life was finished. The Trustees realized that the only way to give the mother renewed interest and confidence would be by suitable employment which could only be achieved by rehabilitating the family in an area giving more scope for employment.

Subscribers will be well aware of the difficulty of obtaining suitable accommodation; the Trustees were, however, successful in securing a flat for which they have undertaken financial responsibility. Through the personal help of one Trustee, the widow was also found employment.

This case will, of course, be the concern of the Trustees for some years, but the arrangements now made may soon enable the family to become self-supporting.

Another case concerns a member of the Institution whose prolonged and serious illness has involved several operations. Whilst it is doubtful whether he will ever be able to resume full time and arduous work, he has been able to undertake light part-time work during the past twelve months. As he has a young family, the Trustees are continuing to make periodical grants and are now considering arrangements for the entry of the eldest boy to one of the schools mentioned earlier in this report.

Other cases which received the attention of the Trustees involved temporary difficulties arising from serious illness. Each case demanded a measure of financial assistance and help in overcoming such problems as house mortgage and similar difficulties.

The comments made in this report provide an explanation of disbursements. For the reasons given the grants made have increased during the year but have been well within the income. Indeed, as the accounts show, there was a surplus and this has enabled additions to be made to the Assets of the Fund, as indicated in the Balance Sheet. This in turn shows that the Reserve Asset of the Fund now exceeds £6,500, almost wholly invested, and thereby providing a most valuable item of income.

This report would not be complete without an expression of the Trustees' thanks to the Fund's Honorary Solicitors, Messrs. Braund and Hill, and the Honorary Accountant, Mr. R. H. Jenkins, F.C.A., for the help and guidance they so willingly give on all aspects of the Trustees' work.

Finally, the Trustees are always grateful to members for calling their attention to any case where it is felt that help is needed. Diffidence in a direct approach is often shown by the most deserving and the prompting of members may enable the Trustees to help.

NOTICES

Obituary

The Council of the Institution has learned with regret of the death during August of Pierre Giroud (*Member*). Born at Roanne (Loire), M. Giroud received his technical education at L'Institut Electrotechnique de Grenoble and the University of Grenoble, where he obtained the degree of Licencié-ès-Sciences in 1921.

After a short period as an engineer with the army, he entered the valve manufacturing industry, and from 1925 to 1930 was Technical Director of the Styx Valve Company. For the next fifteen years he was Chief Engineer of the Professional Radio Department of LMT, Paris. Since 1945, M. Giroud has been with the Société Française Radioélectrique, first as Chief of the Aviation and Navigation Department, and latterly as Director of the Decca Department of the parent organization, Cie Générale de T.S.F.

In 1949 M. Giroud was appointed Chevalier de la Legion d'Honneur, and awarded the Médaille de l'Aéronautique for his services in the field of aeronautical navigation aids.

Elected a Member of the Institution in 1948, M. Giroud took a leading part in the formation of the Comité Française de Brit.I.R.E. He was also a Member of the Société Française des Radioélectriciens.

M. Giroud, who was fifty-six years of age, leaves a widow and two children.

The Third Clerk Maxwell Memorial Lecture

During the 1957 Convention on "Electronics in Automation" at Cambridge, Sir Lawrence Bragg, F.R.S., Director of the Davy Faraday Laboratory at the Royal Institution, will give the third Clerk Maxwell Memorial Lecture. The lecture will take place on Thursday, 27th June, in the Cavendish Laboratory, where, as members will know, James Clerk Maxwell was first Cavendish Professor of Experimental Physics.

Memorial to John Logie Baird

On 12th July last, the Postmaster-General, the Rt. Hon. Charles Hill, P.C., M.A., M.D., LL.D., M.P., unveiled a plaque at the Royal Technical College, Glasgow, in memory of John Logie Baird. Baird, who was a former student of the college, was of course a leading pioneer in the field of television.

The Memorial takes the form of the plaque, placed in the Electrical Engineering Department

of the Royal Technical College, and an endowment to provide an annual Baird Memorial Lecture. A Baird Memorial Prize is also to be established for award annually to the most outstanding student in the College's Associateship course in Electrical Engineering.

Through its Scottish Section, the Institution has made a donation to the Memorial Fund, and was represented at the ceremony by Mr. R. H. Garner (*Associate Member*), a member of the Council.

Correction

Due to an error during printing, Figs. 12 and 13 on page 399 of the July 1956 issue of the *Journal* are incorrect. Revised copies of the complete page have been prepared and will be sent on application.

The revised page will be inserted in bound volumes available at the end of the year, and in reprints of the Discussion on "Technique of Microwave Measurements."

* * *

The author has pointed out an error in the paper "A Very Low Frequency Receiver with High Selectivity," published in the July issue. Page 403, Section 6, second paragraph, second line, *should read* ". . . cycles above the frequency . . ."

Graduateship Examination, November, 1956

The next examination, which will be the first to be held under the revised regulations, will take place on **Wednesday and Thursday, November 21st and 22nd, 1956**. Entries for this examination from home candidates must be lodged with the Institution not later than **October 1st**.

The closing date for entries from overseas candidates for the May 1957 Graduateship Examination is **November 1st 1956**.

New Committee of Merseyside Section

The new Committee of the Institution's Merseyside Section for the 1956-57 session has recently been elected. The Chairman is R. A. Spears (*Associate Member*), and H. Hipple (*Associate Member*) is Vice-Chairman. The duties of Honorary Treasurer and Membership Secretary are to be carried out by S. A. Phipps (*Associate Member*), and S. L. Fife (*Associate Member*) will continue as Programme Secretary. Other members of the Committee are: J. Gledhill, B.Sc. (*Associate Member*), J. S. Urbanski (*Associate Member*) and F. Ellson-Jones (*Associate*).

NOMINATED FOR ELECTION TO COUNCIL

Andrew Donald Booth was born in London in 1918, and was educated at Haberdashers' Aske's Hampstead School. In 1939, while working as a Managerial Pupil in the Aircraft Engine Division of Rootes Securities, Coventry, he obtained an external B.Sc. of London University, with First Class Honours. In 1940-1 he was with Armstrong Siddeley Ltd. From 1941 to 1944 he was a Major Research Scholar at the University of Birmingham, and obtained his Ph.D. for work on explosives.



Lafayette

In 1946 he was awarded a Nuffield Research Fellowship to Birkbeck College of the University of London, where he initiated the Birkbeck College Electronic Computer Project in 1948, becoming Director of the Project and Lecturer in Physics at the College in 1950. Dr. Booth received the D.Sc. of London University in 1951, and became Director of the Birkbeck College Computational Laboratory and University Reader in Computational Methods in 1954.

Dr. Booth has held two appointments in the United States—as a Rockefeller Fellow and Member of the Institute for Advanced Study at Princeton, in 1947, and in 1949 a Visiting Professorship in Theoretical Physics at the University of Pittsburgh.

He is the author of a number of books and over one hundred scientific and technical papers on mathematics, electronics, x-ray crystallography and general linguistics; these include one on computer circuits in the *Brit.I.R.E. Journal*.*

Dr. Booth has been responsible for important inventions in the computer field, including the magnetic drum store and other store and gating circuits, and he designed the computing circuits of the ARC, SEC, and APEXC machines.

A full Member of the Institution, Dr. Booth is serving on the Committee for the 1957 Convention on "Electronics in Automation." He is now nominated for election to the General Council.

* "On optimum relations between circuit elements and logical symbols in the design of electronic calculators," *J.Brit.I.R.E.*, 12, p. 587. December 1952.

Eustace Macdonald Eldred was born at Isleworth, Middlesex, in 1901, and was educated at Worcester College, Westcliff-on-Sea. He began his career as a Boy Clerk in the office of the Inspector of Wireless Telegraphy, G.P.O., and served in the Royal Navy from the latter part of the first War until 1925. For the next few years Mr. Eldred was with Marconi's Wireless Telegraph Co., and in 1930 he transferred to Western Electric Co. During the 1939-45 War he served in the Royal Air Force as a Radar Officer, both in the Middle East and in this country, reaching the rank of Squadron Leader.



Shortly after the war, Mr. Eldred joined the Communications Branch of the Home Office; he is now second-in-charge of this Branch, which is responsible for all Police, Fire Brigade, and Civil Defence wireless schemes and equipment. The Communications Branch also has responsibilities covering other equipment such as Radiac instruments.

Elected an Associate Member in 1953, Mr. Eldred was transferred to full Membership of the Institution in 1954. He has served on the Membership Committee since the beginning of 1956, and has now been nominated for election to the General Council.

* * *

Another nomination for election to the Council is Raymond H. Garner, B.Sc.(Eng.) (*Associate Member*), Principal of Coatbridge Technical College. A note of Mr. Garner's career was given in the *Journal* for June 1953; from 1954 to 1956 he was Chairman of the Scottish Section.

Biographies of the Council's nominees for re-election have been published in the *Journal* as follows:

F. G. Diver, M.B.E. (*Member*), (May 1952).
H. J. Leak (*Member*), (September 1952).

Captain F. J. B. Naish, R.N., M.A. (*Member*), (October 1954).

E. W. Pulsford, B.Sc. (*Associate Member*), (October 1954).

RELIABILITY OF MILITARY ELECTRONIC EQUIPMENT*

by

Lewis M. Clement, B.S.E.E. †

SUMMARY

Reliability is defined and the history of U.S. reliability programmes discussed from the point of view of liaison between Government (user) and industry. Examples are given of reliable equipments and their success is shown to be due to the attitude of the management responsible for their production. Steps for ensuring the design and production of reliable equipment are described.

1. Introductions—Definitions

Reliability is defined as the probability of a device performing its purpose adequately for the period of time intended, under the operating conditions encountered. In measuring reliability it is necessary to specify all requirements, including the objective operating conditions and life.

The following shall be defined in appropriate specifications to assure reliable use and adequate performance:

Use shall be considered to include transportation, installation, maintenance, operation and storage as specified.

Design requirements (performance) must specify the permissible rate of failure both in storage and operation, standards of workmanship, spare parts requirements, maintainability and environment of operation.

It will be understood that the design engineer should consider such matters as simplicity, various forms of redundancy, methods of marginal checking, derating of components, and so forth, in accomplishing the results defined above.

An *equipment* is a combination of items which is capable of operation by itself (except the primary power supply as specified). For example, an equipment may consist of an antenna, antenna tuner, radio transmitter and transmitter modulator.

A *system* consists of a group of equipments especially integrated to perform function or functions. An example of a system is a fire control system including the tracking radar, computer, and mount.

An *accessory* is a supplementary device designed for use in conjunction with an item of equipment or a system, contributing to the effectiveness without extending or varying the basic function of the equipment. Examples are test equipment, recording camera attachment, emergency power supply.

The Government department responsible should provide for the following functions to assure reliable use:—

- Specifications;
- Quality control;
- Field service;
- Trouble reports sent to prime source of design and manufacture (“feedback”);
- Co-ordination;
 - Systems responsibility;
 - Sub-contractor;
 - Government furnished equipment;
- Psychological factors affecting operating personnel;
 - Selection;
 - Training.

2. The Need for Reliability

The success of a mission depends upon the complex electronic equipment which supplements the human senses, performing its special task at the instant required. Failure of only one unreliable component may prevent proper operation and cause serious loss of equipment and even life.

It is recognized that the reliability of much of our military equipment is so low as to impair its effectiveness and the cost of maintaining this equipment, in men and money, is so high, that

* Based on an address at the Admiralty, London, on 21st June, 1956, to representatives of the Services, Ministry of Supply and Industry. A representative of the Brit.I.R.E. was also present. Published by permission of the Royal Naval Scientific Service. (Paper No. 367.)

† Avco Manufacturing Corporation, Crosley Division, Cincinnati 15, Ohio, U.S.A.

U.D.C. No. 621.37/9.004.6:623.

the ability to keep it in operation under war conditions is sometimes questioned.

The cost of maintaining our military equipment in the past, based on the 1952 Rand Report,⁸ was twice the original cost for each year of operation.

One of the most important causes of unreliability is poor engineering. This is forcibly pointed out by Mr. J. M. Bridges, Director of Electronics of the Department of Defense (Application Engineering) in his paper "Sound Engineering—the Foundation of Equipment Reliability,"²⁶ wherein he states:

"The greatest cause of the present unacceptable level of reliability in military electronic equipment is the lack of maturity of product design and failure to evaluate the inherent reliability of design, through realistic engineering tests and service and material evaluation, before major production is undertaken.

"Primarily, this is the result of two somewhat conflicting points of view. Operational and logistics planning officers understandably urge early production of advanced new weapons and associated devices to meet planned military requirements. On the other hand, research and development people generally tend to emphasize the attainment of basic technological goals, often neglecting the laborious and less glamorous job of thoroughly engineering their creations for production and service use.

"Far too often, both the operational man and the research and development man interpret a successful functional demonstration of the first experimental model of an equipment or weapon system as indicating its readiness for production."

Since the War, our military equipment has become increasingly complex. This has been brought about by the requirements of supersonic flight, high altitude flying and the much greater accuracy required from modern fire control systems. Future military requirements may make even more complex systems necessary. It is obvious that we must improve reliability by high priority programmes, by every means within our control.

It is relatively easy and inexpensive to design a complex equipment to perform a complex task. To design a simple equipment to perform the same task is neither easy nor inexpensive.

Since reliability of military equipment is essential for National defence, and complexity is necessary to solve the increasingly difficult military problems, we must take the time, spend the money, use the best talent, ingenuity and facilities available, to develop, design and manufacture the simplest and most reliable equipment which will perform the required tasks.

It is interesting to know that very reliable complex systems can be built and many such systems are in daily use. The telephone system with its microwave television and communication links, the new telephone submarine cable with its built-in 4-valve repeaters designed for no failures in 20 years, and the business and computing machines, are but a few examples of very reliable complex electronic systems in daily use.

3. History of some Reliability Programmes in the U.S.A.

Much of the present work on Reliability in the U.S.A. stems from the much earlier work of the Military Departments, Industry, and the Ad Hoc Group Reliability of Electronic Equipment established by the Committee on Electronics (Department of Defense) in 1950. This Ad Hoc Group stimulated a great deal of interest in reliability. The Aeronautical Radio Inc. (ARINC), together with the Advisory Group on Electron Tubes and its predecessor, Panel on Electron Tubes, the engineering group at Cornell University, and with the co-operation of the Joint Electron Tube Engineering Council (JETEC) and the manufacturers, were responsible for a great deal of the progress in improving reliability of vacuum tubes in the U.S.A.

A recommendation of the Ad Hoc Group to establish a permanent reliability group under the auspices of the Department of Defense, was acted upon, and resulted in the establishment of AGREE* late in 1952.

During the last three years, AGREE has stimulated interest in and made recommendations for the improvement of reliability, by suggestion and co-operation rather than by directive, whilst the approved reports of the committees stimulated thinking and some action of the Military Departments and Industry from

* Advisory Group, Reliability of Electronic Equipment. Office of Assistant Secretary of Defense, U.S.A.

time to time. Recognizing the need for more positive action, this policy was changed and directed toward the solution of specific reliability problems in nine areas.

Ad Hoc groups with carefully selected representatives who could make substantial contributions from the Military Departments and Industry were established to study the nine problems and report their recommendations to AGREE, within approximately six months.

In addition, the charter of AGREE was changed to include two members instead of one from the Military Departments—one technical and one procurement and production.

The present programme for AGREE consists of nine tasks, as follows:

- (i) Develop minimum acceptability figures for reliability of the various types of military electronic equipment. These figures possibly may be expressed as "time between failures" or some other truly quantitative measurement. The basis upon which the figures are determined shall include the factors of operational mission requirements, maintenance, complexity, and such other factors as may be significant.
- (ii) Develop basic requirements for tests to be accomplished on development models which will prove conclusively that the design is capable of meeting the minimum acceptability figure for reliability established for the equipment type. These tests shall be designed to be performed either in addition to, or in conjunction with, whatever performance evaluations are specified for the equipment.
- (iii) Develop basic requirements for tests to be accomplished on pilot-production and on production models which will prove conclusively that the equipment will meet the minimum acceptability figure for reliability established for the equipment type. These tests shall be designed to be performed either in addition to or in conjunction with whatever performance evaluations and operational suitability evaluations are specified for the equipment.
- (iv) Investigate and recommend methods of specifying development procedures to insure that equipment designs will have the inherent reliability required. Some factors which might be involved are:
 - (1) theoretical reliability prediction, (2) thorough component selection, qualification, and application for specific circuit and environment requirements, (3) adequate signal levels and feedback, and (4) minimizing the effects of mechanical shock, vibration and temperature on critical components.
- (v) Establish criteria and methods for specifying the reliability of component parts and tubes in terms of failure rate as a function of time and environment. This is considered essential to a determination of the amount of improvement demanded in various components to meet the overall reliability requirements of the various types of electronic equipments.
- (vi) Study present procurement and contracting practices and regulations to determine their compatibility with reliability objectives. Make recommendations for specific changes as found necessary during the study. Some of the factors involved might be: (1) assessing the implementation of directives on the award of initial production contracts³⁰, (2) methods of selection of contractors for development and production, and the possibilities of including evaluation of the potential contractors' ability to produce reliable designs, and (3) evaluation of combined R. & D. production contracts, (4) in considering award to lowest bidder—the overall cost including operation and maintenance might be considered (might be determined on the basis of predicted reliability).
- (vii) Investigate present practices of packing for shipment and transportation methods and recommend specific improvements which will enhance reliability.
- (viii) Investigate the effects of storage of electronic equipment upon reliability and recommend improvements where desirable.
- (ix) Review present operational methods and procedures to assure that the reliability of equipment in service is kept up to the inherent design level. Factors which might be included are: (1) maintenance based on performance measurement rather than to meet rigid time schedules, (2) marginal testing, and (3) personnel training.

The recommendations of these Ad Hoc Groups when approved by AGREE will be referred to the Office of Electronics, Department of Defense, for study and implementation.

The Electronics Applications (Reliability) Committee was established late in 1952 by RETMA*, to aid in the improvement of reliability of military electronic equipment. Its objectives were:—

- (i) To act as a clearing house for the dissemination of reliability information.
- (ii) To aid in the education of the design and product engineers in the design of reliable and produceable military electronic equipment.
- (iii) To co-operate with the Military Departments, agencies of the Government, Aircraft Industry Association and other reliability Groups, other RETMA Committees and industry, to improve reliability of military electronic equipment.

The policy of the EA(R) Committee, like that of AGREE, was to make progress by suggestion and co-operation. Its membership is large, and representative of Industry, Trade Associations, Universities, the Military Departments and agencies of the Government.

In order to obtain wide dissemination of information, the agenda and minutes of meetings, special reports and the *Electronics Applications Reliability Review* are circulated not only to members, observers and alternates, but also to a larger group totalling some 700 interested people.

The Electronics Applications (Reliability) Committee and the various committees of RETMA and JETEC are co-operating with the Military Products Committees of RETMA and the Military Departments and agencies of the Government in overall military equipment and component problems, including reliability, specifications and so forth. The Committee, through the *Electronics Applications Reliability Review*, has acted as a clearing house for information on reliability and has contributed toward the education of the design and production engineers so that reliability can be designed into electronic equipment at the outset.

Although the articles in the *Review* are intended to reach all engineers in industry and government, the information is specifically

directed to the project and design engineers of military equipment. It is hoped that the articles will be useful to the teaching staffs of the colleges and will give them authoritative information for the education of new electronics engineers in the problems of reliability of electronic equipment.

Recently the EA(R) Committee appointed an Ad Hoc Committee to study the question of reliability education in schools and colleges. In many companies and military establishments, reliability co-ordinators with very broad responsibilities have been appointed. These pioneers are, in our opinion, the forerunners of an entirely new kind of engineer, requiring a broad education: It is this and other phases of reliability education which is being studied by this Committee.

4. The Philosophy of Reliability

The achievement of reliability requires a proper state of mind. If the top management has an intense desire to produce a reliable product, the entire organization becomes imbued with this reliability philosophy and all departments co-operate to the end that reliable products are produced. If, on the other hand, the top management does not have this desire, no amount of specifications or end point tests will guarantee a reliable and high quality product.

Mention may be made of three excellent examples in three different fields:

- (i) *Magnetrons*—complex expensive valves—relatively low production rate.

Aeronautical Radio Inc. (ARINC) had a contract to determine the life of a particular magnetron used in several military electronic equipments. Only four manufacturers' magnetrons were used in these particular equipments in sufficient quantities so that an answer of statistical significance could be obtained. The results showed that the lives of the four makes of magnetron were as follows:

Manufacturer A	—	Under 1500 hours
Manufacturer B	—	„ 500 „
Manufacturer C	—	„ 50 „
Manufacturer D	—	„ 10 „

These magnetrons were used in the same equipment types and were purchased under the same specification and end point tests!

* Radio - Electronics - Television Manufacturers' Association.

In the case of Manufacturer A, the top management and supervision had an intense desire to produce a reliable quality product. Their philosophy is expressed as follows:

One cannot produce a good assembly or product with poor parts.

One cannot produce good parts if the scrap loss is high.

For these and other reasons, this company controlled the quality of the raw materials by chemical and metallurgical tests. They made the best tools and made sure that only good parts were manufactured from the tools. When a poor part was discovered at inspection, the machine was shut down and the tool was repaired. They performed life tests to failure during production, as a control measure, and they used air conditioning, gloves for handling and so forth, where necessary.

Such a policy resulted in a very uniform and highly reliable product. The scrap loss, was very low, which resulted in low cost.

(ii) *Proximity Fuze Valves*—Continuous production of large quantities.

These valves are made by three manufacturers where plant-wide or department-wide reliability philosophy permeates the organization. The control of materials, tools, parts, processes and assembly, is excellent. There is a continuity of production and a control of quality, based on experience feed back and tests to failure. This results in the production of very reliable tubes for their particular purpose. Some proximity fuze contractors do not even perform incoming inspection tests on the valves they receive, but use them directly in the product.

Failure rate is less than one in 10,000 (reliability 99.9 per cent.).

Scrap loss is between 1 and 4 per cent. for the three different manufacturers.

The cost of these valves is very low and comparable to that of home receiver radio valves.

Stimulated by the low scrap loss on the proximity fuze valves production line, one manufacturer established a programme to reduce the scrap loss on his radio and television valves to between 5 and 10 per cent. The first year of operation at the reduced scrap rate enabled this manufacturer to produce an additional one million valves with no additional expenditure for material or labour.

(iii) *Dynamotor*—Electromechanical—made in large quantities.

During World War II a small manufacturer in Chicago produced a very reliable dynamotor at low cost. His philosophy was the same as for the magnetron and proximity fuze valve mentioned above.

This manufacturer controlled the quality of his screw machine and punch press parts by having the operators act as statistical inspectors and check the machine output from time to time in "go—no go" gauges. The machines were shut down immediately, if parts were out of limits. Readjustments of the screw machines were made, and the punch press tools were reground in order to make good parts. Thus no poor parts were made for stock. This resulted in easy assembly and highly reliable low cost dynamotors.

In each of these three cases, by a strong desire on the part of top management to produce a quality and reliable product at the beginning, through thorough mature design proof of design by careful tests and control of quality, highly reliable items were produced economically, due to the savings in low assembly costs, and low scrap loss.

5. The Realization of Reliable Equipment

In addition to contractual and specification requirements, there are many considerations which must be taken into account in order to build reliability into military electronic equipment. Reliable complex equipment can be built and a great deal of satisfactory, very reliable and complex equipment is in daily use. Much of the following information is contained in reports and recommendations of committees, suggestions of individuals, and practices of some members of U.S. industry.

5.1. *Reliability starts at the beginning.*

In order to achieve reliability, it must be considered at the conception of the idea, and be followed at high priority during all the phases, from research and development, product design, laboratory and field testing, procurement and purchasing, production and process control, quality control and inspection, shipping and storage, installation and operation, field maintenance, and to feed back of field performance and failure data to the designers and quality control staff of the contractor.

Research and development programmes must be instituted when the requirements of the ideas

or the methods of accomplishing the results are beyond the then current state of the art. Only after solution of these problems can the development and design engineers, on whom the design responsibility rests, undertake the design of reliable components, apparatus, and ultimately highly reliable military electronic systems which will perform as desired when required. Reliable equipment and systems cannot be obtained from an unreliable or immature design.

5.2. *Design must be based on Specifications*

The present programmes under way, when completed, should make it possible to write specifications, including numerical requirements for reliability, and permit contractors to measure and verify reliability of their engineering pilot production shipments. Mr. James Bridges of the Department of Defense, has said²⁸:

"A firmly expressed specification for reliability, vigorously enforced by government inspectors, will probably discourage inexperienced or unqualified contractors from bidding for the design or manufacture of complex electronic items. Perhaps this may be construed by some as constituting discriminatory and unfair procurement practices. Actually, it is probable that most of the industry will appreciate having a firm requirement for reliability rather than a vague demand that equipment be reliable without reference to its degree or how it can be measured. I think that most of us, in the military and throughout industry, realize that we must put more emphasis on quality and reliability in the procurement of military electronics and that we need to have competition in quality as well as in price."

5.3. *Systems Planning*

Systems reliability involves the proper design of the apparatus, components and their co-ordination. It starts with a complete understanding of the engineering and operational requirements. In addition, systems reliability involves knowledge of quality control, test and inspection, manufacturing techniques, system evaluation, installation, and operation and maintenance conditions in the field.

The design and production engineers should receive a complete indoctrination on all phases of the project, including the past history and reasons for the new equipment, an inspection

of an actual installation, and demonstrations of a similar equipment under operating conditions. If possible, motion pictures of installation, operation, and maintenance of a similar equipment under battle conditions, should be shown. These should indicate the need for human engineering considerations. Instruction books of similar equipment and technical reports should be made available to the design engineers at the start of the contract.

5.4. *Preliminary Design*

Preliminary design, including lay out, mechanical requirements, circuitry and choice of components should be worked out and used as a basis for the calculation of reliability. The following considerations, among others, should be taken into account for the construction of the first engineering model:

- (a) Circuit design and simplification.
- (b) Component selection—qualification and realistic tests to failure.
- (c) Design for ease of operation, ease of manufacture and ease of maintenance.

Improper use, misapplication and poor manufacture of components account for a substantial number of failures in military electronic equipment.

In the design of the engineering model, suggestions should be invited from experts in the manufacturing, quality control, purchasing and field maintenance departments. This help can be of vital importance in influencing design for ease of manufacture, field service and reliability. Such publications as the NEL booklet "Suggestions for Designers"⁶, the "NEL Reliability Design Handbook"⁷ and others given in the Bibliography should be given wide circulation.

The engineering model when completed, after solution of the development problems, should be essentially similar to the production design. It should be thoroughly tested in the laboratory to verify reliability, predictions and performance requirements. The application of components and verification of their use should be made by a component expert—not the original designers. The engineering model should be field tested and evaluated by technical and operational people, prior to the start of the product design phase.

5.5. Product Design

Product design should take into account, in addition to performance, the availability of materials and of time tested components and circuits, storage conditions, maintenance and factory process, methods and quality control considerations.

Pilot production models (Proof of Design) should be completely tested in the laboratory and evaluated by field tests under actual field conditions, before the release for shipment and field use.

5.6. Selection of Contractor

In the procurement of military electronic equipment it is essential to place great importance on the selection of the contractor. He must have a desire to carry out the contract as well as a great deal of experience in the particular equipment field if he is to produce a mature electronic and mechanical design which can be produced by his manufacturing department and which will operate reliably in the field. There is no substitute for demonstrated competence and ability.

6. Conclusions

Programmes under way in the U.S.A. will lead to mature designs and the production of reliable and satisfactory operational complex military electronic equipments. These programmes are receiving very close co-operation between government and industry.

In addition, the educational programme under way must be continued, as it is necessary to indoctrinate those entering this important work from time to time, and get the attention of everyone. "Reliability is everybody's business."

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APPLICANTS FOR MEMBERSHIP

New proposals were considered by the Membership Committee at a meeting on August 28th, 1956, as follows: 37 proposals for direct election to Graduateship or higher grade of membership, and 42 proposals for transfer to Graduateship or higher grade of membership. In addition, 50 applications for Studentship registration were considered. This list also contains the names of three applicants who have subsequently agreed to accept lower grades than those for which they originally applied.

The following are the names of those who have been properly proposed and appear qualified. In accordance with a resolution of Council and in the absence of any objections being lodged, these elections will be confirmed 14 days from the date of the circulation of this list. Any objections received will be submitted to the next meeting of the Council with whom the final decision rests.

Transfer from Associate Member to Member

EVANS, John Harold. *Halifax, Nova Scotia.*
SEXTON, Lt.-Col. Henry George Arthur. *Gorleston, Norfolk.*

Direct election to Associate Member

BEANLAND, Charles John. *Luton.*
BRYANT, Harry Mulrean. *Malvern Link.*
DUNCANSON, Keith Gillanders. *B.Sc. Wellington, New Zealand.*
ELLIS, William Bernard Keble. *Chelmsford.*
HANNIFAN, John Patrick. *Wolverhampton.*
LISTER, Cyril. *South Ruislip.*
McCLOSKEY, Hugh Anthony. *B.Sc. Bathgate, West Lothian.*
O'HANLON, Donald Maxwell. *Ruislip.*
ROTHNEY, Alex Castcl. *Accra.*
TATE, Clifford Edward. *Chelmsford.**
TRAVERS, Lieut.-Com. Frank Guy, R.N. *Edinburgh.*
WAKELIN, Wg. Cdr. Lawrence. *R.A.F. Compton-Bassett.*

Transfer from Associate to Associate Member

BHALLA, Narindar Singh. *M.Sc. Bihar.*
PECK, Charles Owen. *North Wembley.*

Transfer from Graduate to Associate Member

ALLXANDER, James Ronald. *B.Sc.(Hons.). Leigh-on-Sea.*
BROWN, Alan. *Reigate.*
HUDSON, Arthur Renton. *Malmesbury.*
QUARTERMAN, Christopher D. *Ottawa.*

Transfer from Student to Associate Member

BONSON, Leslie Edwin. *London, N.18.*
CHEESBROUGH, John William. *Walsall.*
YEOMAN, Alan Robert Archibald. *Vancouver.*

Direct election to Associate

BRYANT, Thomas William Alfred. *Bangalore.*
CHRISTMAS, Kenneth James. *Colchester.*
FLETCHER, George Robert. *London, S.E.13.*
HOLLOWAY, Flt. Lt. John Henry, M.B.E. *Kenley.*
PERKINS, Cyril Albert. *Gidea Park.*
TALBOT, Leonard Oswald. *Sheffield.*
TODD, James. *Whitburn, Co. Durham.*
TUCKER, Robert Graham Russell. *Welgedacht, South Africa.*
YARWOOD, Gordon. *Blackpool.*

Transfer from Student to Associate

BLOOMFIELD, Oldman. *London, E.1.*
ELVIDGE, Roy Wallace. *London, S.E.13.*
HUSSELBURY, Gilbert Aubrey. *Chelmsford.*
KRUYSHAAR, Willim. *Johannesburg.*

Direct election to Graduate

ARMITAGE, Norman. *Sunderland.*
BRADLEY, Robert Oswald. *Karachi.*
CHAPMAN, Maurice George. *Birchington.*
COLLINS, Terence Allan. *Dartford.*
DUNLOP, Alastair Donald. *St. Paul's Cray.*
IBUKUN, Lawrence Oju. *B.Sc.(Eng.). London, S.W.16.*
INOMA, Raphael Eloh. *Lagos.*
KHAN, Abdul Hannan. *B.Sc.(Eng.). Welwyn Garden City.*
KUMAR, Satyendranath. *M.Sc. Hooghly, West Bengal.*
MASTERS, John Henry. *Folkestone.*
PHILLIPS, Kenneth John. *Beeston.*
PULLIN, Michael. *Caterham.*
TAIT, David Adams Gilmour. *Hounslow.*
WARD, Reginald Havelock. *Crawley.*
WILLIAMS, Laurence. *Cambridge.*

Transfer from Student to Graduate

ASHMAN, Roy John. *St. Albans.*
ASHMAN, William George. *St. Albans.*
BUGEJA, Alban Anton. *London, N.W.5.*
COLE, Horace Albert George. *Reading.*
COULBECK, Bryan. *Hornsea, Yorkshire.*
GITTINS, Leonard. *Wolverton.*
GOUTAMA, Mysore Ananthamurthy, B.Sc. *East Croydon.*
HORGAN, Francis. *Dunmanway, Co. Cork.*
KHER, Sanat Kumar Madhav, B.Sc. *Bombay.*
KNITER, Edmund. *London, N.19.*
McCARTHY, Kenneth John. *London, W.2.*
McDONALD, Brendan Anthony. *Cambridge.*
NARAYAMA, Anur Krishnamachar. *Bombay.*
RYCLIFFE, Norman. *Lower Darwin.*
RODDY, Dennis. *Scarborough, Ontario.*
SIBBALD, John Scott. *Edinburgh.*
WADVA, Kuldip Singh. *B.Sc. Westcliff-on-Sea.*
WAI-CHI WONG. *Hong Kong.*

STUDENTSHIP REGISTRATIONS

AMBROSE, Dunstan Carlyle R. *London, S.W.1.*
ARAVINDAKSHA MENON, T. M. *Poona.*
BANERJEE, Gour. *Serampore, West Bengal.*
BENTLEY, Edward L. *Cottesmore, Rutland.*
BIRD, Gordon Joseph Alexander. *Chard.*
BRFNMAN, James Joseph. *Dublin.*
CHATTERJEE, Akhil Kumar. *Agra.*
DANDEKAR, Shridhar Kashinath. *Bombay.*
DAVIES, Alan Terrell. *Ilfracombe.*
DAVIS, Frank. *Wolverhampton.*
DHODY, Bharat Bhushan. *Jalahalli.*
DUMONT, Joseph Andre. *Singapore.*
FORESTAL, Peter. *Bahrain.*
GHURIANI, Alam Chand. *Bhopal.*
GOSWAMI, Joginder Pal. *Agra.*
HANCOCK, Flg. Off. Kenneth Edney, R.A.F. *Bury St. Edmunds.*

JAGIT RAI. *I.N.S. Valsura.*
KAINTH, Haqiqat Singh. *Jalahalli.*
KAPOR, Onkar Nath. *Jalahalli.*
KRISHNASWAMY, Sundaramurthi. *Mudras.*
LAMBA, Kalyan Dass. *Nilokheri.*
LEUNG SHIV YVEN. *Hongkong.*
LEVI-MINZI, Gad. *Haila.*
LEWIS, Arthur Dennis. *Edinburgh.*
MACKLEY, Alfred. *Christchurch, N.Z.*
MAHMUD, Mohd Hanif. *Macon, Ga., U.S.A.*
MAITRA, Pranab Kumar. *Agra.*
MARATHE, Yashvant. *Akola.*
MARWICK, David Baikie. *Stevenage.*
MATHUR, Satya Prakash. *Jalahalli.*
MOUNTAIN, Robert Giffard. *Keighley.*
NARULA, Bhagwan Dass. *Bangalore.*
NG THIAN HWEI. *Malacca.*
NURTON, George. *Stockport.*

PASKINS, David Cecil. *Brighton.*
PATHANIA, Dharam Singh. *Jalahalli.*
PURUSHOTHAMAN, M. B.Sc. *Madras.*
RAMA CHANDRA WARRIER, K. G. *Madras.*
RIJOUAL, Louis Auguste, B.Sc. *London, S.E.10.*
SANDERS, Lcslic. *Formby.*
SANTRA, Ajit Bchari. *London, N.W.6.*
SCHUMAN, Lein. *Sydney, New South Wales.*
SHARMA, Yad Ram. *Delhi.*
SHELTON, Roy George A. *Johannesburg.*
SHUKLA, Ratan Prakash. *Agra.*
SINHA, Subrata. *Jalahalli.*
SMITH, Noel Godfrey. *London, N.W.6.*
SUBBARAO, Addepalli. *B.Sc. Kurnool.*
URBANSKI, Alfred S. M.A. *Montreal.*
VASUDEVAN, V. *New Delhi.*
WALLACE, David John. *South Harrow.*

* Reinstatement.

MICROWAVE DETERMINATIONS OF THE VELOCITY OF "LIGHT" *

by

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In the Chair: Mr. L. H. Bedford, C.B.E., M.A., Past President.

SUMMARY

A description is given of methods utilizing microwaves for the purpose of measuring the free-space vacuum velocity of electromagnetic waves. The cavity resonator and the microwave interferometer methods are discussed in detail; brief mention is made of the molecular band spectrum method. The values obtained from these methods are compared with optical values.

1. Introduction

Since the war there have been a number of determinations of the velocity of electromagnetic waves and some sort of selection rule is needed if one is to describe any method with sufficient detail to avoid becoming merely an annotated catalogue. A few of these methods are of particular interest to the radio and electronics engineer in that they make use of the new sources and techniques which evolved during the war as a result of the extensive development and application of radar. Thus it is appropriate to consider only these microwave determinations, which are highly accurate compared with pre-war methods and which are relatively novel in practice.

There are seven measurements to mention, involving three entirely different methods. In order of appearance these are: the cavity resonator method of Essen and Gordon-Smith,^{1,2} published in 1947, which gave a value for the vacuum velocity of electromagnetic waves of $299\,792 \pm 9$ km/s and was the first to cast doubt upon the accuracy of the accepted value³ of $299\,776 \pm 4$ km/s; a more refined and somewhat modified cavity resonator method by Essen⁴ (1950); a third form of cavity resonator by Bol⁵ (1950); a microwave interferometer by Froome⁶ (1952); a molecular band spectrum method by Rank, Ruth and Vander Sluis⁷

(1952) involving the ratio of constants determined by optical and microwave methods; a new microwave interferometer by Froome⁸ (1954); and a revision of the band spectrum method by Rank, Shearer and Wiggins⁹ in 1954.

2. Cavity Resonator Methods

The only practical form of cavity to use is a right circular hollow cylinder closed at both ends, the resonant frequency for a perfect conductor being given by

$$f_{imn} = v \left[\left(\frac{r}{\pi D} \right)^2 - \left(\frac{n}{2L} \right)^2 \right]^{\frac{1}{2}} \dots\dots(1)$$

where f_{imn} is the frequency in c/s of the mode designated by the suffix, v is the velocity of propagation in cm/sec in the medium filling the cavity, D is the diameter and L the length of the cylinder in cm, n is a whole number having the same value as the third suffix in the mode designation, and r is the m th root of the Bessel equations $J_1(x)=0$ for E modes, and $J_1'(x)=0$ for H modes. (Also $v=1/\sqrt{(\mu\epsilon)}$ where μ is the permeability and ϵ the permittivity of the medium in the cavity.)

If the cavity is evacuated (being able to perform the experiments in a vacuum is a great merit of these methods),

$$v_0 = f_{imn} \left[\left(\frac{r}{\pi D} \right)^2 + \left(\frac{n}{2L} \right)^2 \right]^{-\frac{1}{2}} \dots\dots(2)$$

No cavity can be of perfectly conducting material, so for real cavities the above formula

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becomes slightly modified to

$$v_0 = f'_{imn} (1 + 1/2Q) \left[\left(\frac{r}{\pi D} \right)^2 + \left(\frac{n}{2L} \right)^2 \right]^{-1/2} \dots\dots\dots(3)$$

where f'_{imn} is the measured resonant frequency and Q is the measured quality factor of the resonance. D and L are still geometrical dimensions, the skin depth of penetration of the wave being included in the $1/2Q$ term.

2.1. *The Method of Essen and Gordon-Smith*³

In the measurement of Essen and Gordon-Smith, E_{010} and E_{011} modes were used, and for both these modes $r = 2.404825$, n being 0 and 1 respectively.

Fig. 1 gives details of their 3000 Mc/s resonator. The cylinder was turned from solid copper and then honed to be as uniform in diameter as possible, the exact dimension being unimportant. The end-faces were ground square and parallel. The end-plates were ground flat and fixed to the cylinder by eight screws, an ample clearance being allowed in the holes of the plates. Resonance was excited and detected by means of coupling probes A, B, of fine wire passing through holes in one of the end-plates, the depth of insertion being variable. Probe A was connected via a coaxial lead to the oscillator. Probe B could be connected in like manner to a superheterodyne receiver for the purpose of detecting the resonance, or a crystal detector could be inserted at C—the resonance then being indicated by current flow in a galvanometer connected across this crystal. (In Fig. 1 the crystal is shown in position.)

The resonator was placed in a bell-jar which could be evacuated, the whole being lagged against thermal disturbance. The system was evacuated for at least 12 hours before any electrical measurements were made.

The determination of resonant frequency consisted of varying the microwave oscillator frequency through the cavity resonance—indicated by a sharp rise in power to either the crystal detector or the superheterodyne receiver—and then measuring the oscillator frequency at this point by comparison with a standard. This type of frequency standard^{10,11} has as its basis a highly accurate quartz crystal oscillator of relatively low operating frequency (e.g. 100 kc/s to 5 Mc/s), which is multiplied in a number of stages of between two and five times

each until frequencies of hundreds of mega cycles are reached. The output of the multiplier is then fed into a crystal diode distorter unit which generates harmonics right into the microwave region. Since this process of frequency multiplication is exact, the accuracy of such a microwave frequency standard can be as great as that of the primary crystal oscillator. The Q of the resonator was found by observing the

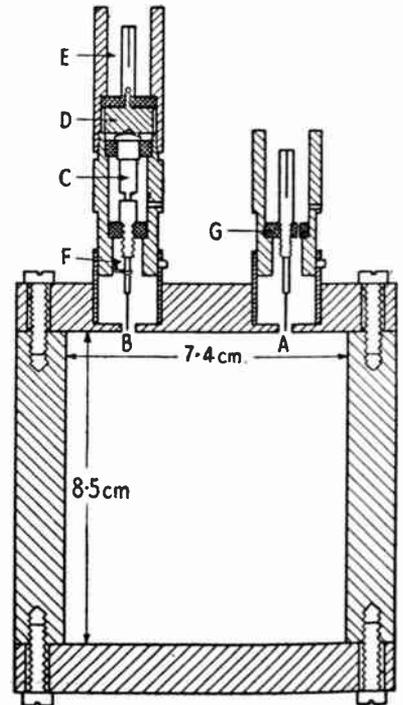


Fig. 1.—Details of the resonator used by Essen and Gordon-Smith (Ref. 2).

change in frequency from the resonant value required to reduce the detected current to $1/\sqrt{2}$ of its peak value. If this change is δf , then $Q = f/2\delta f$.

Both the internal diameter of the cylinder and its length were measured using slip gauges as the fundamental basis. For the former measurement a hollow "box" was made, the two vertical sides being slip gauge combinations closely equal in length to the diameter of the cylinder. These were wrung to a steel optical flat for a base, an additional flat (face down) being wrung to the upper surfaces of the gauge

pile, thus completing the reference standard. By means of a suitable comparator the internal diameter of the copper cylinder could be compared with the internal height of the slip gauge 'box.' The length of the cylinder was found by comparison against a single pile of slips of combined length differing but little from that to be measured. In both cases all the individual slip gauges were measured by optical interferometry—a method which uses a selected monochromatic light source as a length-standard—to an accuracy of one microinch (0.03μ).

Table 1 shows the final results accepted by Essen and Gordon-Smith.

Table 1
Values for resonant frequencies and the deduced values of the velocity of propagation *in vacuo* (c_0)

Mode of Resonance	Correction factor (1 + 1/2Q)	Measured resonant frequency Mc/s	c_0 km/s
E_{010}	1.000 028	3101.25	299 793
E_{011}	1.000 035	3563.80	299 791
E_{010}	1.000 028	3101.28	299 796
E_{011}	1.000 035	3563.77	299 789

Length of resonator = 8.536 37 ± 0.000 08 cm.
Diameter = 7.399 57 ± 0.000 03 cm.
Mean c_0 = 299 792 km/s.

The estimated maximum errors expressed in cm/s due to various causes are listed below:

- 1) Setting of the frequency to resonance and frequency measurement ... ± 1.2 km/s
- 2) Uncertainty of resonator temperature measurement ... ± 0.6
- 3) Uncertainty of dimensional measurement ... ± 0.9
- 4) Residual effects of coupling holes and probes ... ± 1.8
- 5) Non-uniformity of resonator ... ± 3.0
- 6) Uncertainty of Q ... ± 1.5

By linear addition of all these estimated uncertainties of measurement Essen and Gordon-Smith gave a maximum expected error limit of ±9 km/s. The more conventional method of statistical combination would reduce the estimated error to ±4.5 km/s.

The accuracy of the "skin effect" term $(1 + 1/2Q)$ is subject to some uncertainty because of imperfections in the surface of the resonator and consequent lack of knowledge of the precise path of current flow. Although using a measured value of Q must eliminate some of this uncertainty, Essen, in 1950, evolved a second cavity-resonator method of measuring velocity which enables the quality factor term to be studied.

2.2. Essen's Second Method⁴

The basic innovation of this method consisted of using a cylindrical cavity of variable length operating in the H_{01n} ($n=1$ to 8) and H_{02n} ($n=1$ to 3) modes—the length being altered for the purpose of changing n . n is the number of half wave lengths of the standing wave field pattern in the length of the cylinder, thus $2L/n$ is equal to the "guide" wavelength λ . Since the cylinder length (L) could be changed, any uncertainties arising from the coupling probes or lack of flatness of the end-plates do not affect the value of λ if this is derived purely from a displacement of the plunger constituting the lower end-plate of the cavity.

This method also enables the diameter (D) of the cavity to be measured in terms of length and frequency. If λ is determined for the same H_{0m} family of resonances (same value of r) D can be calculated from the expression

$$D = \frac{\lambda_1 \lambda_2 r}{\pi} \left[\frac{f_2^2 - f_1^2}{(\lambda_1 f_1)^2 - (\lambda_2 f_2)^2} \right]^{\frac{1}{2}} \dots\dots\dots(4)$$

Hence, λ_1, λ_2 , are the guide wavelengths corresponding to the frequencies f_1 and f_2 , these frequencies being corrected for Q as before. In Essen's experiments f_1 and f_2 were about 5960 and 9500 Mc/s respectively.

Alternatively, the diameter can be measured in terms of length alone by observations on different modes of resonance at the same frequency (when corrected for Q). Then

$$D = \frac{1}{\pi} \left[\frac{r_2^2 - r_1^2}{\left(\frac{1}{\lambda_1}\right)^2 - \left(\frac{1}{\lambda_2}\right)^2} \right]^{\frac{1}{2}} \dots\dots\dots(5)$$

where λ_1, λ_2 now refer to the measured wavelengths for the modes r_1, r_2 . The frequency for these measurements was 10 830 Mc/s.

Fig. 2 shows a diagram of Essen's variable-length resonator. R is the resonant enclosure excited by means of probes inserted at E. P is

the piston constituting the lower end-plate of the cavity. The plunger carrying P slides in an accurate locating-plate, C. Wires carrying counter-weights (not shown) are fastened to the plunger at D in order to reduce the thrust of the ball at the lower end of the plunger upon the slip gauges beneath it. The lower end of the slip gauges were wrung to the steel flat B. (The micrometer depicted in the diagram was only used for preliminary exploratory measurements—where it was desired to vary L quickly. When a slip gauge was wrung to B, the micrometer anvil was withdrawn below the upper surface of B.)

The cavity and plunger were constructed of steel and the inner surfaces silver-plated. The whole device could be placed in a vacuum enclosure.

The internal diameter of the cavity was measured by substantially the same technique as used for the measurement by Essen and Gordon-Smith. It was found to be uniform to $\pm 1.6\mu$ (± 60 microinches). The plunger displacements were made by means of slip gauges measured by optical interferometry. The method of frequency measurement was again very similar to that used by Essen and Gordon-Smith. Fig. 3 is a photograph of the frequency standard with the cavity and vacuum enclosure to the right of the picture.

Table 2 is a summary of Essen's results, giving three different ways of evaluating c_0 .

Table 2
Essen's results for c_0

(i) Fre- quency (Mc/s)	(ii) Resonant modes	(iii) c_0 from measured diameter (km/s)	(iv) c_0 using calculated diameter	(v) c_0 using correction term $1 + 2.8/2Q$
9500	$H_{011} - H_{018}$	299 790.0	299 793.3	299 792.3
9000	$H_{011} - H_{017}$	299 789.3	299 792.9	299 791.5
5960	$H_{011} - H_{012}$	299 794.6	299 793.1	299 792.6
10 830	$H_{021} - H_{023}$	299 785	299 794	299 792
10 830	$H_{011} - H_{019}$	299 789	299 792	299 791

Column (iii) shows the values of the free-space vacuum velocity of electromagnetic waves (c_0) derived from equation (3) and inserting the measured value of diameter. (The actual length L of the cavity was not measured—this was determined from —in turn

derived from the plunger displacement required to give the modes of column ii.)

Column (iv) shows the values derived by using the purely calculated diameters obtained

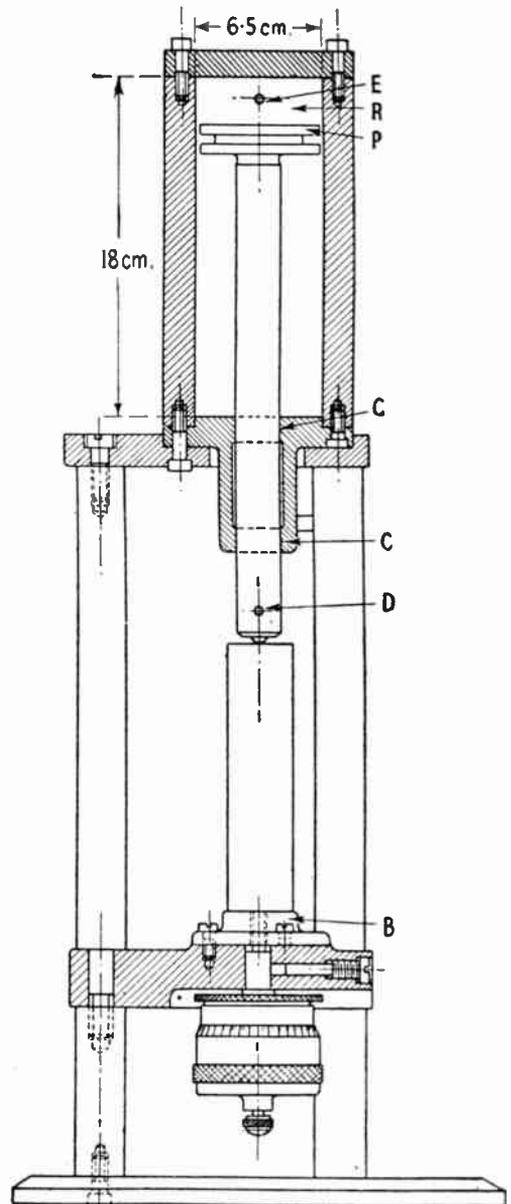


Fig. 2.—Details of the resonator used by Essen (Ref. 4).

from equations (4) and (5). The calculated diameter was found to be 2μ greater than the measured diameter corrected for skin depth, thus showing that the term $(1+1/2Q)$ is indeed somewhat inaccurate.

Column (v) shows the values of velocity obtained by use of equation (3) and an improved "skin correction" term $(1+2.8/2Q)$. This improved Q correction has been derived empirically as that which makes the values of c_0 , obtained from the various modes and frequencies, the most concordant.

Essen decided that the true velocity must lie between the values in column (iv) and column (v), and therefore selected $299\,792.5 \pm 3.0$ km/s as the result of this experiment.

The error limit given was derived from linear addition of the following maximum individual uncertainties:

- | | |
|---|-----------|
| (1) Standard deviation of frequency error of setting of resonance ... | ± 0.4 |
| (1a) Maximum uncertainty of (1) ... | ± 0.9 |
| (2) Length measurement (including temperature uncertainties) ... | ± 0.3 |
| (3) Effect of error in diameter measurement ... | ± 0.6 |
| (4) Effect of wall imperfections (tarnish, etc.) ... | ± 0.6 |

Statistical combination of these uncertainties with the standard deviation (1) would reduce the estimated error limit to ± 1 km/s.

2.3. The Cavity Method of Hansen and Bol⁵

This method employed a fixed cavity, somewhat similar in shape to that of Essen and Gordon-Smith, but operating in H_{012} and H_{021} modes. The resonant frequencies used were in the vicinity of 3000 Mc/s.

To date, no full account of this experiment has been published, but it appears that the silver-plated interior of the cavity had a diameter of about 10 inches and a height of $4\frac{1}{2}$ inches. The upper face was supported upon

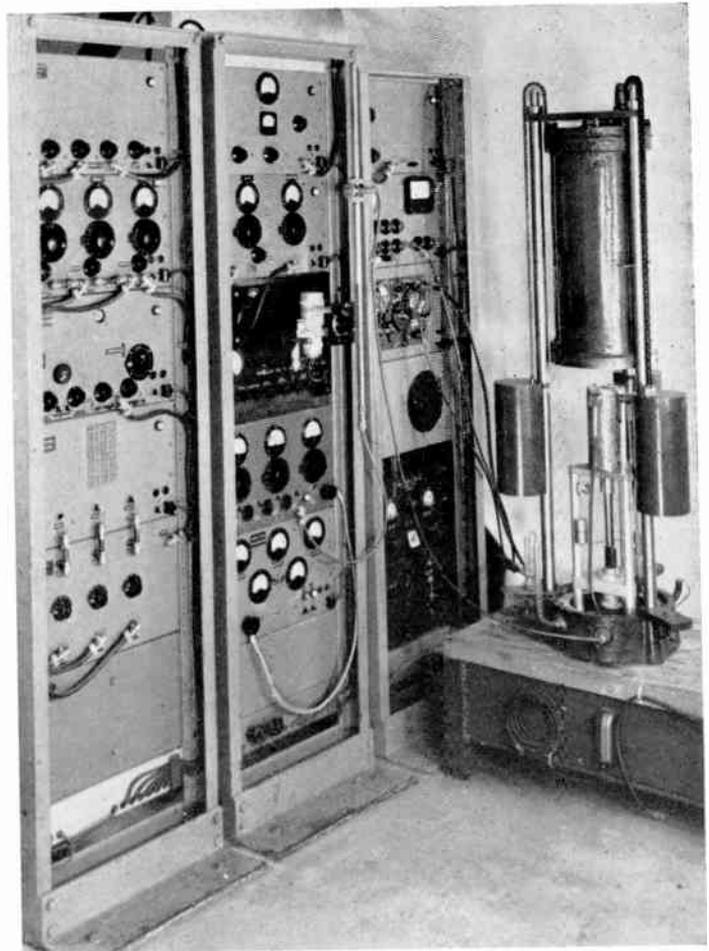


Fig. 3.—Cavity resonator and microwave frequency standard. The resonator is on the right, together with the cover which can be lowered and evacuated. The resonator is excited by a harmonic of a quartz-controlled oscillation multiplied up to the appropriate frequency in the equipment on the left, which also contains the receiver used for detecting the resonance.

three spacer-rods inserted through holes in the cylinder walls, their lower ends resting upon the flat constituting the lower end-plate of the cylinder. These rods had their lengths determined by optical interferometry. The use of two different modes enabled the diameter to be measured electrically—much in the manner of Essen's second experiment. Bol did not, however, vary the length of his cavity, so that a theoretical skin depth correction had to be applied to this dimension. The result obtained

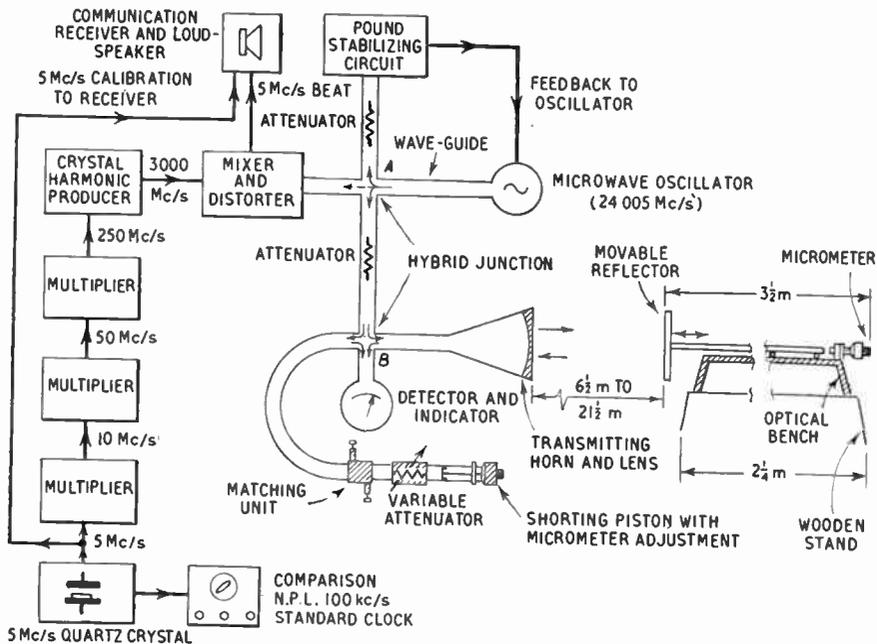


Fig. 4.—Microwave interferometer for velocity determination.

was $c_0 = 299\,789.3 \pm 0.4$ km/s. The error limit quoted does not include an assessment of possible systematic errors. Bol states that any uncertainty of skin depth correction should not increase his value of c_0 by more than 0.5 km/s.

3. Microwave Interferometer Methods

3.1. Froome's First Microwave Interferometer⁶

Optical interferometry — the precision measurement of length using a monochromatic light wavelength for a standard—is a well established and highly accurate technique for measurements up to, say, 18 inches. To increase this range is possible, but cumbersome; and in 1947 (see Ref. 4, p. 276) Barrell suggested the use of microwave interferometry for the purpose of measuring long distances. However, before this is practical, a highly accurate value (i.e. better than 1 in 10^6) for the velocity of electromagnetic waves is essential, for—in the microwave field—wavelength would be determined from frequency and velocity.

The first, and simplest, form of interferometer to be investigated is shown in Fig. 4. Essentially it is a two-beam interferometer with one fixed, and one movable, arm.

The source of microwaves is a Pound stabilized klystron oscillator of frequency of 24 005 Mc/s, corresponding to a wavelength of about 1.25 cm. The energy passes from the valve into the hybrid junction ("magic-T") A where it divides into two equal parts. One part is required to operate the stabilizing circuit; the other enters the second hybrid circuit B, constituting the beam divider of the interferometer.

At B the energy is once more split into two equal parts. Half passes through the transmitting horn out into the open, and is ultimately returned to the horn after reflexion from the distant movable reflector. This represents the "variable" arm of the interferometer.

The "fixed" arm is a wave-guide equivalent of the variable arm. In this, the other half of the energy from B passes along a wave-guide through a "matching" unit and then a variable attenuator, and is finally reflected by an adjustable shorting piston. The function of the matching unit is to balance the reflexions in the other arm occurring at the front surface of the transmitting horn, the unit being placed at the same electrical distance from the junction

B as the horn mouth. Consequently the matching is insensitive to frequency. Furthermore, because the fixed arm is mounted on, and is in good thermal contact with, the side of the transmitting horn, the matching is insensitive to thermal expansion of the horn and wave-guide. The beam divider, fixed arm, and horn are thermally lagged.

Both arms of the interferometer return energy to the hybrid junction B. This energy from each arm once more divides, half passing to the detector and half towards the oscillator. Thus interference between the beams reflected in the open and fixed arms takes place in the wave-guide leading to the detecting device. The intensity of the beam from the fixed arm can be balanced against that from the open arm by adjusting the variable attenuator, so that, if the phase in the open arm is altered by moving the reflector, the detector records zero wherever the phases of the two beams are opposite. This occurs (approximately) for every half-wave shift of the mirror. The basis of the wavelength measurement is thus to displace the mirror through an exact number of minima by means of accurately known end gauges plus a very small (up to 0.01 cm) movement of the micrometer on the mirror bench of Fig. 4. To control the magnitude of the displacement a combination of two end gauges and two slip gauges was used. The two end gauges, of nominal lengths 100 and 60 cm, were of the special combination type, used in precision engineering, which are centrally tapped at each end to receive a loose-fitting screw stud. This stud serves to strengthen the joint made when the flat annular ends of the gauges are wrung together. The two slip gauges, one wrung to each end of the 160 cm combination, bring the total length closely equal to an integral number of "apparent" half-waves. The flat-ended gauge combination is inserted between two spherical con-

tact points, one on the mirror carriage and the other attached to the micrometer anvil.

Fig. 5 shows the transmitting horn with the "fixed" arm of the interferometer fastened to its side. Fig. 6 is a photograph of the 12 inch square movable reflector and its stand.

It has already been indicated that the shape of the transmitted wave-front will change with its distance from the horn. Likewise the shape of the wave-front returned from the reflector will change with distance. In order that these wave-fronts shall be of simple form for

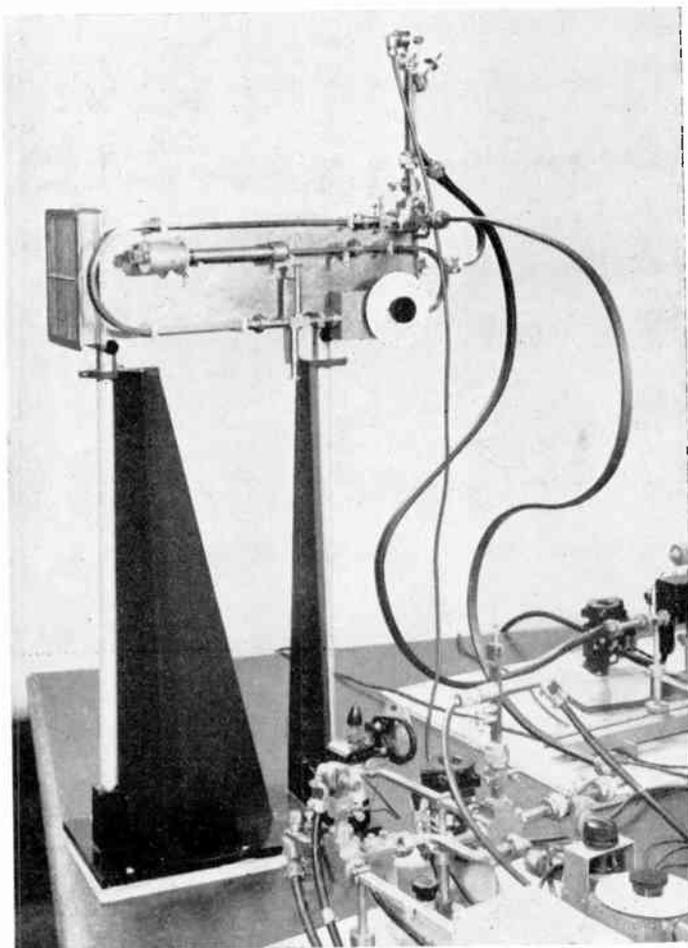


Fig. 5.—Transmitting horn with beam divider, detector arm and "fixed" arm of interferometer attached to its side. (The 24,005 Mc/s oscillator, and part of the control circuit, can be seen in the lower foreground. Part of the 24,050 Mc/s oscillator circuit can be seen in the right background.)

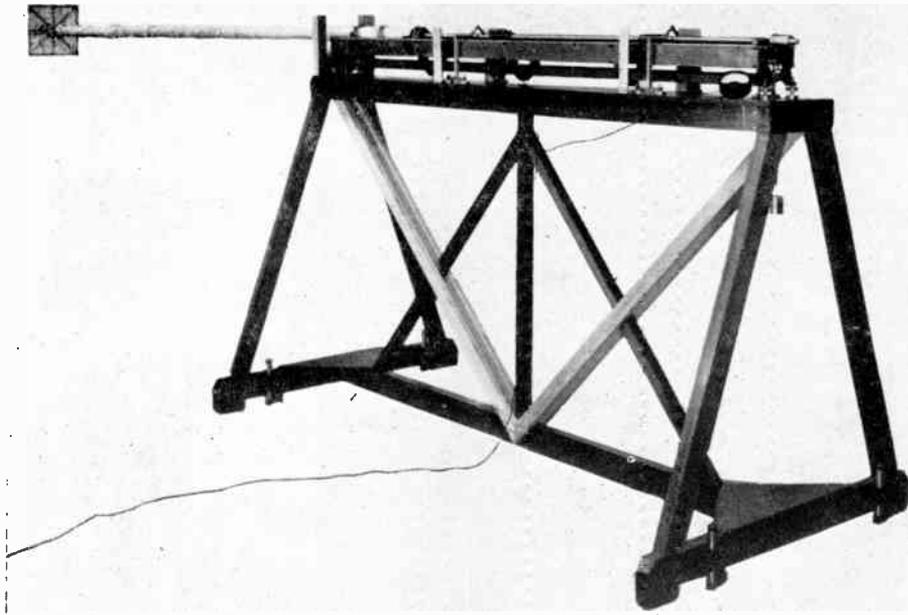


Fig. 6.—Movable reflector and stand.

analytical purposes, large distances are required between the horn and the reflector. Hence the energy returned to the detector by the mirror will be only a minute portion of the outgoing radiation, e.g. 10^{-4} , and the detector must therefore be very sensitive.

A superheterodyne receiver was used throughout for detection. Another stable oscillator (not shown in Fig. 4) provided energy at 24 050 Mc/s, a crystal mixer placed in the detector "arm" of the junction B converting the difference between this frequency and the signal (24 005 Mc/s) into an intermediate frequency of 45 Mc/s. This was amplified, rectified, and indicated by two micro-ammeters in series. One of these meters was placed near the transmitting horn, the other on the mirror bench adjacent to the micrometer. With this device and with a distance of about 21.5 m between the horn and the mirror, the accuracy of a single setting to a minimum was about $\pm 3\mu$, even with the smallest reflector of dimension 6×6 in. (15×15 cm). (These were also the dimensions of the aperture of the transmitting horn used through the experiment.)

In all measurements the mirror was displaced

through 259 minima, corresponding to a distance of about 162 cm. The action of moving the mirror and inserting the displacing gauges caused the top of the large wooden stand carrying the mirror bench to shift, by about 0.001 cm, owing to slight distortion of the framework. This movement was monitored by an independently mounted dial gauge reading to 2.5×10^{-5} cm. Mirror displacements were made at five different distances between the mirror and the transmitting horn to obtain sufficient data for the elimination of diffraction effects. These distances were 6.5, 9, 12, 16 and 21.5 m, and refer to the position of the movable mirror when the combination gauge was withdrawn.

Three different aluminium reflectors were used. These were square, of sides 6, 9 and 12 in. The 6 in. mirror was used at all distances, the 9 in. mirror at all except 6.5 m, and the 12 in. mirror at the three greater distances.

The temperature of the gauge combination was ascertained from three thermometers reading to 0.01°C suitably placed with their bulbs in contact with the surface of the gauge. The length of the gauge at 20°C was determined by a method based on optical interferometry.

The measurements made in air were reduced to the vacuum condition by means of the refractive index formulae for air previously found by Essen and Froome.¹² The air temperature was ascertained to an estimated accuracy of $\pm 0.05^\circ\text{C}$ and the barometric pressure to ± 0.1 mm. The water-vapour pressure was determined to ± 0.1 mm by means of two electrically operated Assman hygrometers.

The technique of the experiment is based on the use of a sufficiently large distance between the horn and the movable reflector so that both may be regarded almost as point sources of radiation. If they were true point sources the wave-front from the horn reaching the mirror would be a sphere of radius z , equal to their perpendicular distance apart. Since the horn and mirror dimensions are equivalent to several wavelengths in extent, the energy re-radiated after reflexion from the mirror will have an additional retardation (over and above z) dependent upon the difference in shape between the spherical wave-front and the plane face of the mirror. This difference is a function of the depth of a segment of a sphere of radius z intercepted by the sides of the mirror aperture. Similarly, the reflected wave, upon reaching the horn, also has a spherical front of radius z . The phase of the radiation conveyed to the waveguide is dependent upon the summation of this wave-front over the mouth of the horn, thus giving rise to another additional retardation dependent upon the spherical segment intercepted by the horn aperture.

Let the total retardation of the wave returned to the horn, expressed as a length, be z_r ; then the foregoing physical picture may be given mathematical expression in the following form:

$$z_r = 2z + \frac{f(h) + f(m)}{z} \dots\dots(6)$$

In equation (6), $f(h)$ represents some unknown function of the horn dimensions and $f(m)$ a similar function of the mirror dimensions. $\{f(h) + f(m)\} / z$ will hereafter be referred to as the asymptotic form of the diffraction correction.

The full theory need not be given here. It is sufficient to mention that the effect of diffraction is to make the measured velocity higher than the free-space value (in this experiment) by a few kilometres per second.

By combining equation (6) with the criterion for interference minima we obtain

$$N\lambda/2 = (z_1 - z_2) - K(\delta_2/z_2 - \delta_1/z_1) \dots\dots(7)$$

where N is the number of half-waves in the mirror displacement ($z_1 - z_2$), and z_1 and z_2 are the mirror-horn distances at each end of the displacement. K is a constant and δ_1 and δ_2 are corrections for the deviation from asymptotic diffraction correction calculated on the basis of scalar diffraction theory.

δ_1 and δ_2 are affected somewhat by the type of distribution of electric field that one assumes for the horn and mirror. The method of evaluation of λ , and thus c_0 , from equation (7) is to solve this equation by a least squares method, and adjust the assumptions concerning these aperture distributions until K is approximately unity. If the deviation from asymptotic diffraction correction is small (e.g. 1 per cent.) this method is highly accurate even if the aperture field distributions differ considerably from the theoretical ones.

Table 3 shows the final results obtained for three different mirrors at a number of mirror-horn distances.

Table 3
Values of c_0 (Unit, 1 km/s)

	Mirror-horn distance (cm)	Observer A	Observer B	Observer C
6 in. (15 cm) mirror	648	299 793.27	299 792.91	299 793.40
	900	2.14	3.32	3.73
	1204	3.38	2.67	3.90
	1601	2.84	2.91	3.21
9 in. (23 cm) mirror	2146	3.21	3.16	3.41
	900	2.34	1.93	2.31
	1204	2.64	2.64	3.16
	1601	2.47	2.17	2.80
12 in. (30 cm) mirror	2146	2.32	1.86	2.14
	1204	1.49	1.99	1.65
	1601	1.95	3.17	2.88
	2146	1.39	1.75	1.41
Mean $c_0 = 299\ 792.6 \pm 0.72$ km/s.				

The error limit represents the standard deviation of a single observation in statistical combination with the estimated systematic errors given overleaf:

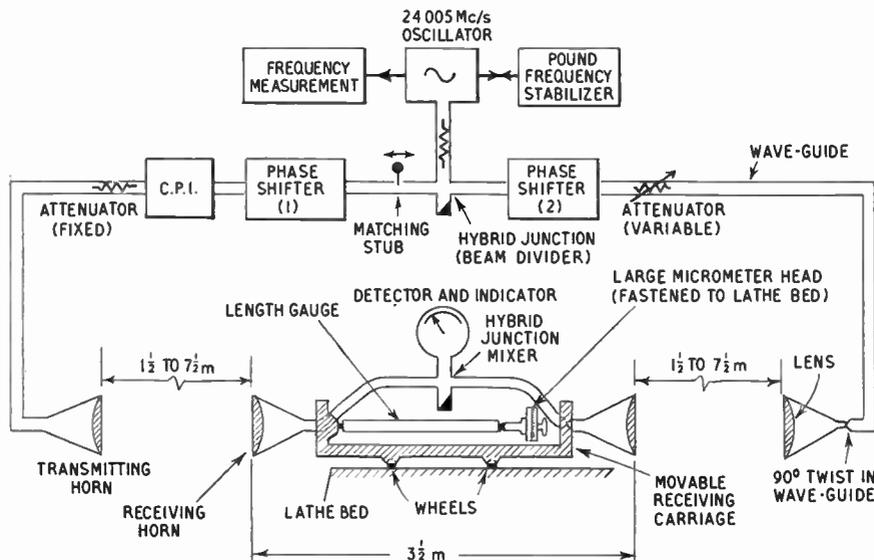


Fig. 7.—Details of four-horn interferometer.

Standard deviation of single observation	km/s	± 0.68
Uncertainty of atmospheric water vapour pressure measurement (± 0.1 mm)	...	± 0.18
Length measurement	...	± 0.09
Gauge temperature uncertainties ($\pm 0.02^\circ\text{C}$)	...	± 0.06
Residual diffraction uncertainty	...	± 0.05
Uncertainty of refractive index formula	...	± 0.05
Air temperature ($\pm 0.05^\circ\text{C}$)	...	± 0.02
Barometric pressure error (± 0.1 mm)	...	± 0.01

3.2. The Second Microwave Interferometer⁸

The simple two-beam interferometer just described suffers from one outstanding disadvantage, namely that the amount of energy returned from the reflector is extremely small. In practice this limits the ultimate sensitivity attainable. The second interferometer investigated, which uses four electromagnetic horns, involves only direct transmission over one air path and is thus potentially a much more sensitive device.

Like its predecessor, the four-horn instrument is a two-beam interferometer working in the Fraunhofer diffraction region. That is, the wave-fronts radiated from the transmitting horns are not planes (as would be the case for a true microwave equivalent to an optical interferometer), but approximate to spheres of radius equal to the separation between trans-

mitter and receiver. The theory of this type of quasi-spherical wave interferometer is similar to that of the earlier interferometer. Less integration is required, however, and the operation can be extended to include phase distortion of the transmitting and receiving apertures.

Fig. 7 shows in diagrammatic form all the essential details of the four-horn interferometer. The source of microwaves is again a Pound stabilized reflex klystron oscillator of frequency 24 005 Mc/s.

Energy from the oscillator passes to a hybrid junction ("magic T") which serves as beam divider, from which it passes through two long waveguide arms to the pair of transmitting horns. The matching stub and phase-shifter (1) to the left of the beam divider, together with the constant phase auxiliary interferometer (c.p.i.) constitute a device for altering the amplitude of the energy transmitted down this arm without producing a phase displacement. The phase-shifter (2) to the right of the beam divider, together with the variable attenuator, is required in order to adjust and balance the position of the first interference minimum.

The movable part of the interferometer consists of a pair of receiving horns mounted on a carriage (Fig. 8) largely constructed of silica tubes (for thermal stability to minimize the effect of room temperature gradients as the

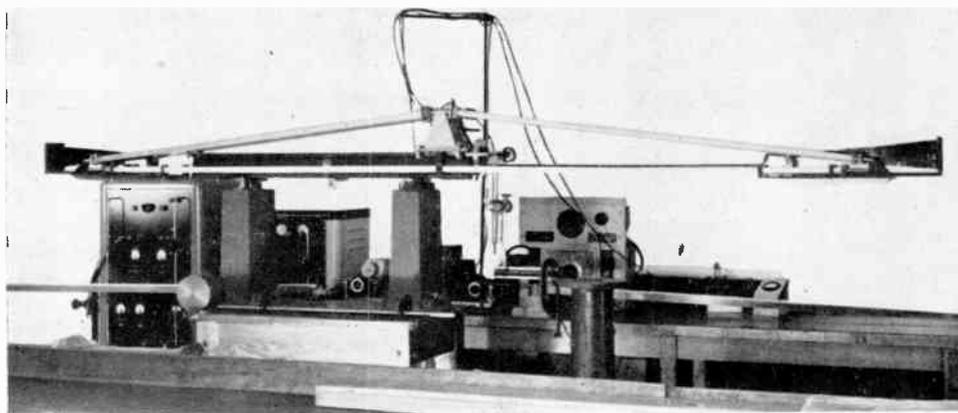


Fig. 8.—Movable carriage of experimental prototype four-horn interferometer.

carriage is displaced) and arranged between the transmitting horns. The two received signals are mixed to produce interference and detected by means of a simple superheterodyne arrangement employing the eighth harmonic of a 3000 Mc/s klystron local oscillator. This oscillator is unstabilized, and the intermediate frequency amplifier (45 Mc/s) consequently has to have a band-width of 2 Mc/s. The output from this amplifier is rectified and indicated on a milliammeter. An interference minimum is then represented by minimum current through the meter. By such means the carriage position can be set on a minimum to better than 1 micron.

To make a wavelength measurement the micrometer head is set at some convenient reading, the carriage supporting the receiving horns being held against the anvil by means of a weight and pulley arrangement. Phase-shifter (2) and variable attenuator are adjusted to give zero current in the detector. The carriage is then displaced through 162 minima by means of a metre bar (end-gauge) which has a slip gauge wrung on to each face to bring the total length closely equal to 81 wavelengths. A small movement (e.g. 20μ) of the micrometer suffices to set exactly upon the 163rd minimum. The carriage micrometer has a vernier calibrated to 0.25μ .

Because the transmitter-receiver separation is set between 2 m and 8 m, the displacement of the carriage through 1 m is sufficient

to produce considerable change in the amplitude of the received energy producing interference. If the amplitudes of these received signals are adjusted (by means of the variable attenuator) to be equal at the first interference minimum, then at the 163rd minimum the signals will be by no means equal; consequently the minimum will no longer be sharp and the sensitivity will be much reduced. The constant phase interferometer (c.p.i.) prevents this inequality.

The basic theory of the c.p.i. is very simple. If two equal vectors, initially parallel (equal waves in phase), are rotated in opposite directions through the same angle, the direction of their resultant is unchanged while its amplitude is reduced.

Fig. 9 is a diagram of the instrument. It consists of a wave-guide interferometer utilizing a hybrid junction for the dual purpose of beam division and recombination.

Referring to Fig. 9, the energy from the beam divider of the four-horn interferometer enters the *E*-plane arm of the c.p.i. At the centre of the junction the wave divides into two equal parts and enters the arms containing the piston reflectors. The waves reflected from these pistons interfere at the centre of the junction, and normally some energy is transmitted through the output arm (*H*-plane) and the remainder is returned along the *E*-plane arm. On the other hand, when the two reflected waves arrive in phase at the *H*-plane arm, all

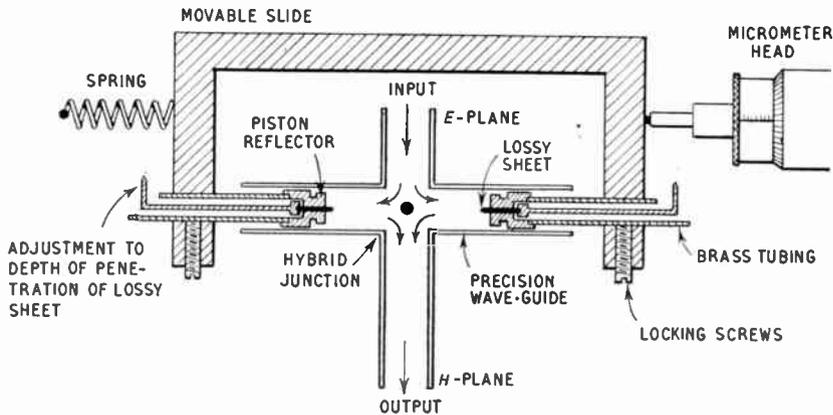


Fig. 9.—Constant phase waveguide interferometer

the input energy is transmitted to this output arm. If the micrometer reading is now changed, the phases of the piston-reflected waves are rotated in opposite directions by the same amount so that the output amplitude is reduced, but phase—at least in ideal conditions—remains constant.

In practice the device is subject to a number of small errors, all of which can be eliminated. These arise from the following deviations from ideal behaviour:

(a) The amplitudes of the waves in each of the piston arms are never exactly equal. Adjustment to near equality is made by small sheets of graphite-loaded paper which protrude by controllable amounts from the face of each piston. The effect of any small residual unbalance is eliminated by the experimental procedure to be described.

(b) Weak multiple reflexions can occur between each piston reflector and the central matching post of the hybrid junction. If these multiple reflexions are exactly in or out of phase with the primary reflexions when the c.p.i. is set for maximum transmission, their phase disturbance is at all times negligible. This condition is achieved by use of the locking screw which fixes each piston to the movable slide; by this means one can vary the distance between piston and matching post. The experimental procedure eliminates any slight deviations from perfection in this adjustment.

(c) Direct coupling between input and output arms. This effect is eliminated by the experimental routine to be described.

(d) When the device is used to reduce the transmitted amplitude from the initial position of maximum output, the energy not transmitted is reflected back along the input arm. A small amount of the reflected energy can in turn be reflected from the beam divider of the main interferometer thereby altering the phase of the energy leaving it. A matching stub placed adjacent to the beam divider is adjusted to minimize this disturbance, and phase-shifter (1) is then used to ensure that the residual effect is almost exactly in or out of phase with the primary energy from the beam divider. In these circumstances the remaining error is eliminated by the experimental procedure.

(e) Errors produced by reflexion from the fixed attenuator or waveguide arm between the c.p.i. and transmitting horn. There are two such errors:

(e₁) The reflexion may pass back to the main beam divider, thereby producing a small alteration of phase of the main beam in similar manner to (d). As this disturbance is dependent upon the product of two small reflexions it is not likely to be very large, but is not eliminated by the experimental routine finally adopted. It was assessed as negligible by means of the following experiment. The interferometer was set up for the shortest transmitting-receiving horn separation where error (e₁) would be greatest. A wave-length measurement was made using the full procedure to be described. A $\frac{1}{4}\lambda_g$ spacer was then inserted between the fixed attenuator and c.p.i. and the measurement repeated (λ_g = wave-length in guide). No

detectable difference in measured wave-length resulted, and consequently it is possible to assert that the effect of (ϵ_1) was less than 1 in 10^6 in this position so that its effect upon c_0 would be less than 1 in 10^7 .

(ϵ_2) The reflexion will suffer partial reflexion from the c.p.i. itself when the latter is not set in the position of maximum transmission. The error so produced is eliminated by the experimental routine.

Although it is very difficult to adjust the c.p.i. to fulfil all the conditions imposed, it is correspondingly easy to decide when the optimum conditions have been attained. The c.p.i. is first set at a position of maximum transmission; phase-shifter (2) and the variable attenuator are adjusted until the detector on the receiving carriage of the four-horn interferometer reads zero (i.e. the two received waves are of equal amplitude and opposite phase). The variable attenuator is then adjusted to decrease the amplitude of the wave emerging from it, and the c.p.i. micrometer rotated clockwise (to position A) to produce a corresponding decrease in amplitude so that the detector again reads zero. (A small movement of the carriage micrometer may be necessary.) The c.p.i. micrometer is now rotated counter-clockwise through the position of maximum transmission to the other position (position B) of amplitude balance. If the c.p.i. is in perfect adjustment no further movement of the carriage micrometer should be necessary. If the c.p.i. produces a phase displacement between positions A and B, then the carriage micrometer has to be rotated an amount corresponding to one-half of this deviation. For reasons to be given later a carriage shift averaging 10μ was permitted because the mean of the carriage micrometer readings for positions A and B corresponds accurately to the phase from the c.p.i. when in the position of maximum transmission midway between A and B.

The c.p.i. micrometer is next rotated through $\frac{1}{4}\lambda$ from the initial position of maximum transmission to another such position. This results in a phase change of π in the output wave, so that phase-shifter (2) and the variable attenuator are altered to re-balance the detector. The variable attenuator is next altered the same amount as previously and the c.p.i. micrometer then moved clockwise to position A_1 and counter-clockwise to position B_1 . Again, the

receiver carriage should not have to move more than 10μ between the A_1 and B_1 positions.

Lastly, the whole procedure is repeated with the c.p.i. being used to produce a larger change in amplitude. If the A and B or A_1 and B_1 positions do not produce more than 20μ phase shift the instrument is in satisfactory adjustment.

It is opportune to remark here that the output-phase deviation between the A and B or A_1 and B_1 positions gives an indication of the residual error to be expected from the device. Tests made by deliberate and systematic maladjustment of the parts of the c.p.i., phase-shifter (1), and matching stub, showed that an out-phase change corresponding to 400μ between the A and B or A_1 and B_1 positions was needed before a wave-length measurements error of 1 part in 10^6 resulted. It was thus concluded that a 20μ shift or less produced negligible errors.

Apart from diffraction which is discussed later other errors arise from: (1) multiple reflexion of micro-wave energy between transmitting and receiving horns; (2) transmitted energy scattered from some fixed object (e.g. the floor) into the receiving horns; (3) errors inherent in the measurement of the refractive index of the atmosphere, and thus in the reduction of the wave-length measurements to vacuum conditions.

Error (1) depends only upon the separation between the transmitting and receiving horns and reverses for a $\frac{1}{2}\lambda$ displacement of the receiving carriage. Thus the error can be eliminated by making at least two wave-length measurements, the carriage for the second measurement being displaced by a quarter wave-length from the initial settings.

The disturbing effect of the second error averaged about ± 3 parts in 10^6 when the plane-wave lenses were in position on transmitting and receiving horns (Series I). For Series II the disturbance averaged about ± 6 in 10^6 , and for Series III about ± 12 in 10^6 . (It should be mentioned that for Series II and III the ratio of energy transmitted away from the axis of the horns to the axial energy is greater than for Series I.) The effect was largely eliminated in Series I by making wave-length measurements for a number of slightly different transmitter-receiver distances. Besides the systematic change of measured wave-length (with distance) due to diffraction, a periodic effect due to scattering extending over some 4

to 100λ is to be found. For about half the Series I measurements the effect of scattering was eliminated by selecting the measurement at the peak of the cycle and averaging it with that at the trough. For the other half (where the disturbing influence was greater) an additional pair in quadrature with the extreme pair was included.

This process of elimination is very tedious, so that the distances selected for the Series I experiments were also used in the Series II and III, although (by virtue of the different radiation patterns of the horns) for these latter series the effect would not necessarily be totally eliminated by the use of such distances.

The refractive index error (3) arises from the instrumental errors in the measurement of barometric pressure, water-vapour pressure, air temperature; and from the formula used to extract refractive index from these measurements. The formula used was that given by Essen and Froome¹² from measurements made at 24 000 Mc/s. It is believed to be accurate to 1 part in 10^7 in both the dry-air and water-vapour corrections.

The following is the detailed procedure finally adopted for making wave-length measurements:

[1] The observer, screened by two wooden sheets from the transmitted radiations, sets the large micrometer on the receiver carriage at a convenient reading.

[2] The c.p.i. being set at a position of maximum transmission (defined as the mean of the A and B positions), the variable attenuator and phase shifter (2) are adjusted to give zero detector current at the first minimum.

[3] The observer makes five settings on this minimum by means of the carriage micrometer.

[4] The carriage is run to the limit of its movement, the temperature of the end-gauge is taken and the gauge is then inserted between carriage and micrometer anvils (exactly as depicted in Fig. 1).

[5] The c.p.i. is turned to position A and the observer makes five settings on the 163rd minimum.

[6] The c.p.i. is turned to position B and the observer again sets on the 163rd minimum. The mean of the readings of the carriage micrometer for positions A and B is taken to represent the true position of the 163rd minimum.

[7] The end-gauge is removed, its temperature is taken again, and the carriage returned to

its initial position. Operation [3] is then repeated to correct for systematic drift of the first minimum during the insertion and removal of the gauge.

Residual c.p.i. errors from causes (a), (b), (d), (e₂) have now been eliminated. The observer now proceeds:

[8] The c.p.i. reading is changed by $\frac{1}{4}\lambda_g$ to the next position of full transmission. (Defined as the mean of positions A₁ and B₁.) The carriage micrometer is now advanced by $\frac{1}{4}\lambda$ until the first minimum reappears.

[9] Operations [3] to [7] are repeated. This eliminates c.p.i. error type (c) and also the multiple reflexion error.

[10] The carriage micrometer is now turned through $\frac{3}{8}\lambda$ and operations [2] to [9] repeated. This puts the multiple reflexion errors in quadrature with their earlier effect, and is thus a useful manoeuvre for the assessment of these errors.

[11] Atmospheric pressure, temperature and humidity are taken at the beginning and end of these two sets of observations.

[12] There is still the effect of scatter from fixed objects to be eliminated. This is done and necessitates the taking of several more sets of slightly varied transmitter-receiver separations.

In order that diffraction could be studied in

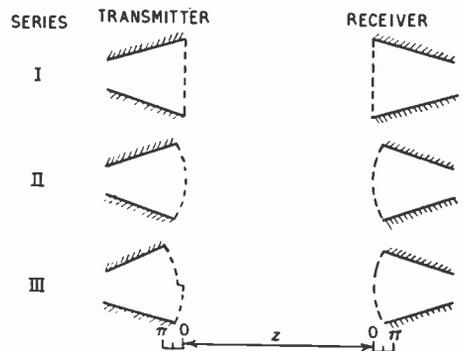


Fig. 10.—Approximate shapes of transmitted wavefronts and receiving surfaces (equatorial E- or H-plane sections).

great detail, three series of wavelength measurements were made, each with different forms of radiated wavefronts. Ten different transmitter-receiver horn separations were used for each series.

Table 4

Measured velocities reduced to *in vacuo* values (km/s)

Position	Mean z_1 (cm)	Series I	Series II	Series III
1	247.0	299 892.44	299 877.60	299 866.73
2	270.5	872.20	862.14	853.94
3	301.0	853.71	847.74	839.57
4	323.5	843.80	839.54	831.94
5	350.5	835.10	831.27	825.53
6	422.5	820.18	818.22	814.72
7	485.0	812.84	812.45	809.43
8	513.5	811.02	811.38	809.85
9	635.0	804.40	804.12	803.71
10	732.0	800.95	800.25	797.61

Table 5

Final values of c_0 (km/s)

Series I	Series II
299 793.06	299 793.15
3.14	3.04
2.83	3.17
2.69	3.07
2.78	2.27
2.77	2.34
2.73	3.21
3.34	4.40
3.33	3.32
2.80	2.24
mean = 2.95	mean = 3.02

For the four-horn interferometer the basic equation may be written, in terms of velocity,

$$c_0 = c + 2 K n f (D_{z_1} - D_{z_2}) / N \dots\dots\dots(8)$$

where c_0 is the free space vacuum velocity of electromagnetic waves, c the measured vacuum velocity obtained from the product of measured wavelength and frequency (f) with air refractive index (n). This refractive index was obtained in exactly the same way as for the first interferometer. K is a constant, N is the number of half-waves in the carriage displacement ($z_1 - z_2$); D_z is the additional retardation of the received wave (i.e. in addition to z) calculated on the basis of expected field distributions at the horn mouths; z_1 and z_2 are the two values of z (the transmitting to receiving horn distance) or each end of the carriage displacement. These field assumptions are adjusted until the least-squares result gives $K \cong 1$, the best values of c_0 then being obtained. (D_z will, of course, have an inverse variation with z for its asymptotic term).

The three series of experiments described were performed under conditions of large diffraction error, and two of them (Series II and Series III) had bad phase distortions deliberately introduced at the mouths of the horns. Fig. 10 depicts the actual transmitted wave-fronts and shape of receiving equiphase surface for each series. Thus it was necessary to establish the criteria governing the accurate operation of the interferometer for these instances.

The exact analytical form of D_z is rather complicated, especially for curved transmitted wave-fronts and curved receiving (equiphase)

surfaces, but it is given in full for some simple shapes in Ref. 8.

Here it is sufficient to state that, providing z is a large number of wavelengths, D_z is an infinite convergent series of the form:

$$D_z = \frac{A_1}{z} + \frac{A_2}{z^2} + \frac{A_3}{z^3} + \frac{A_4}{z^4} \dots\dots\dots(9)$$

The constants A_1, A_2 etc. are a function of horn mouth aperture distributions (amplitude and phase) but are independent of z , the transmitting-receiving horn separation. For plane transmitted wave-fronts and plane receiving surfaces, $A_2 = A_4 = A_6$ etc. = 0, so that the series converges very rapidly. When phase errors are present at the horn mouths the even orders of $1/z$ appear and the experiments must be planned so that orders higher than $1/z^3$ are negligible. When the results are evaluated neglecting all series terms except the first, one has the "asymptotic" evaluation of the results. The deviation of the true evaluation from the asymptotic can be used as a means of assessing the magnitude of the residual error arising from the elimination of the diffraction effect.

Table 4 shows the actual measured velocities for each series before applying the diffraction correction.

Table 5 shows the free-space vacuum velocities obtained after application of the diffraction correction by the least-squares adjustment method.

It is seen that the largest diffraction correction (for position 1) is not far short of 100 km/s. Series III could not be accurately evaluated because of the difficulty of calculating the deviation of the diffraction correction from the

asymptotic form. It was evaluated approximately by using a second order least squares solution assuming, firstly that the deviation from asymptotic form varied as $1/z^2$, and secondly as $1/z^3$. The true result must lie between the two values so obtained. A value of 299 793.5 was so chosen.

Including an assessment of possible systematic errors (below) with the standard deviation of a single observation, the final values of c_0 were taken to be 299 793.0 ± 0.3 km/s for Series I; 299 793.0 ± 0.7 for Series II; 299 793.5 ± 1.5 for Series III.

The following were the estimated systematic instrumental errors:

	km/s
Length measurement	± 0.09
Atmospheric water vapour pressure (± 0.05 mm)	± 0.09
Gauge temperature (± 0.02°C)	± 0.06
Refractive index formula	± 0.05
C.p.i. residual	± 0.03
Air temperature (± 0.05°C)	± 0.02
Barometric pressure (± 0.1mm)	± 0.01

For Series I the standard deviation of a single observation was ± 0.25 km/s and the estimated diffraction residual error was ± 0.09 km/s; for Series II the corresponding figures were ± 0.6 km/s and ± 0.3 km/s respectively; for Series III the figures were ± 1.3 and ± 0.6 respectively.

In considering these results it should be mentioned that this prototype four-horn interferometer was used under conditions of large diffraction correction in an unsuitable room where disturbances due to random scattering of radiation were high—in order that the errors inherent in the instrument could be ascertained. The final form of four-horn interferometer which operates at 72 000 megacycles is now in use under conditions where these effects are less by more than one order of magnitude.

4. The Band Spectrum Method of Rank^{7,9}

It is well known that the frequencies of the rotational energy levels, J , of diatomic or linear polyatomic molecules are expressed by the relationship

$$\nu = F(J) = BJ(J + 1) - DJ^2(J + 1)^2 + \dots \dots (24)$$

where B , and D being pure frequency units.

Some gases have systems of band spectra extending from the infra-red to microwave frequencies and it is possible to measure

$2B - 4D$ for the ground state in pure frequency units in the microwave spectrum by observing the $0 \rightarrow 1$ rotational transition. However, B and D for the ground state can also be measured from measurements of the infra-red absorption bands, but these values will be expressed as the inverse of wavelength measurements (cm⁻¹ units). It follows that the ratio of B (microwave) to B (infra-red) is equal to the velocity of light *in vacuo*.

Rank and his colleagues selected hydrogen cyanide as being the most satisfactory gas for the purpose. The wavelengths of the members of the infra-red bands were very accurately determined by optical interferometry. However, the B values deduced from them are somewhat less accurate because these are obtained from wavelength differences between relatively closely spaced lines.

The microwave absorption spectra in the millimetre region were taken from measurements by Nethercot, Klein, and Townes.¹³ The frequencies used ranged from 72 000 Mc/s to 87 000 Mc/s, and power in this region was obtained from the third and fourth harmonics of a K-band klystron oscillator tunable about 12.5 mm wavelength. By sweeping the microwave frequency, absorption lines could be displayed on a cathode ray tube with harmonics from a frequency standard superimposed.

Rank⁷ obtained a preliminary value for the vacuum velocity of light of 299 776 ± 6 km/s; a later⁹—and more accurate determination—yielding 299 789.8 ± 3.0 km/s.

5. Conclusion

How do the microwave methods compare with other recent precision determinations? One of the most outstanding is Bergstrand's¹⁴ value for c_0 of 299 793.1 ± 0.2 km/s obtained from a modulated light-beam method operating over a distance of the order of 6 km. The error limit quoted includes an assessment of possible systematic errors. The British Ordnance Survey¹⁵, using a production model of Bergstrand's apparatus, have obtained values of 299 792.2 ± 0.13 and 299 792.4 ± 0.11 km/s for measurements over two geodetic bases of length 25 km, and 11 km, respectively. Here the error limits are mean root mean square errors and do *not* include possible systematic errors. (The standard deviation of a single observation would be 3-4 times greater than the mean r.m.s. error.)

A near-microwave method is that of Aslakson.¹⁶ He used the American "Shoran" radar equipment (300 Mc/s frequency) in a most extensive survey of geodetic distances in Florida. He has published two values, namely $299\,792.4 \pm 2.4$ km/s and $299\,794.2 \pm 1.4$ km/s.

We see that a diversity of methods are in general producing concordant results about 17 km/s higher than the Birge value of 299 776 km/s. However, not all the new results agree within their assessed error limits. This is not a new feature in the history of experimental science.

Table 6

Summary of Values obtained for C_0 .

Birge ³ (1941)	299 776 \pm 4	km/s
Essen & Gordon Smith ¹ (1947)	792 \pm 9	
Aslakson ¹⁶ (1949)	792 \pm 2.4	
Essen ⁴ (1950)	792.5 \pm 3.0	
Bol ⁵ (1950)	789.3 \pm 0.4	
Aslakson ¹⁶ (1951)	794.2 \pm 1.4	
Bergstrand ¹⁴ (1951)	793.1 \pm 0.2	
Froome (1952)	792.6 \pm 0.72	
Rank and others ⁹ (1954)	789.8 \pm 3.0	
Froome (1954)	793.0 \pm 0.3	
Edge ¹⁶ (1956)	792.4 \pm 0.11	

6. Acknowledgments

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The illustrations are reproduced from the *Proceedings of the Royal Society* (Refs. 2, 4, 5 and 6).

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NATIONAL RADIO SHOW, 1956

This year's National Radio and Television Exhibition, held at Earls Court, London, from 22nd August to 1st September, recorded a total public attendance for the ten days of 340,902, an increase of about 25,000 over 1954 (last year's Show was only open for eight days).

Broadly speaking, there were three technical aspects which drew most attention—the use of transistors in commercially available equipment, the introduction of printed circuit techniques in domestic radio and television sets, and the acceptance of the v.h.f. wave-band for broadcast receivers and radiograms. More striking perhaps than any technical advance was the accent on recruitment to all branches of the radio industry, as well as to the “user organizations” such as the Services, the B.B.C. and the G.P.O.

The “Careers in Electronics” display organized by the Radio Industries Council went to great pains to inform the potential radio engineer or technician of the opportunities offered and of the type of work which he or she might expect. Authoritative advice was the keynote of the display, and members of the Institution's staff co-operated with lecturers from technical colleges in providing information. The user organizations drew the attention of the visitor to the more interesting aspects of their work, and made especial use of “live” displays. The Services included one of the most comprehensive exhibits yet shown to the public on guided missiles, while on the Post Office stand, electronic devices for letter sorting, for providing random numbers in connection with the Government's Premium Bonds scheme, for telephone switching and speech synthesis were shown.

Transistors have now been incorporated into two types of commercial equipment—in portable receivers and record players which use only transistors, and in the output stages of car radios, where, even though the earlier stages of the receiver use conventional thermionic valves, considerable current economies are obtained.

This year at least half a dozen receiver manufacturers are making use of printed circuits, and it appears that the technique is now becoming established as a means of reducing production costs and saving space. For the first time, a television set has a printed

circuit chassis, but in the main the technique is used in sub-assemblies such as audio frequency pre-amplifiers, filter units and switches. Many of the techniques associated with the use of printed circuits were of course a feature of this year's Radio Components Show, reported in the May issue of the *Journal*.

Over two hundred of the new radio receivers (and nearly all radiograms) incorporate a v.h.f. band, and there has been an increase in the number of manufacturers producing television sets combining a v.h.f. sound receiver; there were, indeed, a handful of combined television-radiograms.

Increasing competition, together with Government restrictions on hire purchase, has led to the development by several manufacturers of television receivers which are similar to the standard type in appearance but which omit one or more stages of amplification, and use a less complicated time-base unit. Thus, although only suitable for operation in high signal strength areas, an appreciable saving in cost is achieved. The main improvement in television receivers this year has been the application of electrostatically focused tubes, which reduce assembly costs and setting up time, and, it is claimed, are unlikely to need subsequent re-adjustment. Many of the larger receivers have a 21-inch picture tube which uses wide angle (90 deg.) scanning, and this achieves a reduction in tube length to such an extent that the tube is no longer than the 17-inch 70 deg. type. Aluminizing and ion-traps are refinements which have become fairly general with a view to increasing screen life.

High-fidelity sound reproduction has maintained its place as an essential feature of the Radio Show, and the majority of manufacturers produce radiograms with multiple loudspeakers. These cover a much wider frequency range and, by emitting sound in three directions, give an illusion of a three-dimensional source. The raising of the upper limit of the frequency range has led to the development of the electrostatic loudspeaker by several manufacturers.

Figures announced by the industry show that this year there should be an appreciable increase in radio exports over last year's value of nearly £33M. Before the War exports of radio equipment were worth only £2M per year.

SOME ASPECTS OF TRANSISTOR PROGRESS*

by

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SUMMARY

Some of the more significant developments during the last seven years are surveyed with emphasis on interrelations between research progress and practical achievements. Transistor technology is outlined briefly and the development of the equivalent circuit used to illustrate advances in theory. The slow entry into the applications field is accounted for by the rapidity of evolution of the device.

1. Introduction

The period which extends from the announcement of the discovery of the transistor to the present day has seen the publication not only of a very large number of scientific and technical papers representing contributions to semiconductor physics and advances in transistor technology, but also of many attempts at assessing, in a general way, the part which semiconductor elements are going to play in the electronic and communication engineering of the future. After seven years of progress in the field, it seems not inappropriate to reverse that process, to look back upon this period of intense research and development activity, and, by comparing prophecies with achievements, research results with improvements in practice, to arrive at a clearer picture of the present trends of development and to obtain a firmer foundation for further predictions.

In the following survey some of the more significant developments which have taken place during the period under discussion will be outlined, and interrelations between advances in theory and achievements in practice will be emphasized. No attempt will be made at reporting comprehensively every advance that has taken place, rather will those items be selected for discussion which are thought to be illustrating a general trend, or which seem likely to prove of technological significance within the next few years.

Even if the somewhat over-optimistic prophecies of the period immediately following

the announcement of the transistor are discounted; if, in other words, it is accepted that the transistor would always complement rather than supersede the valve, it nevertheless seemed highly probable in 1950-51 that by 1954-55 transistors would have found their way into a considerable number of practical applications and that they would feature as a standard component in many items of commercially available equipment. Except for the field of hearing-aids—relatively unimportant in this connection—until the beginning of 1955 nothing of this kind had happened in this country and little more seemed to have happened in the United States. In 1951-2 experimental transistor radio receivers, experimental oscillators, amplifiers and switching circuits had all been constructed, and details concerning their design and performance were available. In mid-1954 further experimental radios and switching circuits, together with experimental television receivers and power supply units were being described and demonstrated. There can be no doubt that the later experimental models represented improvements on the earlier ones and that one aspect in which they differed from the former was particularly significant: this was the use of junction transistors in place of the point contact types incorporated in most of the earlier models. Nevertheless, as far as commercially available, fully engineered equipment was concerned, the impact of the transistor was very small in the United States until 1955, when it may be said to have begun with the marketing of the first transistor portable radios, and still is so in this country.

If one attempts to account for this slow rate of progress one is immediately faced by the often discussed question of the relative

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advantages of transistors over valves. This follows from the fact that, unlike the first thermionic triode, the first transistor did not offer entirely new functional possibilities, but rather promised to perform known and already explored functions more economically. However, even without entering the arena of "valve versus transistor" contests it is possible to discover several reasons which could and probably did account for the comparative slowness of entry of transistors into the field of large scale application, and to do so by considering the history of transistor development alone. Three factors in particular suggest themselves as being largely responsible for the present gap between promise and achievement. Two of them arise from developments within the transistor field itself, the third is connected with progress in the "opposite camp," that of the valve. Before discussing these factors in detail, however, it will be useful to summarize and review the development of transistor technology from 1948 until now.

2. Survey of Transistor Technology

Transistor manufacturing operations are conveniently subdivided into three stages which may be denoted as raw material preparation, device assembly operations, and final encapsulation and testing operations.

2.1. Raw Material Preparation

It is probably the first of these, the raw material preparation stage, which has attracted the greatest attention on account of the extremely high degree of purity which has to be achieved in the basic material. This requirement arises from the necessity to control the equilibrium concentration of mobile carriers within the bulk of the semiconductor. One of the important material constants, resistivity, is determined by this carrier concentration, and it is the concentration of "impurity" atoms, i.e. atoms other than those forming the basic crystal structure, which in turn determines that of the carriers. The carriers themselves may consist either of "excess" electrons which, being surplus to the requirements of the valence bond mechanism which holds the crystal lattice together, are not bound to any particular atom, but are interacting with the crystal lattice as a whole in a manner which enables them to acquire additional kinetic energy in the presence of an electric field of magnitude E , and thus to drift with a velocity $\mu_n E$, where μ_n is the

electron mobility, in the direction of the field or else they may consist of "holes"—broken valence bonds due to missing valence electrons. These broken bonds may be transferred from one lattice atom to another; their motion exhibits the characteristics of a virtual positive particle of electronic charge, which will drift with a velocity of $\mu_p E$ in a field of strength E (μ_p = hole mobility).

Within a given semiconductor, hole and electron densities are not independent of one another, but their ratio under thermal equilibrium conditions can be controlled by the addition of certain types of impurity atoms to the crystal, and the excess electrons or holes which play a major part in the functioning of the transistor are so introduced, "donor" impurities yielding excess electrons, and "acceptor" impurities (by removing electrons from valence bonds) yielding holes.

For transistor quality germanium a typical impurity concentration is represented by 1-impurity atoms per 10^8 germanium atoms, or 1 milligram of impurity to 20-60 kilogram of germanium. Where, as is normally the case, one type of impurity is so predominant as to make carriers of one type ("majority carriers") very much more numerous than carriers of the opposite type ("minority carriers") the material is described as being "n-type" if the majority carriers are electrons; "p-type" if they are holes.

Although it is unlikely that purification to the extent of removal of impurities to a level of perhaps 1 in 10^{10} formed part of any pre-transistor manufacturing process, methods were evolved already during the initial phase of transistor development which permitted such degrees of purity to be attained without undue difficulty in the case of elemental semiconductors like germanium or silicon. Purification processes thus do not in general form one of the factors in transistor manufacture over which control is difficult or uncertain. The method used, known as "zone-refining," is based upon a utilization of differences between the solubility of impurities in solid and in liquid material.

If narrow molten zones are passed along material in the form of a rod, impurities will be accumulated at one or the other end of the rod, and a continuation of this process will result in material being obtained which possesses the required degree of purity. To such material controlled amounts of donor or

ceptor impurities may then be added to yield material of desired conductivity type and resistivity—a process known as “doping.” Resistivity measurements form a convenient method of process control at this stage.

While the purification requirements just outlined derive from the necessity to control equilibrium concentration of carriers, the next process of the raw materials preparation stage is intended to ensure that the crystal lattice within which the flow of carriers takes place approximates as closely as possible to a structure of ideal regularity. In so far as an ideal lattice does not possess boundaries, this requirement is obviously impossible of fulfillment; what can be ensured, however, is the absence of internal crystal grain boundaries, and the minimization of crystal defects, both of which adversely affect the performance of the finished product. For this reason, the purified and doped material has to be melted once more and to be solidified under such conditions that

single crystal of suitable dimensions is obtained. Two methods of crystal growing are currently used. In the first, the crystal is pulled vertically from molten material, in the second method, polycrystalline material contained in a horizontal boat is converted into a single crystal by the passage of a molten zone along the boat. For germanium both methods have yielded good results; for silicon and other semiconductors, vertical pulling appears to be the only satisfactory method at present. In each case a crystal seed must be used to provide a “starting pattern” for the building up of the crystal.

The production of large single crystals free from grain boundaries and irregularities under factory conditions probably constitutes the main achievement in the process of transferring transistor operations from laboratory to factory.

Crystal growing furnaces have been designed which combine a very high degree of temperature control with automatic regulation of such factors as pulling rate, degree of agitation of melt and crystal, and, where crystals with inhomogeneous impurity concentrations are to be grown, as described below, with automatic control of impurity additions.

The quality of single crystal material is reflected in the lifetime of minority carriers since crystal faults favour the process of recombination of minority and majority carriers. Lifetime measurements thus form an important process control check.

2.2. Device Manufacturing Operations

The second stage in the manufacture of transistors comprises all those operations which lead to the creation of the complete device assembly. The structure obtained will conform to as great a degree as possible to a specification laid down on the basis of an empirical or theoretical design theory. Design theory forms the means by which performance requirements can be translated into data concerning material constants and device geometry, and in so far as it is derived from basic principles it affords a check on the degree of understanding of the action of the device which has been achieved. It will be seen later that one of the significant changes in transistor technology has been the progress from empirical to theoretically designable structures.

Device assembly begins with mechanical cutting and polishing processes which transform the single crystal ingot into small wafers of controlled thickness and suitable size. From this stage onward, operations depend upon the type of transistor which is being made. For point-contact types the wafers are surface lapped, tinned on one side, soldered to a support (which will form the “base” connection), and etched.

As the result of a series of mechanical operations, accurately shaped wire whiskers are obtained and are brought into contact with the germanium surface at a controlled pressure and at an accurately maintained spacing. The latter is normally of the order of 1.5–3 thousandths of an inch and has to be kept to the specified value to within very close limits to ensure similarity of electrical characteristics. The two wires form the other two electrodes of the transistor—“emitter” and “collector.”

For grown junction transistors which are derived from crystals into which the required conductivity and impurity concentration profile has been “built” during the growing process, the device assembly consists of the attachment of leads to the three regions of different conductivity. While this is a relatively simple operation for the two end regions—which will form the emitter and collector of the device—the attachment of a lead to the base region, which may be less than 0.003 in. thick, represents a delicate operation, comprising first an electrical probing of the junction bar surface to locate the base region, followed by a capacitor discharge miniature welding process.

The second kind of junction transistor, the alloyed junction type, involves rather different processes of assembly. Here the electrically homogeneous wafer obtained by cutting, lapping and etching of the single crystal material has first to be transformed into a transistor by the fusing into its surface of a metal which will alloy with it in such a way as to form a region of conductivity type opposite to that originally possessed by the whole of the wafer. The process is carried out in an inert atmosphere with pellets of the alloying metal placed in contact with the germanium surface. The depth of penetration—which determines the width of the base region—has to be accurately controlled by a suitable time-temperature programme. The alloying material commonly used in conjunction with *n*-type germanium to form *p-n-p* transistors is indium. For *n-p-n* transistors antimony serves the same purpose.

2.3. Finishing Operations

The final group of operations comprises those finishing processes which have been found—often empirically—to improve transistor performance, and concludes with the encapsulation and final testing of the device. One class of finishing operations has been found to be of particular importance with regard to the quality of the final product; perhaps significantly this is one which relates just to that aspect of the semiconductor in respect of which the latter departs most markedly from the ideal state—its possession of a surface. During early experiments on rectification by semiconductor contacts it had already become clear that conditions at the surface of a semiconducting material could differ markedly from those which prevailed within the bulk of the material, and it was established that the surface properties were subject to changes which could be brought about by a variety of agents including changes in ambient atmosphere and chemical treatments.

When transistor properties began to be investigated it was found that certain final surface treatments—usually involving the removal of a microscopic layer of material by some etch process—could have a marked beneficial effect upon the subsequent performance of a finished transistor, and a final etch process of some form or other is found near the end of every production line, whether it is for a point contact or junction type.

The susceptibility of germanium or silicon surfaces to changes in ambient atmosphere and especially a marked deterioration of electrical characteristics brought about by small amounts of moisture on these surfaces requires that the finished device be protected by some form of encapsulation and a variety of metal cans, glass bulbs, resin and solder seals have been used with varying degrees of success.

Electrical finishing treatments such as ageing may or may not be used in the case of junction transistors. For point-contact transistors, a different type of electrical treatment, called “forming”, does however play a very important part. Forming entails the application of a series of electrical pulses, usually capacitor discharges, to the collector point, as the result of which significant improvements in electrical characteristics, and especially in the emitter to collector current multiplication factor, are obtained.

One feature which has been characteristic of transistor manufacturing activity in general is the close similarity between the factory processes and the original laboratory processes from which they are derived. There has been little movement, during the period under review, towards the highly mechanized semi-automatic assembly line which is normally associated with quantity production. The reasons for this apparent backwardness of transistor manufacturers are twofold: firstly, the production yields obtained during pilot production exercises were generally low and subject to fluctuations which suggested that a number of factors affecting the quality of the final product were not yet understood; secondly, the development of new types of transistors was proceeding at a rapid rate making it desirable to maintain a higher degree of manufacturing flexibility than could easily be provided for with the introduction of automatic machinery.

The result is that a transistor factory of today still exhibits almost a process to process correspondence to a laboratory production group. In fact the improvement in control and yield rates which has marked the last two or three years may be taken to have come about as a result of the factory's closer approach to laboratory conditions of control, demonstrated, for example, by the widespread use of manipulator box assembly techniques which ensured that the elements are not exposed to unknown ambient influences.

Technological Progress

The previous section gave an indication of the nature and magnitude of the operations involved in the production of semiconductor devices. For the purpose of the present review the origin and the subsequent development of these techniques is of greater relevance than their mere enumeration.

Transistor history was first made in the physics laboratory—the discovery of crystal triode action occurred in the course of a long term investigation into the physical properties of semiconducting materials, and especially of the surface of such materials, at the Bell Telephone Laboratories.

Nevertheless the invention—and even more the subsequent development—was based on a closely co-ordinated team work involving physicists, mathematicians, metallurgists and circuit engineers. This feature accounts for the fact that many of the techniques just described were already being developed side-by-side with the early investigations into the behaviour of the transistor and explains the resulting rapid progress in the establishment of a transistor technology during the first third of the period under review. Thus, while the first transistor, point contact triode, was briefly described in two letters to the Editor of the *Physical Review* in 1948,^{1,2} the next two to three years saw the publication of many papers dealing with the various processes which form the basis of present-day transistor technology. For example, the principle of utilizing the impurity segregation effect which occurs during the freezing of a molten substance was mentioned in several papers during the year 1950,^{3,4} while the subsequent development of zone-refining methods led to the publication of a full mathematical analysis of them in 1952.⁵ The zone-refining process has remained essentially unchanged since then, although certain refinements have been proposed recently.⁶ Methods for the preparation of large single crystals were reported in a number of papers during 1950-51.^{4,7} While the methods used were based on principles established long before the beginning of the interest in semiconductor devices they involved considerable further developments. By mid-1952 the vertical pulling method for growing single crystals had been thoroughly explored and the stage had been reached where the introduction of the automatic controls mentioned earlier transformed the

process from a laboratory experiment to a factory operation. At the same time horizontal growth methods had also been evolved^{7a} and were carried out experimentally. As far as the raw materials preparation stage was concerned the period mid-1952 to spring 1953 saw the consolidation of manufacturing operations which, for germanium at any rate, have subsequently remained essentially unchanged.

The evolution of device fabrication methods took place almost in parallel with the above developments. The production of junctions by means of doping during vertical crystal pulling had been perfected during 1951⁷ while the alloying method of making junctions was first described in 1950.⁸ Descriptions of transistors obtained by alloying impurities into opposite faces of a thin germanium wafer followed in 1951-2.⁹

The development of device theory showed a somewhat different pattern. The point contact transistor had in a way preceded its theory—particularly with regard to the interpretation of the mechanism of current multiplication at the collector point and of the forming process closely linked with it. These, together with considerations regarding the factors governing the injection of carriers by the emitter and the transport of injected carriers to the collector region formed the subjects of a number of investigations, the results of which were again largely published between 1950 and 1952.^{10,11,12} Even so, the difficulty of representing the three-dimensional flow by an adequate model, and of including all the processes which were thought to occur in the collector region caused theoretical interpretations to be of a very tentative nature, and made experimental verifications of them somewhat uncertain.

However in 1949 W. Shockley¹³ published, under the title "The theory of $p-n$ junctions in semiconductors and $p-n$ junction transistors," a paper of considerable scope which on the basis of a one-dimensional model evaluated the structure of the potential barrier between regions of different conductivity type within one semiconductor for both an abrupt and a gradual transition between them, derived expressions for the d.c. and a.c. characteristics of such " $p-n$ junctions" and finally discussed in considerable detail a structure termed "junction transistor" in which two such junctions were placed close enough to enable carriers injected by the one to diffuse to the other and, given

suitable biasing conditions, to flow across it.

It was highly significant that this paper—which was to become the foundation for a whole edifice of “Device Design” theory—provided a basis for a much more comprehensive and detailed explanation of the electrical characteristics of such an idealized junction transistor than had (or indeed has) been achieved for a point contact structure, however idealized. The reason for this lay partly in the simpler geometry of the assumed junction structure, partly it was the fact that surface behaviour, which was much less amenable to complete analysis, played a much smaller role in the former structure than in the latter.

The first junction transistors to be actually produced were announced in 1951.^{14,15} For their preparation a technique of doping the melt twice in rapid succession during the crystal pulling operation was evolved. “Grown” junction transistors were obtained of a structure closely approaching the idealized geometry which underlies Shockley’s analysis. A comparison of theory with experiment could thus be carried out. This led to the broad verification of Shockley’s theory although minor discrepancies were noted, which acted as an incentive to the further development of the theory outlined in the next section. In particular, the effects of a modulation of the width of the base layer due to variations of collector voltage were investigated by Early,¹⁶ while the range of validity of Shockley’s equations was further analysed and extended by various workers, interested in explaining observed deviations from predicted behaviour at higher current levels or higher frequencies.^{17,18} Later work led to the suggestion of a modified type of junction transistor for high frequency use which incorporated an additional region of material of high resistivity between the base and the collector region. Such “*n-p-i-n*” and “*p-n-i-p*” transistors (the *i* denoting intrinsic, i.e. net impurity free material) offer one possibility of extending the use of transistors to higher frequencies.¹⁹

Two other such developments promise to be of considerable practical importance, the drift transistor, the theory of which was worked out by Kroemer,²⁰ and the very recently announced diffused junction transistor,^{21,22} which is based upon a novel fabrication technique originally applied to the preparation of silicon photo diodes (“solar cells”) and capable of yielding

very much thinner base layers in transistors, and hence very much higher frequencies of operation.

While device theory development thus differed from that of raw material preparation processes in continuing to progress at a fast rate, it provided already in 1951 enough information to make the junction transistor stand out as being “designable”—in contrast to the point contact type. This, together with the greater control which could be achieved in the manufacture of the junction types accounts for the almost complete shift in emphasis away from point-contact and towards junction types. This shift occurred in the main during the period 1952-3 and was accompanied by the publication of the very considerable amount of work on junction transistor theory already referred to.

While a survey of this work would fall outside the scope of this article, it is instructive to consider in some detail the progress towards fuller understanding of junction transistor behaviour. The next section presents a very broad outline of this development with special emphasis on its bearing upon transistor equivalent circuits.

4. Transistor Theory and Transistor Equivalent Circuits

While to the physicist, the transistor may have represented an experimental verification of theories relating to electron energy levels and to the nature of carrier diffusion in the presence of potential barriers in semiconductors, to the electronics engineer transistors formed a new circuit element which, when used in conjunction with other such elements amplified, oscillated, or performed switching functions.

The task of designing transistor circuits required that the transistor itself could be represented in the form of equivalent circuits, built up of basic elements such as impedances and voltage or current generators. An equivalent circuit would be adequate provided it constituted a fair approximation to those aspects of transistor behaviour which were relevant to a particular design problem. This restriction was a very important one, for it made it possible to formulate equivalent circuits of transistors without getting involved in the theory of their physical action at all.

There are evidently two fundamentally different approaches to the problem of formulating an equivalent network to any circuit

element. The basic one starts from an analysis of the physical principles underlying the mode of action of the device, arrives thereby at the desired current-voltage relations and expresses the latter in terms of a network "analogue." The alternative method consists in studying empirically the behaviour of the element over the range of interest and synthesizing a network which simulates this behaviour, in other words, treating the transistor itself as a black box.

Both the black-box and the analytic approach have played a part in the development of transistor equivalent circuits, and it is instructive to follow the progress from the former to the latter since it is closely linked with the advances in our understanding of the transistor during the period under review.

4.1. "Synthetic" Equivalent Circuits

The first comprehensive discussion of the circuit behaviour of transistors was presented by Ryder and Kircher²³ in July 1949. In their introduction to this paper these authors made it clear that the "synthetic" method was being used: ". . . in order to discuss its circuit aspects, little reference to the transistor is necessary. One needs only certain properties of the transistor which are empirically obtainable by measurement; these properties then determine the behaviour in the manner prescribed by general network theory." The circuit aspects considered were those of small signal amplification, for which the transistor can be represented by a combination of passive and active linear elements. The one chosen was the by now very familiar "T"-network involving the low frequency z -parameters consisting of passive emitter, base and collector impedances together with a current or voltage generator in the collector branch. Although the form of the T-network suggested an analogy to the physical structure of transistors it could not be taken as deriving from the theory of transistor action. In fact, for the point-contact transistors upon which in the main this paper was based, no comprehensive theory has been evolved even today, although a number of papers have been published in which theories to account for the observed current multiplication at the collector were put forward.

With the transistor represented by its equivalent T-network, the performance characteristics of the three basic amplifier configurations—"common base," "common emitter" and

"common collector" could be calculated, matching requirements in cascaded amplifiers formulated and similar analyses carried out. The choice of a T-network was, except for the above noted analogy to transistor structure, arbitrary. In accordance with general network theory, once the transistor was represented as a linear four-pole device, characterized by input variables v_1, i_1 , and output variables v_2, i_2 , it could be represented by a number of active networks depending upon the choice of the dependent variables and of the one or two generator circuits.

A number of typical examples are shown in Fig. 1. Whichever network was chosen to represent the device, the information it synthesized was the same and represented a linearization of the measured characteristics at a chosen operating point. Such representations were thus not applicable to circuit problems which involved the large signal (and thus very non-linear) properties of the transistors. To include the latter, and, in particular, for dealing with the switching and negative resistance properties of point contact transistors, special methods (e.g. graphical ones) had to be devised (cf. Anderson²⁴). Nevertheless in practice rapid progress was made with the design and construction of prototype digital computers. One of the major difficulties, the variation of characteristics from one point contact transistor to another, was overcome by surrounding the transistor with suitable limiting diodes so that voltage levels and steady state currents were fixed independently from the transistor.²⁵

4.2. "Analytic" Equivalent Circuits

When the successful production of the first junction transistor was announced in 1951¹⁴ it was a natural development to adapt the body of equivalent circuit theory which had grown up around the point-contact transistor, by choosing suitable values for the component impedances or admittances, to junction transistor use. Thus the starting point for junction transistor circuit theory remained, initially, the empirical characteristics of the device, in spite of the theory already available concerning junction transistor action.¹⁵

However there were several reasons which made a more analytic approach to junction transistor equivalent circuits desirable. Compared with the point contact types in which a strong electric field assisted the passage of

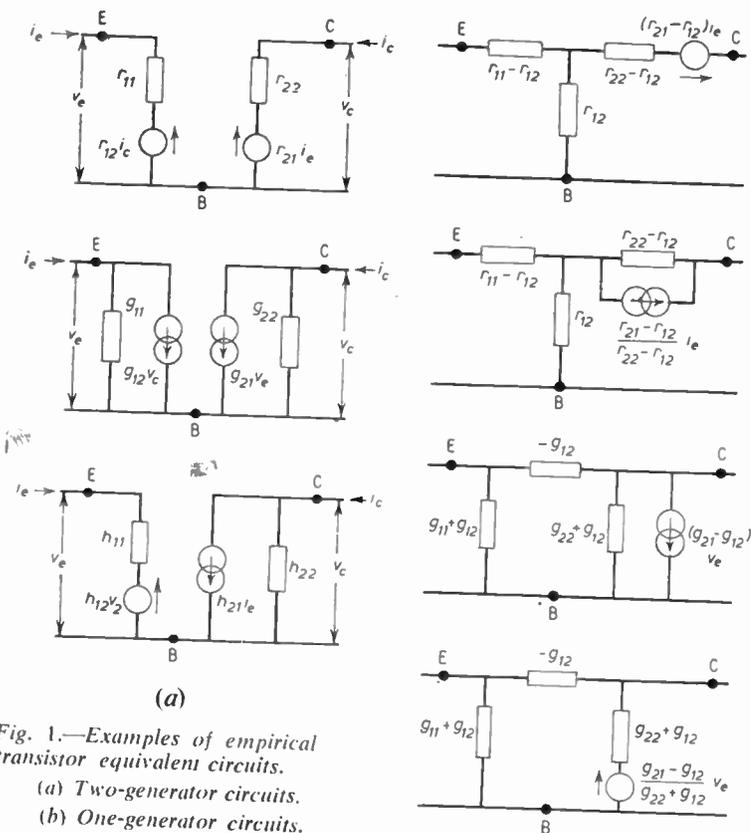


Fig. 1.—Examples of empirical transistor equivalent circuits.
 (a) Two-generator circuits.
 (b) One-generator circuits.

carriers from emitter to collector, the early junction transistors had considerably more severe frequency limitations. Carrier flow from emitter to collector consisted of a diffusion process which, with base widths of a few thousandths of an inch, would result in phase shifts and reduction of gain at frequencies well below the region at which point contact types would operate satisfactorily, requiring that frequency dependent elements be incorporated in the equivalent circuit. The strong temperature dependence of both large and small signal parameters made it necessary to consider aspects not covered by the small signal equivalent circuit at all in order to achieve temperature stabilization of circuits.

At the same time the work on the physical theory of junction transistor action inaugurated by Shockley progressed as efforts were made to pave the way towards improving the frequency characteristics of junction transistors by a fuller understanding of the theory.

The emphasis was placed on bridging the gap still existing between the diffusion equations which have been shown to govern the motion of electrons and holes within the semiconductor material on the one hand, and the empirical "T" or "hybrid" networks which represent the small signal behaviour of the transistor on the other.

The Shockley analysis has shown that the essential small signal characteristics of a $p-n$ junction could be obtained from a solution of the diffusion equations for minority and majority carriers in each region. Thus for the flow of holes in an n -type region, for example, a solution is required of

$$\frac{\partial p}{\partial t} = \frac{p_n - p}{\tau_p} + D_p \frac{\partial^2 p}{\partial x^2}$$

where p and p_n denote actual and equilibrium hole concentration in the n region, τ_p is the lifetime of a hole (with regard to hole-electron recombination processes which would lead to its elimination), and D_p is the diffusion constant for holes. By assuming the hole concentration to consist of a d.c. and an a.c. component namely

$$p = P_0 + p_1 e^{j\omega t} \text{ where } p_1 \ll P_0,$$

solutions for P_0 and p_1 as functions of x are obtained. The appropriate boundary conditions at the junctions ($x=0$ and $x=w$) follow from the basic relation between changes in hole density, p and changes in potential, V :

$$p = p_n \exp(qV/kT) = p_n \exp(\Lambda V)$$

$\Lambda = q/kT$ where q =electronic charge, T =absolute temperature, k =Boltzmann's constant. If V is of the form $V_0 + v_1 \exp(j\omega t)$, the "small signal" relation between the hole density and applied voltage assumes the form

$$p_1 = \frac{\partial P_0}{\partial V} v_1 = p_n \Lambda \exp(\Lambda V) v_1$$

Corresponding equations govern the density distribution of electrons. The hole and electron

currents are related to the hole and electron concentrations by the equations

$$I_p = -q D_p \frac{\partial p}{\partial x} \quad I_n = q D_n \frac{\partial n}{\partial x}$$

where n is the electron concentration and D_n the electron diffusion constant.

If the procedure just outlined is carried out with reference to the one-dimensional idealized transistor structure shown in Fig. 2 in which a base region of width W separates emitter and collector regions, voltages V_e and V_c are applied across the emitter-base and the collector-base junction, and the currents represent the sum of electron and hole currents, then complete expressions for both large and small signal relations are obtained. The large signal relations have been discussed in a paper by Ebers and Moll²⁶; on account of the non-linearities involved they do not lend themselves to the formulation of an equivalent circuit of a simple type.

The small signal short circuit admittance parameters, y_{ik} which determine the relations between the alternating currents i_e , i_c and voltages v_e , v_c through

$$i_e = y_{11} v_e + y_{12} v_c$$

$$i_c = y_{21} v_e + y_{22} v_c$$

when derived in the above manner, are given by the expressions

$$y_{11} = G \theta \coth \theta + Y_n \cong G \text{ for } \frac{W}{L_p} \ll 1$$

$$y_{12} = -G \theta \operatorname{cosech} \theta / K' \cong -G / K'$$

$$y_{21} = -G \theta \operatorname{cosech} \theta \cong -G$$

$$y_{22} = G \theta \coth \theta / K' \cong G / K'$$

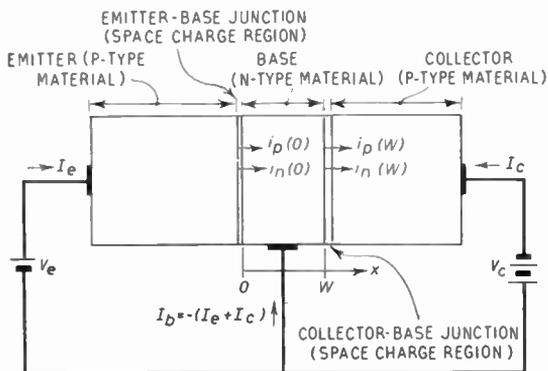


Fig. 2.—Idealized p-n-p transistor structure.

where

$$G = \frac{q}{W} n_p p_n \exp(\Delta V_e) (\cong \Delta I_E)$$

$$\theta = \frac{W}{L_p} (1 + j\omega\tau_p)^{\frac{1}{2}}$$

$$Y_n = G \frac{D_n n_p W}{D_p p_n L_n} (1 + j\omega\tau_n)^{\frac{1}{2}}$$

$$1/K' = \frac{\exp(\Delta V_c)}{\exp(\Delta V_e)}$$

L_p = hole diffusion length in n -region

L_n = diffusion length in p -region

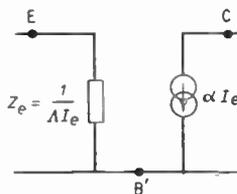


Fig. 3.—Equivalent circuit for transistor based on simple diffusion theory.

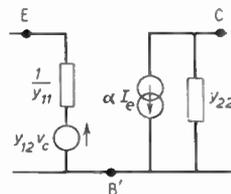


Fig. 4.—Modification of equivalent circuit of Fig. 3 to include the Early effect.

They thus lead to the theoretical equivalent circuit for the transistor shown in Fig. 3, which is characterized by an input impedance

$$\frac{1}{y_{11}} = z_e \cong \frac{1}{\Delta I_E} \quad (I_E = \text{d.c. emitter current})$$

and a (short-circuit) current gain factor from emitter to collector given by

$$\alpha = y_{21}/y_{11} = \frac{G \theta \operatorname{cosech} \theta}{G \theta \coth \theta + Y_n}$$

On account of the exponential terms in the expression for K' , the value of $1/K'$ for normal operating voltages, i.e. V_e positive, V_c negative and in excess of 0.5 volts, will be extremely small so that the feedback admittance y_{12} and the output admittance y_{22} become almost zero and can be neglected. These facts were in contradiction with experimental data.

Early^{16, 27} showed that the theoretical values for both parameters were greatly affected if account was taken of the fact that the width of the base layer was dependent upon the collector voltage. This base-width modulation results from the fact that the collector barrier layer increases in width with increasing reverse voltage, thus encroaching upon the narrow base.

In terms of the preceding results, base width modulation affects the value of the factor K

which enters into the feedback and output admittances. Its value changes from $1/K'$ to

$$\frac{1}{K} = \frac{1}{\Lambda L_p} \frac{\partial W}{\partial V_c} \operatorname{cosech} \frac{W}{L_p} + \frac{\exp(\Delta V_c)}{\exp(\Delta V_e)}$$

The theoretical equivalent circuit thus becomes modified to the one shown in Fig. 4 in which the voltage generator $y_{12} v_c$ and output admittance y_{22} due to the Early effect have been incorporated.

The above derivation of the equivalent circuit was based upon the solution of the carrier diffusion equations. In order to represent transistor behaviour fully a number of

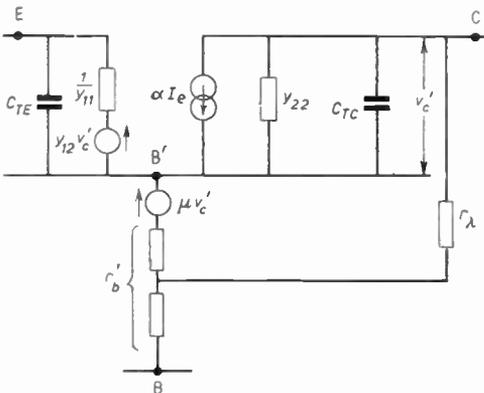


Fig. 5.—Further development to Fig. 3 to take into account passive capacitances, Early effect, external base resistance and surface leakage effects.

other factors not emerging from the differential equations must be added. These arise firstly from the passive capacitances of the emitter and collector barrier layers, C_{TE} and C_{TC} , secondly from the majority carrier resistance of the bulk material between the actual base region of the junction and the external connection to it. The value of this “external” base resistance will be affected by the base width modulation effect mentioned above so that it is represented as a resistance r'_b in series with a voltage generator $\mu_{bc} v'_c$. Finally surface leakage effects may be included as a resistance r_λ , and account taken of the actual geometry of the junction which will determine to what extent the flow paths of the different constituents of the base current will vary. A complete theoretical equivalent circuit may take the form shown in Fig. 5.

It is worth noting that although the development of the theory of the transistor led to the gradual improvement of its theoretical equivalent

circuit, the terms linked most closely with “transistor action” remain those derived by Shockley from the solution of the diffusion equation, modified by the Early-effect terms. Whereas originally the theoretical equivalent circuit had too few elements to be transformed into a representative empirical equivalent circuit of the T or π type, with the later forms of the theoretical circuit such transformation was not only possible but, as the number of elements and cross connections increased, necessary for practical purposes.

4.3. Equivalent Circuit and Frequency Dependence of Parameters.

In order to assess the frequency dependence of the admittances many simplified forms representing approximations to the theoretical expressions valid for certain frequency ranges have been developed. Of these perhaps the most instructive, since most general, is the one proposed by Zawels.²⁸ Zawels developed the analogy between the admittance expressions and the transmission line equations already pointed out by Early and was thereby led to what he described as the “Natural Equivalent Circuit of the Transistor.” This describes the high frequency behaviour of the admittances accurately and can be progressively simplified to lower frequencies until it again assumes the familiar T or π network shape (Fig. 6).

While all the above considerations were based upon small signal solution of the diffusion equation this limitation was not a necessary one, since for a signal of the form $P_0 + p_1 e^{j\omega t}$ solutions can also be obtained for the terms derived from P_0 . Here the interest is centred upon large signal behaviour, especially the changes associated with changes in the sign of V_E and V_C . Such considerations are relevant to switching applications in which the transistor may be transferred from an OFF state in which both junctions are reverse biased to an ON state in which the emitter alone, or both emitter and collector, are forward biased (“Saturation”). While steady state solutions for the total as opposed to the small signal currents had already been obtained by Shockley, it became necessary to obtain transient solutions which indicated the relationship between the geometry of the junction and the speed of response to sudden changes in applied voltages or currents. One effect in particular which was noted in both p-n junction diodes and junction transistors was the so called “hole-storage” effect. This

represents a limit to the speed with which large changes in minority carrier concentration can be obtained, and is linked to the fact that minority carriers cannot be made to disappear instantly but must either be swept out of a region by a suitable collecting field or else will disappear by recombination with majority carriers—a process governed by a finite lifetime. In practice the hole storage effect means that a junction which has been biased in the forward direction will not assume its normal high reverse impedance immediately upon reversal of the applied potential but only after a finite interval during which the impedance gradually increases as the minority carrier density is diminished.

4.4. Current Dependence of Equivalent Circuit Parameters

While the theory of the small-signal equivalent circuit was extended in response to the

aim of extending the h.f. performance of junction transistors, and the calculations of large signal transient solutions were linked to considerations of switching performance, another development took place which reflected the desire to gain control over those factors of transistor behaviour which would make operation at large power levels feasible.

It had been noticed that severe nonlinearities resulted if the power level at which a junction transistor amplifier was operated was increased above levels of perhaps 10–15 mW. This effect was traced to a dependence of the small signal parameters on operating currents which was not accounted for by the Shockley and Early theories. In particular the current amplification factor α ($=\partial I_c/\partial I_e$) was found to decrease with increasing current levels. Investigations into the underlying causes led to a further improvement in understanding of junction transistor operation and important extensions to the theory. Briefly, these extensions consisted of taking two factors into account which had been heretofore neglected: the effect of the surface, and the changes in the flow of carriers which took place if the density of carriers increased to such an extent that effects due to the field set up by the carriers themselves could no longer be neglected. Under such conditions the equation governing the carrier flow would contain in addition to the diffusion term $D\partial^2 p/\partial x^2$ also a drift term of the form $\mu p E$.

Thus an examination of the range of validity of the simplifying assumptions, both with regard to the geometry and to the pure diffusion flow of the carriers was published by Rittner in June 1954.²⁹ He found that while Shockley's theory was applicable to the emitter and collector regions for all current values of practical importance this was not so in the case of the base region where the assumptions implied very low current densities—lower than used in practical devices.

Rittner, using the theoretical results of Herring³⁰ and van Roosbroeck³¹ was able to obtain solutions of more general equations describing minority carrier flow in the presence of both diffusion and drift motion. He found that in both the two limiting cases of (i) small injection levels—i.e. minority carrier densities in the base region very much smaller than the equilibrium concentration of majority carriers in that region—and, (ii) very large injection levels, the minority carrier density decreased

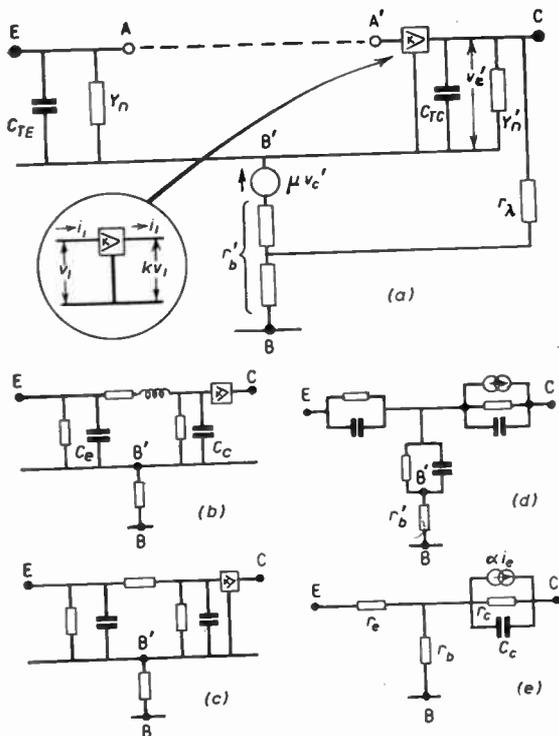


Fig. 6.—Transmission line equivalent circuit and its progressive simplification.

- Y_n, Y'_n = admittance linked to majority carrier flow.
- r_λ = Surface leakage term.
- A-A' = Transmission line representing minority carrier flow.

linearly from the emitter to the collector side of the base, but that in the high injection level case the diffusion constant was effectively doubled. This result had also been deduced by Webster¹⁷ in connection with some considerations of the operation of power transistors.

4.5. High Frequency Considerations

The work outlined above together with similar investigations into the design of transistors capable of operating at higher frequencies established that for junction transistors of both the grown and the alloyed type the main factors affecting the high frequency characteristics were the transit time of minority carriers across the base region, τ , the collector barrier capacitance, C_c , and the external base resistance, r_b' . This result was summarized^{27,32} in the proposal of a "figure of merit" for h.f. performance of different transistors given by $1/r_b' C_c \tau$.

Efforts were accordingly made to reduce these parameters by suitable changes in the device geometry. Examples of the resulting types comprise the "well"-type and the related surface-barrier transistor, the $p-n-i-p$ and $n-p-i-n$ transistors and the drift transistor.

In the "well" and surface barrier types a compromise is reached between the conflicting requirements of small base layer width and low external base resistance by using a relatively thick germanium wafer and drilling, or etching, a circular region down to the required thickness with the emitter and collector electrodes facing one another across the thin region. At the same time the electrodes are made small to reduce the collector capacitance.

A different approach is used in the "swept intrinsic" ($p-n-i-p$, $n-p-i-n$) and "drift" transistors. Here a non-uniform impurity density within the base region is used, which, in the case of the drift type²⁰ consists of an exponential change of impurity concentration with distance, the concentration being largest at the emitter side. In the $p-n-i-p$ type,¹⁹ a uniformly doped region on the emitter side of the base is followed by an intrinsic region in which a strong field ensures that injected minority carriers are rapidly swept to the collector. The detailed theory of these two types of transistor indicates that the modification in base layer structure yields improvements with regard to all the factors which enter into the h.f. figure of merit.

It may perhaps be taken as a measure of the generality achieved in transistor design theory that the latter could be applied without the need for any extension to the type of structure obtained by means of the new diffusion technique of junction fabrication mentioned above. Although this results in junction transistors with base layers which are an order of magnitude smaller in width than those obtained by the older techniques, and in spite of the fact that these base layers tend to be of the non-uniform impurity concentration type typical of the "drift" transistor, the theory has become sufficiently comprehensive to be applicable in a direct manner, and to enable the derivation of an appropriate equivalent circuit to be carried out. The latter again permits the prediction of the high-frequency performance of the device and takes into account the fact that because of the extreme thinness of the base region and the presence of the drift field, minority carrier transit time is so short in the diffused junction transistor that even with material of short minority carrier lifetime recombination in the base region becomes quite negligible and other factors like emitter diffusion capacitance and base resistance determine the ultimate frequency limitations.

5. Conclusions

It was emphasized at the beginning of this review that only during the last 12-18 months has the transistor begun to establish itself as a component used in mass produced commercial equipment. The preceding six years represented a preparatory phase which led up to the present stage by virtue of the very active research and development effort which characterized the evolution of semiconductor elements. It appears probable that during this phase the rather spectacular development of transistors and related devices to some extent delayed their widespread adoption owing to the fact that whenever a particular type of device had reached a stage where its commercial use became feasible, a superior product would already have been announced by one of the semiconductor laboratories, giving rise to a series of situations in each of which the promise of future achievement overshadowed all that had already been achieved. Thus, while prototype point-contact transistor computers were in process of construction junction transistors proved to be feasible and to offer a degree of

designability far in excess of any that could be foreseen for the point contact types. Again while the grown junction type of transistor entered the pilot production stage the practicality of the alloyed junction type with its promise of easier large-scale production was established. In much the same manner various methods of improving high frequency characteristics followed one another finally to culminate, very recently, in the announcement by the Bell Telephone Laboratories of the diffusion technique for the fabrication of very thin junctions.

It was thus inevitable that a certain degree of stability was awaited before the entry of the transistor into its first future mass market was staged. By the end of 1954 the point had been reached, in respect of low and medium frequency transistors, which made, at any rate in the opinion of several U.S. manufacturers, the transistorized portable radio receiver a commercially attractive proposition. During the following year the majority of set manufacturers—all of whom had been experimenting with the new element for a considerable time—announced transistor portable receivers.

The next stage in the domestic entertainment field will be the automobile radio which will almost certainly be launched within the next few months. After that it is doubtful whether there will remain any part of the domestic radio (and television) field in which transistorization will not become of commercial importance.

With regard to the use of transistors in computer and switching circuits the rate of progress has been lower for the obvious reason that performance requirements are considerably more severe than in the case of domestic entertainment equipment. Here the position is complicated by the fact that—until the advent of the diffused junction types which have, however, not yet progressed beyond the “feasibility proof” stage—not only did the junction transistor set limitations with regard to its large signal characteristics, such as finite “OFF” and “ON” impedances when used as an electronic switch, and hole storage effects when used as a pulse amplifier, but whereas in the radio and transmission field the transistor’s only rival consisted of the thermionic valve, in the switching field the cold cathode tube represents a significant competitor.

As switching elements for moderate speed requirements cold cathode tubes are able to

offer advantages similar to those provided by the transistor and to do so at a cost which may, in certain applications, tilt the balance in their favour. To quote an example, cold cathode tubes have been successfully used in automatic telephony both as pulse counting, i.e. computing, elements and as “switches” through which speech circuits are set up. In this field therefore it is as yet impossible to say with certainty what the position of the transistor will be in ten years time although the most probable development will be towards an electronic exchange containing both transistors and cold cathode tubes. What is virtually certain is that the progress of the transistor in the telephone switching field would have been a much more rapid one had there not existed already an alternative element, comparable to the transistor in some of its performance characteristics as well as in its economics.

Summing up, we can thus say that three factors have been responsible for the relative slowness with which the invention of the transistor has made its impact upon the electronics industry. The early transistors were almost immediately overshadowed by later more promising developments which together with the large research effort which made further rapid advances likely, suggested to many a wait-and-see policy as the wisest course during the period 1948-52. Manufacture of the new device proved not so easy as to permit a drastic reduction in price. Finally with regard to switching and computing applications the transistor had and has to compete with other circuit elements which offer in relation to the thermionic valve similar advantages as the transistor itself.

Looking ahead with the above assessment in mind certain predictions can be made with what appears a reasonable degree of safety. Thus the acceptance of the transistor in the domestic entertainment field will act as a powerful incentive towards improvements in manufacturing techniques leading to true mass production and consequent cost reductions. This development will in turn benefit also the more “difficult” types of switching transistors so that an increase in the rate of transistorization of computers can be expected. The understanding which has been achieved with regard to design and circuit theory will pave the way for application extensions and for the development of further specialized types which

are capable of performing required functions in a simple and economical manner. Finally, the extension of transistor techniques to the v.h.f. field and beyond, which the diffused junction technique promises to make possible, will open up the important field of mobile communication equipment.

The above considerations thus suggest that the next five to seven years will see the dramatic expansion of transistor applications which, when it was first suggested, seemed to be inspired by an undue optimism. Even then it will not be true—as has sometimes been proposed—that the transistor has made the thermionic valve obsolete. But whereas in 1953 it seemed that the transistor and valve would complement one another, it is probable that by, say, 1965, over a wide range of equipment the valve will at best supplement the transistor.

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537.311.33:621.375.4

Behaviour of the transistor at high current densities. F. H. STIELTJES and L. J. TUMMERS. *Philips Technical Review*, 18, pp. 61-68, July 1956.

At high current densities the simple theory of the junction transistor is no longer valid because the minority concentration in the base ceases to be everywhere negligible compared with the majority concentration. One consequence of this is that the base loss drops fairly quickly to half its initial value as the current density is raised; another consequence is that the emitter loss gradually increases. The increase in emitter loss continues long after the base loss has become constant, the net result being that the total losses go on increasing and the current amplification factor falls off. The higher the equilibrium concentration of majority charge carriers in the emitter, the slower the rise of emitter losses with current densities. Where *p-n-p* alloy transistors are concerned, this higher concentration can be obtained by the employment of a gallium-indium alloy as acceptor material for the emitter instead of the usual pure indium.

539.154.3:621.37/8

A nuclear magnetic resonance apparatus. A. K. SAHA, B. M. BANERJEE, T. P. DAS, D. K. ROY, S. K. GHOSE ROY and T. GHOSE. *Indian Journal of Physics*, 30, p. 211, May 1956.

Following in the main Gutowsky's model, a nuclear magnetic resonance apparatus has been set up. It includes both Purcell's double bridge and marginal oscillator circuit for the detection of nuclear resonance signals. A Bloch head arrangement has also been set up recently, and a detailed account of the instrument is given, with some records of the signal obtained by different techniques.

621.316.97

Magnetic field strength in the corners of a shielded space (corner effect). H. KADEN. *Archiv der Elektrischen Übertragung*, 10, pp. 275-82, July 1956.

The corner effect comes into being when the direction of the outer magnetic field is perpendicular to a shielding wall; if its direction is parallel to the shielding walls, the field inside the shield is uniform throughout. When in the former case a corner is approached from the inside, the field rises rapidly, viz., as a function $1/\Delta r^{4/3}$ (Δr = radial distance from the corner). The magnitude $|H|$ of the magnetic field strength H is plotted in the ordinate as referred to the field strength H_i existing at a great distance from the corner. On the abscissa the quantity $2\Delta r/D$ (D = distance of the shielding walls) has been chosen as variable. Assuming for instance $2\Delta r/D = 0.1$, then $|H|/|H_i| = 5.6$, and for $2\Delta r/D = 0.01$ it is found that $|H|/|H_i| = 120$. The direction of the field is shown in a figure to run across the corner. The corner effect can be cut down either by reinforcing the shielding walls near the corners, or by rounding out the corners.

A selection of abstracts from European and Commonwealth journals received in the Library of the Institution. 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.

621.372.5

The wave representation of an equivalent noise quadripole. H. BAUER and H. ROTHE. *Archiv der Elektrischen Übertragung*, 10, pp. 241-42, June 1956.

After a brief introduction into the theory of waves it is shown that sources of noise current and noise voltage can be interpreted as "impressed" noise waves. From this information the equivalent noise quadripole is calculated in a wave representation. The relationship between the wave matrices (scattering matrix, T-matrix) and the impedance matrices is derived in detail in an appendix.

621.373.423

The equivalent noise-wave quadripole of transit-time tubes. H. BAUER and H. ROTHE. *Archiv der Elektrischen Übertragung*, 10, pp. 283-98, July 1956.

In an earlier paper by these authors (see above) the noise-wave quadripole has been introduced as the equivalent for the description of the noise behaviour of amplifiers at highest frequencies. The present paper shows that the parameters of this quadripole can be calculated with many transit-time tubes. The significance of the parameters for the analysis of noise sources is derived and the measurement of the parameters of a low-noise travelling wave tube with inherent defects is described as an example.

621.374:621.314.7

A transistor frequency divider. M. VALERIANI. *Elettronica*, 5, p. 68, March 1956.

The frequency divider described is a new version of the type of circuit already in operation with valves, the regenerative divider of the Miller type. The standard frequency is 100 kc/s, and is divided in three stages down to 1 kc/s and 800 c/s. All constructional details are given. Total power consumption is below 200 mW and estimated life is around 100,000 hours.

621.375.1

Control of amplifiers by the multiple echo system. G. ZETTI. *Elettronica*, 5, p. 77, March 1956.

A control system for amplifiers is described which is capable of supplying information either on the amplification curve or phase shift of the amplifier under test. After some considerations on a few simple and fundamental cases, the author examines and interprets the deformations of the controlling impulses in the more general and practical cases. The article concludes with a note on the shape and duration of the control impulse with data on the network to produce it.

621.375.121.018.782.3:621.397.62

Phase linearity of television receivers. A. VAN WEEL. *Philips Technical Review*, 18, pp. 33-51, July 1956.

Increasing the selectivity of i.f. amplifiers of television receivers entails considerable deviations from the linear relationship between phase and frequency necessary to provide a picture of good quality. Phase compensation at the transmitter is limited by the differing phase characteristics of receivers, and optimum compensation at the receiver is usually expensive. An i.f. amplifier possessing an optimum amplitude characteristic within the pass-band, high selectivity, and which is very nearly phase linear is described. Bode's theorem has been used to design a 5-stage amplifier, the amplitude curve of which falls to 50% of maximum amplification at the limits of the pass band, the requisite selectivity at frequencies capable of causing interference being provided by four trap circuits. Optimum picture quality has been obtained for the given band-width. The picture quality of the phase linear receiver is less sensitive to detuning than it is with ordinary receivers.

621.395.623.8

Loudspeaker equivalent circuit for receiver measurements. H. MAYR. *Elettronica*, 5, p. 73, March 1956.

A four terminal equivalent circuit of a moving coil loudspeaker is described, which presents an input impedance very close to that of a loudspeaker, and an output voltage proportional to the sound pressure on the axis of the loudspeaker. The validity of the equivalence is limited on the high end of the spectrum to those frequencies for which the diaphragm may still be considered rigid.

621.396.11

Ionospheric prediction methods and the probable sources of error. S. S. BARAL. *Indian Journal of Physics*, 30, p. 189, April 1956.

The various sources of error in the prediction of foE, foF1, foF2 and (M3000)F2 are discussed. It is shown that the deviations of the foE and medium-latitude foF1 predictions are to be ascribed to inaccuracy in sunspot number prediction. The deviations of high and low latitude foF1 predictions are to be ascribed to deviation from $(\cos \chi)^2$ law. Deviations of foF2 and (M3000)F2 predictions are caused by the insufficient knowledge of the diurnal and seasonal trends of these parameters. Interpolation errors of foF2 and (M3000)F2 are due to incomplete knowledge of the geographical distribution of these parameters. The law of geomagnetic control, on which the predictions are based, is different for different hours of the day. For instance, during equinox months, the geomagnetic latitude distribution of foF2 values shows a cusp near the geomagnetic equator for hours for which the F-layer is separated into F1 and F2 and a single maximum near the geomagnetic equator for hours for which the layer is not so separated. It has been found that the inaccuracy in M.U.F. prediction cannot be completely accounted for by the inaccuracies of fo and M predictions taken together. Study of the day to day dispersion of foF2 values from their monthly median shows that the dispersion is low for low values of the solar zenith angle. No such generalization can, however, be made in the case of the dispersion of (M3000)F2 values.

621.396.62.029.62:621.376.3

Measurement of the spurious frequencies radiated by an f.m. receiver. J. MEYER DE STANDELHOFFEN. *Elettronica*, 5, p. 56, March-April 1956.

A sub-committee of the I.E.C. has undertaken a number of measurements on f.m. receivers from fourteen different firms, in order to compare various methods which could be used as international standards. The main characteristics of these methods are enumerated, and their results summarized. The results are compared with those obtained through a simplified calculation. The measurements made at distances of 30, 10 and 3 metres give equivalent results, to a degree of precision sufficient in the majority of practical cases.

621.396.62:621.317.729

Comparison of standardized instruments for the measurement of spurious radiating frequencies. C. EGIDI. *Elettronica*, 5, p. 64, March 1956.

This short note relates to the measurements on f.m. receivers mentioned in the paper by J. Meyer de Stadelhoffen. A comparison is made between the portable measuring instrument of the I.E.N.G.F. and the fixed R.C.A. installation at Zürich. The measurements made following the I.E.C. method on the fourteen receivers mentioned in the previous paper are given, and a graph is given relating these measurements with others which follow the empirical method of disturbing a television receiver situated a short distance away.

621.396.674.3

Observations on the theory of radiation fields and impedance of aeriels. K. FRANZ. *Archiv der Elek-trischen Ubertragung*, 10, pp. 269-73, July 1956.

For aeriels of arbitrary shape a relationship is given between aerial inductance and overall frequency response of the radiation resistance. The finite nature of the reactive power concentrated near the aerial is proved. A long-wave dipole of maximum damping is calculated. A conversion is carried out from the limiting case of the reactance of an aerial enclosed in a cavity to the impedance of a radiating aerial. The classes of given fields are shown for which it is possible to find subsequently conductor configurations satisfying the boundary conditions, in analogy to a known method of potential theory.

621.398:629.13

"Jindivik"—radio controlled aircraft. E. W. BAYNTON, B. S. DEEGAN and R. W. LESLIE. *Proc. Instn Radio Engrs, Australia*, 17, pp. 267-77, August 1956.

The Jindivik is a jet powered target aircraft, which is controlled by radio either from a ground station or from a shepherd aircraft. The switching method of control is used; control signals transmitted over the radio link specify the required flight manoeuvres which are carried out under the control of the automatic pilot system. An f.m./a.m. telemetry system based on inductance type transducers transmits flight data back to the ground controller. Twin track magnetic tape equipment records the control and telemetry signals throughout each trial for subsequent study.