The Journal of the

BRITISH INSTITUTION OF RADIO ENGINEERS

FOUNDED 1925 INCORPORATED BY ROYAL CHARTER 1961

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

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The Annual Report of the Council of the Institution

The Council has pleasure in presenting the first Annual Report of the Institution since it was Incorporated by the grant of a Royal Charter. The Annual General Meeting will be held on Wednesday, 24th October 1962, at the London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, London, W.C.1, commencing at 6 p.m. (Notice of the meeting and Agenda were published in the August 1962 Journal.)

INTRODUCTION

THIS report reviews Institution activity for the 12 months ended 31st March 1962. The outstanding event of the year was the advice from Her Majesty's Privy Council, recorded in the August 1961 *Journal*, that a Royal Charter of Incorporation had been granted to the Institution.

This recognition came just 36 years after the foundation of the Institution in October 1925. The previous 35 annual reports of the Institution provide evidence of the manner in which the Institution has fulfilled the objects and purposes for which it was founded, which have again been avowed in the terms of the Royal Charter of Incorporation.

As shown throughout the following report, increased momentum has been given to every Institution activity. In the light of subsequent events, the 1961 Convention on "Radio Techniques and Space Research" was most opportune, providing, as it did, a valuable forum for examining new developments in these aspects of radio and electronic science and engineering.

Wider information services were provided by larger *Journal* content and by an increase in the number of meetings of the Institution held in London and throughout all its Sections. This was aided by the development of Group activity; the Television Group particularly distinguished itself in the valuable report it submitted to the Committee on Broadcasting.

A fundamental aim of the Institution during the whole of its existence has been to ensure adequate facilities for the training of the radio and electronic engineer. Development of radio and electronic science has intensified this need and once more it is possible to refer to the progress which has been made during the year in this aspect of the Institution's work. Discussions have been held with other engineering Institutions on the National Certificate Scheme, as well as the Common Section A Examination. This development has largely arisen from the meetings of the Joint I.E.E.–Brit.I.R.E. Committee which was established in January 1962.

Not the least important of the work done in shaping future policy was the visit of the Secretary to Canada and the United States of America to implement the Council's wish to strengthen not only the Institution's Commonwealth ties, but indeed, relations with all kindred organizations overseas. As shown in the report of the Executive Committee, such work calls for considerable concentration of effort in the immediate future.

Similar concern for the future is indicated by the start that has now been made on extending the Institution building, and by the activities of the latest Standing Committee—the Research Committee.

Sustained enterprise and an even greater expansion of Institution activity will continue to be required in the years ahead. The present position and achievements of the Institution owe much to the services of members on the various Committees and to the support which has been given to Institution activities by all members.

EXECUTIVE COMMITTEE

Before and subsequent to the lodgement of the Petition to Her Majesty's Privy Council for the grant of a Charter of Incorporation, the Executive Committee, in consultation with the Petitioners, was responsible for the drafting of Bye-laws. The draft Bye-laws were referred to Corporate Members for confirmation shortly after the year under review.†

In this work, as in the drafting of the original Petition, the Council of the Institution wishes to acknowledge the assistance given by Mr. C. Gray Hill, of Braund and Hill, Solicitors to the Institution, and by Sir Lynn Ungoed-Thomas, Q.C., M.P.‡

When allowed by Her Majesty's Privy Council the Bye-laws will prescribe the government and running of the Institution. The Council of the Institution has, however, asked that the Rules governing the formation and activities of Sections, Groups and Divisions of the Institution shall be separate from the Bye-laws. A specially appointed Committee of the Institution is drafting these rules to cover the Local Sections in the United Kingdom and the special requirements of Branches or Divisions of the Institution overseas. Such rules will be subject to allowance by The Lords of Her Majesty's Privy Council. Full details will, of course, be circulated to all Corporate Members of the Institution.

The Chartered body is continuing to develop the work and policy initiated by former Councils who operated under the Memorandum and Articles of the old Institution.

A particular example—referred to in the 1960 Annual Report—is the extension of Institution activities overseas. That report referred to the intention to review the Institution's work in Canada. Immediately after the grant of the Charter, the Secretary of the Institution made an extensive tour of Canada and the United States of America.

Arising out of Mr. Clifford's discussions with members and with professional bodies in Canada, the Council agreed that steps should be taken to have the Institution incorporated in Canada in accordance with Canadian law. This may best be done by promoting a Private Bill in the Canadian Houses of Parliament. Legal opinion has therefore been sought in Canada, and Messrs. Gowling, MacTavish, Osborne and Henderson of Ottawa, are acting for the Council in consultation with the Institution's Solicitors and Counsel in London.

The Council has also appointed Messrs. Snyder, Craig & Co. of Toronto as the Institution's Accountants and Auditors in Canada. This follows in principle the arrangements made in 1951 for Messrs. Fraser and Ross of Bangalore to act as the Institution's Accountants and Auditors in India.

In order to provide greater autonomy for members in countries of the Commonwealth the Council is investigating the possibility of providing separate secretarial facilities in some countries; this may best be achieved by co-operation with other Institutions who also have local sections in the countries concerned.

The Executive Committee is also considering a proposal which will enable Proceedings to be published regularly to reflect the activities of members in Canada and India. The first issue of separate Canadian Proceedings of the Brit.I.R.E. was published in September 1961, and with the first Convention to be organized by the Indian Sections in Delhi in 1963 it is hoped to commence regular publication of similar Proceedings for India.

In all these matters the Council has been pleased to have discussions with many Commonwealth members, and particularly with Major General B. D. Kapur (Chairman of the Institution's Indian Advisory Committee) and with Mr. L. H. Paddle (who was a founder member of the Institution and who has been prominently associated with the membership in Canada), both of whom visited England during the year and attended meetings of the Council.

Commonwealth Conference on Communications Satellites. The Council always welcomes the opportunity for closer relationship with the Commonwealth countries. The Commonwealth Conference on Communications Satellites held in London in March 1962 and sponsored by Her Majesty's Government, provided an occasion to entertain representatives of Commonwealth Administrations who attended the Conference.

A reception for the delegates was given by the President and officers of the Institution at the Savoy Hotel on 29th March and gave an opportunity early in the Conference to bring together again many delegates to the Institution's 1961 Convention on "Radio Techniques and Space Research".

Joint I.E.E.–Brit.I.R.E. Committee. This Committee, comprising four members from each Institution, was set up on the invitation of the Institution of Electrical Engineers for the purpose of examining

† The first Special General Meeting of Corporate Members of the Chartered Institution was held on 23rd May 1962 and a report of the meeting was contained in the August 1962 *Journal*.

‡ Since the submission of the draft Bye-laws to the Privy Council Sir Lynn Ungoed-Thomas has been appointed a Judge of the High Court.

the possibility of closer co-operation between the two Institutions. The first meeting of the Joint Committee was held on 6th February 1962 and the Councils of the two bodies subsequently approved the following terms of reference:

"To suggest and to examine means by which through collaboration between the two Institutions the progress of electronic and radio engineering can be fostered and to make recommendations for submission to the Councils of the two Institutions."

A considerable measure of agreement has been reached on several matters of common interest to the members of both Institutions, e.g. reciprocal arrangements for members to attend ordinary and group meetings. Joint meetings have already been held in some of the Local Centres or Sections and the Committees of the Medical Electronics Group of the I.E.E. and the Medical and Biological Electronics Group of the Brit.I.R.E. are collaborating to promote joint meetings in the 1962–63 session.

Some agreement has also been reached on the participation of the Brit.I.R.E. in the Engineering Institutions' Part 1 Examination scheme, and in membership of the Engineering Institutions' Joint Council.

Membership of Other Bodies. Council accepted the invitation of the British Conference on Automation and Computation for the Institution to become a member and two representatives of the Institution are now serving on the Council of the B.C.A.C.

The Institution has also been accepted as a member of the British Nuclear Energy Society.

National Productivity Year. The Council has been pleased to co-operate with the British Productivity Council in their plans for a "National Productivity Year" from November 1962 to November 1963. It has, for example, agreed that the Convention to be held in 1963 should have as its general theme "Electronic Aids to Industry" and a special Convention Committee has been appointed to arrange the programme. Local Section Committees are also organizing meetings in their respective areas at which papers will be read to indicate the most effective ways in which radio and electronics can be used toward improving productivity.

Institution Building. The reports of all the Standing Committees indicate the increasing rate of development of the Institution's activities. Problems which have confronted the Council for several years have been not only the acquisition of funds to purchase a suitable building for the Institution but, more recently, the fact that it is at present extremely difficult and costly to obtain either a freehold building or site in London.

The Council is therefore pleased to announce that the negotiations for acquiring from the Ministry of Works the leases of both Nos. 8 and 9 Bedford Square have been completed. Plans have been approved for the necessary interior structural alterations in order to merge the two buildings, thus providing for the adequate housing of the Institution's staff, extension of the Library, and holding some Institution meetings. Structural and building work will obviously take time and involve a great deal of capital expenditure, and this is referred to in the report of the Finance Committee. The Council believes, however, that all members will endorse its decision to acquire these two leasehold buildings for the Institution's needs without involving the Institution in heavy mortgage commitments.

RESEARCH COMMITTEE

During the year a Standing Research Committee was appointed with the following terms of reference:

"To consider the research needs of the United Kingdom and the Commonwealth in developing radio and electronic science and engineering, to consider all possible means by which research may be fostered in radio and electronics, and to advise the Council of the Institution on schemes of Research Studentships and Fellowships and other endowments which may be sponsored by the Institution and to act as a selection committee if and when appointments are made to such posts."

The Committee has started work on a report reviewing and assessing the pattern of future research in radio and electronics, which it is hoped to publish about the end of 1962.

One of the first tasks of the Committee was to implement the decision of the Council to establish Research Studentships in order to encourage fundamental research in radio and electronic engineering. The Council authorized the establishment of an Institution Research Fund and agreed that the awards should be named "The Mountbatten Research Studentships". By so naming the first of the Research Scholarships the Council has sought to honour an outstanding Member whose confidence in the purpose and objects of the Institution has been fully demonstrated over the past twenty-seven years, and whose especial concern for the co-ordination and development of research in radio and electronics has been a source of inspiration.

MEMBERSHIP COMMITTEE

The Membership continues to grow steadily and once again there has been a marked increase in the applications for Corporate and Graduate Membership. The increase in the number of Student registrations also augurs well for the future strength of the Institution.

The total membership and net increase over the last 10 years is shown in Table 1.

Table 1

Total membership at 31st March		*Net increase during the year*
1962	8108	1041
1961	7067	735
1960	6332	419
1959	5913	291
1958	5622	54
1957	5568	176
1956	5392	310
1955	5082	332
1954	4750	367
1953	4383	365

Table 2 gives an analysis of the elections and transfers considered during the year. Altogether 146 more proposals were considered than in the preceding year. The marked rise in Graduate and Associate Member elections is demonstrated by increases of 55% and 32% respectively on last year's election figures. The number of elections to Graduate is particularly noteworthy, as a large proportion of Graduates qualify for Corporate Membership within a few years.

Some confusion appears to exist in the minds of enquirers as to the status of Associateship and the qualifications required. The experience and responsibility in the profession required for election to this grade is commensurate with that required for Associate Membership. The main difference between the two grades of membership is in academic qualifications, and it is for this reason that Associates cannot be classified as Corporate Members.

In addition to the information given in Table 2, 725 applications for Student Membership were approved during the year, whilst 168 Students achieved Graduate Membership and 30 achieved Associate Membership over the same period. In the new Bye-laws of the Institution there is an important change of regulations regarding Student Membership. The new Bye-law 17 provides that no person shall be registered as a Student after having reached the age of 25 years, or shall remain a Student after reaching the age of 28 years. Registration will thus be restricted to genuine students who are engaged upon, and who intend to complete a course of study to obtain Graduate membership at a reasonably early age.

Further promise of future growth of membership is given by the number of inquiries. There were 3,964 inquiries in 1961–2; this is 1006 more than for the previous year.

In last year's report it was stated that Council was discussing the desirability of forming two Membership Committees, one to deal with proposals for corporate membership, and the other to deal with proposals for the non-corporate grades. No decision has yet been reached on this, and the question is still under review. Meanwhile the consideration of proposals is not being delayed.

Appointments Register. There is still a shortage of qualified radio and electronic engineers, as shown by the advertisements appearing regularly, not only in technical journals, but in the national press. The main

Table 2

	Considered	Member	Associate Member	Companion	Associate	Graduate	Total
Direct election	726	17	122	1	61	380	581
Reinstatements	11	—	5	—	1	5	11
Transfers from other grades .	554	20	162	—	10	168	360
	1291	37	289	1	72	553	952
Losses by resignation, expulsion, decease and transfer . .		11	50	—	53	150	264
Net gain in Membership . .		26	239	1	19	403	688

function of the Institution's Appointments Register has, therefore, been to help employers in making known their vacancies. During the year, only 33 members actually required introductions through the Appointments Register, and for that small number, no fewer than 128 introductions to prospective employers were effected.

This does not, of course, take into account the other "employer" inquiries such as requests for advice and assistance in making known their requirements to universities, technical colleges and the technical and national press.

Obituary. Council regret having to record the death of a number of members during the year, and in particular that of Dr. Charles Cornfield Garrard, who was the sixth President of the Institution in 1942, having originally been admitted to membership of the Institution in 1932.

TECHNICAL COMMITTEE

In recent years the Committee has been primarily concerned with the writing of reports and co-ordinating Institution activities in the preparation of standards and specifications. The Committee has these functions under review and furthermore intends to provide some overall arrangement for closer relationship with other Standing and Group Committees. It is probable, therefore, that the work of the Technical Committee will be divided as a result of the report which is being submitted to the Council of the Institution.

Reports and Recommendations

Reliability. The subject of Reliability has occupied the Committee's attention at almost every meeting during the past year. The results of these discussions were published in the April 1962 issue of the *Journal.* The Committee prepared a bibliography which was prefaced by some remarks on the general approach to Reliability which it was thought had not been previously stated with enough emphasis. Such fundamental considerations are not limited in application to radio and electronic engineering but are common to all branches of engineering.

The National Council for Quality Control and Reliability has developed its activities during the year. As reported in the last Annual Report the Institution is a constituent member of the National Council and is represented on that Council by the Chairman of the Technical Committee, Mr. F. G. Diver, who is also the Chairman of the Industry/Government Committee of the National Council.

"Recommended Methods of Expressing Electronic Instrument Characteristics." The eighth in this series of Recommendations is now in preparation and is concerned with Rectangular Pulse Generators. The last two sets of Recommendations, Numbers 7 and 8, will be published during 1962 and early 1963. The complete list of Recommendations is given below with their publication dates.

1. A.M. or F.M. Signal Generators	(January 1958)
2. Cathode-Ray Oscilloscopes	(January 1959)
3. Low Frequency Generators	(March 1960)
4. Valve Voltmeters	(April 1960)
5. A.C. Bridges	(August 1960)
6. Stabilized Power Supplies	(February 1961)
7. Wave and Distortion Analysers	(October 1962)
8. Rectangular Pulse Generators	(Early 1963)

Standards

The Technical Committee regards Standards as a most important aspect of engineering and in its own field the Committee is endeavouring to improve the quality and extent of Institution support for the activities of the British Standards Institution. To ensure quick liaison between the Technical Committee and the Institution's representatives serving on British Standards Institution's Technical Committees, each member of the Technical Committee has accepted responsibility for a group of representatives of the Institution on B.S.I. Committees, thus ensuring that technical advice is quickly available when required.

The number of representatives serving on B.S.I. Committees has increased by two during the year and the new Committees on which representatives have been appointed are:

TLE. 12/2—Mechanical Standardization of Transistors

DPE. 4 —Magnetic Tape for Data Processing

Through its representation on B.S.I. Committees the Institution maintains contact with developments in International Standardization carried out by the International Electro-technical Commission. At least one member of the Institution represented the B.S.I. in International Electro-technical Commission meetings in 1961 and further invitations have been issued to representatives of the Institution to attend the meetings of the I.E.C. during 1962.

The drafting of Standards and Specification is often a tedious and slow business, but it is nevertheless an important part of engineering development. The professional Institution can provide in these discussions an impartial view to balance the views of industry and of the Defence Services, whose opinions may well be influenced by non-technical considerations.

EXAMINATIONS COMMITTEE

The Graduateship Examination. As shown in Table 3 there was a noticeable increase in the number of candidates entering for the Graduateship Examination in 1961. The increase was mainly in the number of candidates entering for Section A; the number of candidates completing the entire examination did not increase significantly. The overall results for the year —263 candidates succeeded (in both Sections) out of the 757 candidates who wrote the examination—shows a 5% reduction compared with the 1960 results.

The impending changes in the Graduateship Examination syllabus probably accounted for some of the increase in examination entries and this trend has continued, 595 entries having been accepted in May 1962, an increase of 72 over November 1961. There is still a tendency for some candidates to enter for the examination without adequate preparation. This is no doubt the cause of the poorer overall results. Now that more colleges are offering courses preparing candidates to sit the Graduateship Examination, it is hoped that better results will be realized.

The 1961 Examinations were held at 71 centres throughout the world.

Exemptions. The continuing increase in the number of applications for membership has brought with it a corresponding increase in the number of candidates applying for exemption from the Graduateship Examination. In the period under review 1049 applications were received of which 421 were granted entire exemption and 540 were granted exemption from part of the Examination. The remaining applications were refused or deferred.

Theses. Only two theses were accepted in lieu of the entire Graduateship Examination out of seven submitted. A further six candidates were, however, granted permission to submit theses after the approval of the submitted synopsis. These figures emphasize the high standard expected and the strict control exercised over this alternative method of satisfying the Examination requirements.

Approval of Courses. Applications were received from a further 46 technical colleges inviting consideration of the extent to which exemption from the Institution's Graduateship Examination would be allowed on successful completion of the college courses. The majority of the applications were based on courses leading to the award of Higher National Certificates and Diplomas. In the main, the Institution's concern has been with the standard and scope of additional endorsement subjects in radio and electronics.

Considerable co-operation has been received from the technical colleges concerned, often as a result of members of the Institution visiting colleges and discussing with departmental heads the Institution's requirements. In consequence, many more colleges are now offering courses which meet the Institution's Graduateship Examination requirements, especially in the specialist subjects.

These courses, which are post-National Certificate, and which are run on a part-time day or evening basis, are assessed by the Institution. Some of the earlier courses which have been run for the past two or three years and assessed by the Institution have now also been accepted by the Joint Committee for National Certificates as endorsements to the Higher National Certificate.

Prize Winners. The Council takes this opportunity of congratulating the following candidates who were awarded prizes for their performance in the examinations held during 1961.

PRESIDENT'S PRIZE

Derek Wilfred Kent (*Graduate*). Enfield, Middlesex.

S. R. WALKER PRIZE

Peter Ridley (*Student*). Brampton, Cumberland.

ELECTRONIC MEASUREMENTS PRIZE

Hans Arno Fritz Korb (*Associate Member*). Switzerland.

Table 3

Graduateship Examination Entries and Results for 1961

	May 1961	*November 1961*
Entries received	480 (408)	523 (399)
Candidates who wrote the examinations	380 (306)	377 (297)
Candidates who succeeded in Section A	94 (88)	83 (69)
Candidates who succeeded in Section B	42 (46)	44 (36)
Number of candidates who successfully completed the full examination requirements	43 (49)	50 (40)

Figures in brackets are for 1960.

AUDIO FREQUENCY ENGINEERING PRIZE

Percy Childe (*Graduate*). Hong Kong.

The Associated Television Prize was withheld as no candidate reached a standard which was thought sufficiently outstanding for the award of a prize.

The present terms of reference of the Mountbatten Medal are felt to be too narrow and the Council is revising the terms of award of this prize.

Acknowledgments. The Council is particularly grateful to the members of the Institution who act as examiners in the Graduateship Examination and as assessors for the technical college courses. These members devote a great deal of time to the setting and marking of question papers and scripts and also in attending Committee meetings.

EDUCATION AND TRAINING COMMITTEE

The Institution's education and training policy has been laid down in the two reports prepared by the Education and Training Committee and published in the *Journal*.† The Committee has thus been able to devote more time to some of the other aspects of its work. Mention was made in the last Annual Report of the establishment of an Education Group and the Education and Training Committee have undertaken to organize meetings.

In its first session of meetings, the Group has held two symposiums and one evening meeting, all of which were very well attended and demonstrated the need for meetings on education topics. Further developments in this activity are planned and an increased number of meetings, both in London and in conjunction with Local Sections, are proposed in the future. It is also the intention of the Committee to encourage the submission of papers on education and training for publication in the *Journal* of the Institution.

The Future of Higher Education. There has been much discussion in the Press and amongst educationalists on the evidence which has been submitted to the Government Committee appointed "to review the pattern of full-time higher education" under the Chairmanship of the Right Hon. the Lord Robbins, C.B., Professor of Economics, University of London. The Education Panel of the Committee devoted a great deal of time to preparing evidence for submission to the Robbins Committee, much of which was based on the two reports previously mentioned. This evidence was published in the March 1962 issue of the *Journal*.

The final report of the Robbins Committee is awaited with great interest since it is likely to set the pattern of higher education for the future.

The Graduateship Examination. The changes in the Graduateship Examination which were announced in the last Annual Report have now been promulgated and the new syllabuses were published in the twenty-eighth edition of the Institution's Membership and Examination regulations. The changes in Section A will be introduced in May 1963 and those in Section B in November 1963. These changes were originally announced in the Institution's report "The Education and Training of the Professional Radio and Electronic Engineer." The proposal in that report that the Graduateship Examination should be extended to include a separate Section C comprising a paper "Principles of Management" is still being considered by the Council. It is felt that an understanding of management problems should be a prerequisite for election to Corporate Membership but is not necessary for Graduate Membership.

Common Educational Standards for all Engineers. The existence of over twenty professional engineering institutions, each concerned with the specialist needs of its own branch of engineering, precludes the establishment of a common examination syllabus by which applicants for membership of *all* institutions can be tested.

For many years, successive Education Committees of the Institution have expressed their belief in the desirability of reaching common understanding with other engineering institutions on common subjects of examination. It is still believed that there is a sufficient amount of common ground to warrant the establishment of a common Part I for all of the engineering institutions' graduateship examinations. Subsequent parts or sections would then leave adequate room for including the specialist needs of each institution. Moves in this direction coincide with the possibility that the National Certificate scheme will be common to all engineers at the Ordinary level.

Representation on Other Bodies. This year has been particularly noteworthy for the fact that the Institution has been invited to nominate representatives to serve on a number of committees concerned with education matters. Apart from the advisory committees of colleges of technology to which the Institution is

† "The Education and Training of the Professional Radio and Electronic Engineer", *J.Brit.I.R.E.*, **20**, pp. 643–56, September 1960. "The Practical Training of Professional Radio and Electronic Engineers", *J.Brit.I.R.E.*, **23**, pp. 171–6, March 1962.

often invited to appoint representatives, the main developments were the invitations from the Joint Committee for National Certificates and Diplomas in Electrical Engineering, and the Electrical Engineering Advisory Committee of the London and Home Counties Regional Advisory Council for Technological Education.

The Joint Committee for National Certificates in Electrical Engineering has grown up as a committee comprising representatives of the Ministry of Education and the Institution of Electrical Engineers together with some independent members. The Institution now has one representative sitting on this Committee and this will be particularly helpful in allowing the Institution's views to be made known, and in helping to ensure that some suitable National Certificates and endorsement subjects are available to students studying to satisfy the Institution's examination requirements by this route.

The Institution has always considered that it would be desirable to establish a separate Higher National Certificate in radio and electronic engineering administered by the Institution in conjunction with the Ministry of Education. Notwithstanding the representation now secured on the Joint Committee for National Certificates in Electrical Engineering, it is hoped that a separate scheme for National Certificates in Radio and Electronic Engineering will be set up.

During the year the Council renewed petitions to the Ministry of Education which were first started in 1935 and even then aimed at securing separate recognition of the requirements of the radio and electronic engineering profession.

In the last decade an increasing number of technical colleges have provided facilities for endorsement subjects in radio and electronics. Whilst at first regarded as a concession to the Graduate requirements of the Institution, the response and demand now amply justify the establishment of a separate scheme in radio and electronics such as is at present provided in the civil, mechanical, electrical, chemical, gas, production, building and mining engineering fields.

Representation on the London and Home Counties Regional Advisory Council for Technological Education is another important development. The work of the Council and their Advisory Committees in the respective subjects is to ensure that every new course is supported by an adequate demand, that it is carried out in a college which is suitably equipped with staff and laboratory facilities, and that there is no unnecessary duplication of courses in technical colleges serving the same areas.

Practical Training. It was reported in the last Annual Report that the Committee had been divided into two separate panels to enable a number of items of work to proceed simultaneously. The Practical Training Panel had a particularly active year and has been mainly occupied in preparing practical training reports concerned with (*a*) the professional engineer and (*b*) the technician. The former report was prepared and published in time for the meeting of the Education Group held on 27th September 1961. The discussion of the report was followed by a number of papers on practical training which were subsequently published in the *Journal* of the Institution.†

The Panel is now preparing a similar report to be concerned mainly with the training of technicians and others engaged in a technical capacity in the radio and electronics industry. Problems encountered are the absence of clear terms defining the levels of employment of technicians and an accepted term to describe lower grade technical employees. The word "mechanic" is not often used in the radio and electronics industry but it is perhaps desirable that this term should be adopted to cover the large number of workers in the industry equivalent to the craft workers in other industries.

The Training Panel has been fortunate in being able to call upon a group of members and non-members whose main concern is the training of technicians and mechanics. It is apparent that there are already moves to alter the training pattern and to break away from the standard five-year apprenticeship and this tendency will be commented upon in the Report.

† "A Symposium on Practical Training for Radio and Electronic Engineers", *J.Brit.I.R.E.*, **23**, pp. 259–72, April 1962.

LIBRARY COMMITTEE

Periodicals. During the past twelve months a number of new technical periodicals in the field of radio and electronics have been published. These include *World Aviation Electronics*, *Measurement and Control*, *World Medical Electronics*, *Instrument Review*, *International Science and Technology*, *Research and Development* and *Journal of the British Interplanetary Society*. New sets of bibliographies include *British Technology Index*, *Solid State Abstracts* and *Computing Reviews*. Some 240 periodicals are now received in the Library and 42 of these are bound in volumes. Complete volumes and single issues are available on loan, through the post, to members who are unable to visit 9 Bedford Square.

Stock of Volumes. New books added to the Library during the year total 187 and the stock is now some 2800 catalogued books. The acquisition of No. 8 Bedford Square will enable Library facilities to be extended.

Loans. The increase in membership has had an effect on the work of the Library. The number of loans, including renewals, has risen to 1548, an increase of approximately 10% on last year.

One of the important aspects of Library service is the provision of technical information. This varies from answering simple inquiries to providing extensive bibliographies. An example of this service is the bibliography prepared for the Technical Committee in connection with the Report on Reliability mentioned in last year's Annual Report and published in the April 1962 *Journal*.

Acknowledgments. The Institution wishes to thank members who have presented books to the Library during the past year, and publishers who have sent books for review in the *Journal* which have subsequently been placed in the Library for the use of members.

PROGRAMME AND PAPERS COMMITTEE

(including the Specialized Group Committees)

The 1961 Convention. The outstanding feature of the 1961–62 session was the Convention on Radio Techniques and Space Research, which was held at the University of Oxford in July 1961. A detailed report of the Convention was given in the August and September 1961 issues of the *Journal*. The direct planning of the Convention was the responsibility of the Convention Committee under the chairmanship of Mr. Ieuan Maddock, O.B.E., B.Sc. (Member).

A total of 43 papers was presented and while the majority of these papers referred to work being carried out in Great Britain and the Commonwealth, other contributions were received from the U.S.A. and U.S.S.R. Publication of the papers commenced in the August 1961 issue of the *Journal* and was completed in June 1962. Attendance at the Convention was international in character and the initiative of the Institution in arranging such a meeting at this time was widely praised.

Institution Meetings in London. The number of meetings held in London has been maintained at the level of the previous year, a total of 31 meetings having been held; a number of these were symposiums consisting of more than one session and the effective total may thus be considered to be forty.

Following the establishment during the year of the Education Group, there are now six Specialized Groups sponsoring meetings. The broad aim of the Programme and Papers Committee is to cover all branches of radio and electronic engineering by ensuring that matters not falling within the fields covered by the Specialized Groups are covered by meetings arranged by the main Programme-Committee.

The policy of arranging occasional large symposiums was followed again during this session and a very successful three-day meeting on "Recent Developments in Industrial Electronics" took place towards the end of the session. This consisted of 27 papers and attracted a total attendance of nearly 300. The success of this meeting is considered to augur well for the future of the Industrial Electronics Group which will be established during the coming year. Other symposiums included the one-day meeting on "Data Transmission" and "Practical Electronic Aids for the Handicapped", while the Education Group organized comparable meetings at the beginning and end of the session.

Attendance at evening meetings in London during the session averaged 85; the major symposiums were attended by an average of 150.

Local Section Meetings in Great Britain. During the year yet another Local Section was established—the East Midlands Section. Its first session of four meetings in Leicester was considered as being experimental in order to determine the likely support and it is pleasing to record that the venture was fully justified and that the Section will take a full part in the 1962–63 programme.

Altogether meetings were held in 19 centres by 10 Sections—a very effective way of identifying members throughout the country with the main work of the Institution. The total number of meetings held by these Sections during the year was 81, an increase of six over the previous year.

The major Local Section meeting for the year was the Conference on "New Electronic Techniques in Non-Destructive Testing", a one-day meeting arranged by the West Midlands Section in Wolverhampton. Over 100 engineers attended to hear six papers which it is hoped to publish in the *Journal* in due course.

Features of the South Western Section's activities were joint meetings with local branches of the Royal Aeronautical Society and the British Computer Society, both of which attracted good attendance from all bodies concerned. The Southern Section was invited to participate in a discussion meeting on electronic engineering education arranged by the Southern Centre of the Institution of Electrical Engineers. Of particular interest was the meeting of the North Eastern Section held in conjunction with the School of Signals at Catterick Camp and this is intended to be the forerunner of regular future meetings at this centre.

Overseas Sections. The activities of the Sections overseas have been maintained. Following the visit to Canada of the Secretary, Mr. G. D. Clifford, the organization of Sections in Montreal and Toronto has been placed on a footing which will facilitate further expansion and already the number of meetings held during the Session by the Montreal Section has been increased.

The Committee had discussions during the year with Major-General B. D. Kapur, Chairman of the Indian Advisory Committee, regarding the scope of the Convention which is to be held in Bangalore in 1963. The Committee is assisting the organizers of the Convention in obtaining papers by engineers from the United Kingdom.

Consideration of Papers. The number of papers submitted to the Committee for publication has continued to rise and the Specialized Group Committees have made appreciable contributions in securing papers from within their fields of interest. The total of 165 for the year under review included Convention and Symposium papers; 130 were accepted as submitted or with only minor amendment while of the remainder about half were returned for revision; the relatively small balance was rejected.

Award of Premiums. The Council has pleasure in announcing that the following awards have been made to the authors of outstanding papers published in the *Journal* in 1961.

THE CLERK MAXWELL PREMIUM

To Professor D. G. Tucker (Member) for his papers "Elimination of Even-order Modulation in Rectifier Modulators" and "Constant Resistance Modulators". (Published in the February and June 1961 issues of the *Journal* respectively.)

THE HEINRICH HERTZ PREMIUM

To Dr. D. C. Cooper and Dr. J. W. R. Griffiths (Associate Member) for their joint paper "Video Integration in Radar and Sonar Systems". (May.)

THE SIR J. C. BOSE PREMIUM

To Dr. S. Deb and Mr. A. N. Daw for their joint paper "Variation of L.F. Noise Figure of a Junction Transistor". (January.)

THE A. F. BULGIN PREMIUM

To Dr. B. G. Bosch and Dr. W. A. Gambling (Associate Member) for their joint paper "Techniques of Microwave Noise Measurement". (June.)

THE LESLIE McMICHAEL PREMIUM

To Messrs. R. Hearn, J. R. Bennett and B. A. Wind for their joint paper "Some Types of Low Noise Amplifiers". (November.)

THE ARTHUR GAY PREMIUM

To Dr. J. Przybylski and Dr. G. N. Roberts for their joint paper "The Design and Construction of Tunnel Diodes". (December.)

THE LORD BRABAZON AWARD

To Mr. J. S. Shayler (Associate Member) for his paper "Radio Guidance Elements of the B.L.E.U. Automatic Landing System for Aircraft". (January.)

THE CHARLES BABBAGE PREMIUM

To Mr. S. Morleigh (Associate Member) for his paper "A Dielectric Drum Storage System". (March.)

THE LORD RUTHERFORD AWARD

To Professor H. Elliot, Dr. J. J. Quenby, Mr. D. W. Mayne and Mr. A. C. Durney for their joint paper on "Cosmic Ray Measurements in the U.K. *Scout I* Satellite". (September.)

THE VLADIMIR K. ZWORYKIN PREMIUM

To Dr. I. A. Boyd and Mr. W. R. Eadie (Associate Member) for their joint paper "Continuous Electronic Recording of the Activity of the Perfused Frog Heart." (November.)

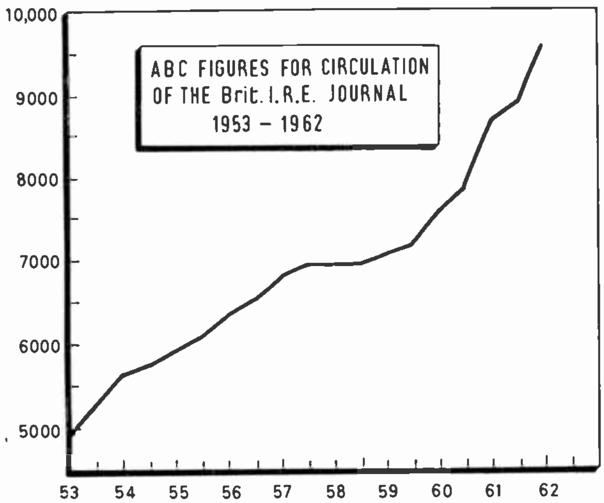
THE MARCONI PREMIUM

To Mr. N. Purnell and Mr. T. T. Walters for their joint paper "An Equipment for Automatically Processing Time Multiplexed Telemetry Data". (March.)

The Associate Rediffusion Premium, the J. Langham Thompson Premium, the Dr. Normal Partridge Premium and the Hugh Brennan Premium were withheld as papers of high enough standard had not been published.

The Journal. With effect from January 1961 the *Journal* format was increased to provide about one-fifth extra editorial content per page. Notwithstanding this increase however, the two half yearly volumes for 1961 contained 1092 pages (564+528 pages), an increase of about 15% over the year's volume of the smaller format for 1960.

The increase in circulation of the *Journal* over the past year has been maintained at a higher rate



than ever before as may be seen from the accompanying graph, based on figures issued by the Audit Bureau of Circulations. It is confidently expected that the circulation for the second half of 1962 will not be far short of 10,000 thus placing the *Brit.I.R.E. Journal* firmly among the leading specialized journals in the field of radio and electronics.

During the year the regular features in the *Journal* which are intended to keep members in touch with Institution affairs have been maintained. Articles and new items on matters of interest to radio engineers have been published and it is hoped that these extra features in the *Journal* will be augmented during the coming months.

Other Publications. In the autumn of 1961 the first issue of the *Canadian Proceedings of the Brit.I.R.E.* was published. This is intended to be an occasional publication for members throughout North America and may well serve as a prototype for similar Institution ventures in the future.

The ninth issue of the "List of Members" was in course of preparation at the end of the year. This publication fulfils a valuable purpose in facilitating contact between members, and enabling prospective members to secure support for their proposals.

The value of the leaflet "Guidance for Authors", first published in the *Journal* in June 1957, has been well demonstrated by the demand from prospective authors. Only a few revisions to the leaflet have proved to be necessary over the years and a reprint has recently been produced.

Acknowledgments. During the year the Institution has been indebted to the London School of Hygiene and Tropical Medicine, University College London, and the School of Pharmacy for the provision of facilities for holding meetings. Thanks are also due to the educational and other establishments elsewhere in Great Britain and overseas who have assisted Local Sections in a similar manner.

Before acceptance for publication in the *Journal* papers have necessarily to be refereed by members of the Programme and Papers Committee, the Committees of the Specialized Groups, or members having particular specialist knowledge, and the Council is grateful to all who have helped in this way.

Finally, acknowledgment must be made to the editors of many technical and scientific journals who have included details of Institution meetings and other activities in their publications.

FINANCE COMMITTEE

The Income and Expenditure Account and Balance Sheet for the year ended 31st March 1962 are published on pages 193–4 of this *Journal* and are the first Accounts of the Chartered Institution.

In consultation with the Council and the Institution's Accountants, opportunity has therefore been taken to produce the Accounts in a different form.

Members of the Institution, as incorporated under the Companies' Act 1929, agreed at the thirty-sixth Annual General Meeting† that the properties and monies of the Institution should be formally transferred to the Chartered Institution. For this year, therefore, no comparative figures are given, but it is pleasing to report that the total revenue of the Institution reflects increased income from all sources.

Bearing in mind the legal and other costs involved in connection with the Charter, the organization of the 1961 Convention, and the overall increase in supplies and service costs, it was expected that there would be an excess of expenditure over income for the year.

Charges for postage, telephone and printing were all subject to basic increases which, coupled with the Institution's increasing need of such services, resulted in a substantial rise in expenditure on such items. In addition, there were other costs over which the Institution had no control, e.g. the compulsory Graduated Pension Contributions and increased contributions to the National Health Insurance Scheme. The excess is reasonably small, however, and it should be remembered that many of the costs are non-recurring.

The main change in the presentation of the Accounts is on the Balance Sheet. The Reserves of the Institution are now grouped under the heading "Surplus and

† Reported in the February 1962 *Journal*.

Reserves". The former Reserve Account will henceforth be known as "Accumulated Fund". The contributions to the Building Appeal received during the year have been placed to a "Building Reserve" and from this Reserve has been taken the capital expenditure incurred during the year for some of the structural alterations necessary to Nos. 8 and 9 Bedford Square.

As mentioned in the report of the Executive Committee, the welding of the two buildings now leased to the Institution will take some time. A new system of central heating will have to be installed, and apart from adequate administrative offices, the Library will be extended, Committee rooms provided, and a Lecture Room built suitable for accommodating members attending Group meetings and some of the general meetings of the Institution.

Some of the balance remaining in the "Building Reserve" at the end of each year will be retained as fluid cash to finance further expenditure on the building alterations, and the remainder will be invested and added to the General Investments Accounts. As will be seen from the Schedules, total investments as at 31st March, 1962, were £24,893.

By spreading the capital expenditure on the building over a period of years, and provided that the Institution continues to receive financial support from members and industry, it will be possible to convert the existing two buildings into admirable Institution headquarters, with the possibility of further acquisition of adjoining buildings if and when necessary.

Numbers 8 and 9 Bedford Square will be leased from the Ministry of Works for a minimum period of twenty-one years from 1963 and there is reasonable prospect of continued tenure beyond this period.

GENERAL

Extension of accommodation is permitting the engagement of staff necessary to meet the services required in a steadily expanding Institution. The Council welcomes this opportunity of expressing appreciation to the twenty-eight members of the present staff for loyal service during a year of exceptional pressure of work.

Thanks are also expressed for the help given by all those who have served on Committees and in other ways supported the Council's endeavours to give the maximum service to members and to the profession.

Schedules of Investments as at 31st March, 1962

SCHEDULE (1)—GENERAL FUND

		£	s.	d.
250 Units	The A.E.G. Unit Trust	149	1	1
£100	Associated Electrical Industries Limited 6% Debenture	98	10	0
£1,300	British Electrical 3% Guaranteed Stock 1968/73	990	10	6
£500	The British Petroleum Company 8% Cumulative First Preference Stock ..	684	12	9
£3,600	British Transport 4% Guaranteed Stock 1972/77	3,298	10	9
£125	Cable & Wireless (Holdings) Limited, 500 Ordinary Stock Units of 5/- each	481	13	5
£500	City of Birmingham, 6% Redeemable Stock, 1974/76	493	8	4
£1,500	Government of the Commonwealth of Australia 5½% Loan 1977/80 ..	1,480	5	2
200 Units	Commonwealth Unit Trust Fund	100	0	0
£2,200	4% Consolidated Stock	1,931	18	6
£1,200	5% Conversion Stock 1971	1,186	18	3
£1,500	3% Exchequer Stock	1,428	10	7
£919/5/-	Ether Langham Thompson Limited, 3,677 Ordinary Shares of 5/- each (*Donated*)	—		
2,000 Units	Falcon Trust	500	0	0
£1,000	Government of the Federation of Rhodesia and Nyasaland, 6% Loan Stock 1978/81	988	0	1
£500	Hawker Siddeley Group Limited, Ordinary Shares of £1 each ..	746	4	6
£500	Imperial Chemical Industries Limited, 5% Cumulative Preference Stock ..	452	19	6
£300	Middlesex County Council, 6¼% Redeemable Stock 1975/77 ..	300	0	0
£250	National Commercial Bank of Scotland, Ordinary Shares of 10/- each	1,425	6	0
1,500 Units	Orthodox Unit Trust	930	6	10
£100	Plessey & Company Limited, 200 Ordinary Shares of 10/-	449	13	3
£240	The Shell Transport & Trading Company Limited, Ordinary Stock ..	1,632	5	6
£200	3% Savings Bonds 1960/70	200	0	0
£500	South Durham Steel Iron Company Limited, Ordinary Shares of £1 each	1,040	5	1
£100	C. Townsend Hook & Company Limited, Ordinary Shares of £1 each	413	4	6
£2,000	3½% War Stock	1,464	4	3
		22,866	8	10
	(Market Value as at 31st March, 1962, £21,424/16/6.)			
	Halifax Building Society	441	0	2
	Cash at Bank	1,585	13	9
		£24,893	2	9

SCHEDULE (2)—BUILDING INVESTMENTS ACCOUNT

	£	s.	d.
Halifax Building Society	4,558	19	10

THE BRITISH INSTITUTION OF RADIO ENGINEERS

GENERAL ACCOUNT

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st MARCH, 1962

	£	s.	d.	£	s.	d.
ADMINISTRATION EXPENSES:						
Salaries and State Insurance	16,861	4	5			
Pension Scheme	1,321	11	6			
Postage and Telephone	3,019	5	11			
Printing and Stationery	2,381	14	7			
Travelling and Entertaining Expenses	1,575	0	9			
Delegates' Expenses	563	5	4			
Council and Committee Expenses	1,127	12	11			
Audit Fees	210	0	0			
Bank Interest and Charges	1,074	10	8			
Legal and Charter Expenses	602	2	8			
Sundry Expenses	203	6	5			
				28,939	15	2
INSTITUTION'S PREMISES						
Rent, Rates and Insurance (Net)	1,590	6	6			
Lighting and Heating	605	5	0			
Office Expenses and Cleaning	1,153	8	11			
Repairs	340	13	2			
				3,689	13	7
INSTITUTION'S JOURNAL, LIST OF MEMBERS, LIBRARY, HISTORY AND OTHER REPORTS (*Net*)						
Printing and Publishing less Advertising Receipts	13,249	8	6			
Postage	3,788	8	1			
Envelopes and Wrappers	1,036	4	5			
				18,074	1	0
1961 (OXFORD) CONVENTION AND DINNER EXPENSES (*Net*)				509	4	11
EXAMINATION EXPENSES						
Printing of Papers and Regulations	509	2	10			
Examiners' and Invigilators' Expenses and Fees	1,003	7	11			
Hire of Accommodation	159	13	9			
				1,672	4	6
SECTION EXPENSES						
Printing, Stationery and Postage	881	1	9			
Hire of Accommodation, etc.	1,352	8	4			
Travelling Expenses and Subsistence	1,544	2	8			
				3,777	12	9
GRANTS TO OTHER INSTITUTIONS				582	6	6
PREMIUMS AND AWARDS				138	1	7
DEPRECIATION						
Office Furniture and Fittings	474	15	6			
Library	188	11	3			
				663	6	9
				£58,046	6	9

	£	s.	d.
Subscriptions including arrears received	31,571	19	2
Donations from Industry	1,948	11	7
Examination and Exemption Fees	5,323	2	9
Entrance and Transfer Fees	2,544	11	6
Sales of Publications, etc.	8,564	15	11
Interest on Investments (Gross)	1,162	15	10
Radio Trades Examination Board—Secretarial Charges	3,500	0	0
Excess of Expenditure over Income carried to Reserve Account	3,430	10	0
	£58,046	6	9

THE BRITISH INSTITUTION OF RADIO ENGINEERS

GENERAL ACCOUNT

BALANCE SHEET AS AT 31st MARCH, 1962

	£ s. d.	£ s. d.	£ s. d.
Surplus and Reserves			
Accumulated Fund			
Balance 1st April, 1961	15,300 10 7		
Less Excess of Expenditure over Income for the Year	3,430 10 0		
		11,870 0 7	
Building Reserve			
Donations received during year ..	6,058 7 9		
Less Expenditure on Buildings during Year	1,499 7 11		
		4,558 19 10	
			16,429 0 5
Current Liabilities			
Sundry Creditors		8,803 1 9	
Subscriptions and Examination Fees in Advance		7,159 16 1	
Bank Overdraft		20,230 4 2	
			36,193 2 0
			£52,622 2 5

	£ s. d.	£ s. d.
Fixed Assets		
Office Furniture and Fittings at Cost	9,034 10 7	
Less Depreciation to date	4,766 10 7	
		4,268 0 0
Library at Cost	3,116 0 1	
Less Depreciation to date	1,416 0 1	
		1,700 0 0
Investments at Cost		
See Schedule (1) (see page 192)		24,893 2 9
Building Investments Account		
See Schedule (2) (see page 192)		4,558 19 10
		35,420 2 7
Current Assets		
Stock of Stationery, Journals and Examination Papers at Valuation	4,951 3 8	
Income Tax Repayment Claim	1,720 14 1	
Sundry Debtors	6,815 13 6	
Sections—Balances at Bank and in Hand	328 6 0	
Balances at Banks Overseas	3,305 15 6	
Cash in Hand	80 7 1	
		17,201 19 10
		£52,622 2 5

Signed: J. L. THOMPSON (*Chairman of Finance Committee*).
A. A. DYSON.
G. A. TAYLOR (*Honorary Treasurer*).
G. D. CLIFFORD (*Secretary*).

REPORT OF THE AUDITORS TO THE MEMBERS OF THE BRITISH INSTITUTION OF RADIO ENGINEERS

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.

We have examined the above Balance Sheet and annexed Income and Expenditure Account which are in agreement with the books of account. In our opinion and to the best of our information and according to the explanations given to us, the said accounts are properly drawn up and the Balance Sheet gives a true and fair view of the state of the Institution's affairs as at 31st March, 1962, and the Income and Expenditure Account gives a true and fair view of the Excess of Expenditure over Income for the year ended on that date.

42, Bedford Avenue, London W.C.1.
7th September 1962.

GLADSTONE, JENKINS & CO.
Chartered Accountants, Auditors.

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 of the Institution's Benevolent Fund will be held on WEDNESDAY, 24th OCTOBER 1962, at the London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, London, W.C.1. The meeting will commence immediately after the Annual General Meeting of the Institution (approximately 6.30 p.m.).

AGENDA

1. To confirm the Minutes of the Annual General Meeting of Subscribers held on 24th January 1962. (Reported on page 97 of Volume 23 of the *Journal*, February 1961.)

2. To receive the Annual Report of the Trustees. (Published on page 196 of this *Journal*.)

3. To receive the Income and Expenditure Account and Balance Sheet of the Benevolent Fund for the year ended 31st March 1962. (Published on page 198.)

4. To elect the Trustees for the year 1963.

   Rules 5 and 6 state:

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

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

   The retiring Trustees are:

   Rear Admiral Sir Philip Clarke, K.B.E., C.B., D.S.O. (*Past President*)
   Air Vice-Marshal C. P. Brown, C.B., C.B.E., D.F.C. (*Vice-President*)
   I. Maddock, O.B.E., B.Sc. (*Member*)
   E. A. W. Spreadbury (*Member*)
   A. A. Dyson, O.B.E. (*Member*)

5. To appoint an Honorary Treasurer and an Honorary Secretary.

   Mr. G. A. Taylor (*Member*) is eligible for re-election as Honorary Treasurer and
   Mr. G. D. Clifford (*Member*) is eligible for re-election as Honorary Secretary.

6. To appoint Honorary Solicitors.

   The Trustees recommend the re-appointment of:

   Mr. C. Gray Hill, 6 Gray's Inn Square, London, W.C.1.

7. 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.

8. Any other business.

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

Brit.I.R.E. Benevolent Fund

Annual Report of the Trustees for the year 1961/62

The Trustees of the Benevolent Fund submit the following report to subscribers on the work of the Fund for the year ended 31st March 1962. The Income and Expenditure Account and Balance Sheet for the year are published on page 198 of this Journal.

The Brit.I.R.E. Benevolent Fund was established twenty-one years ago and, as reported at the last Annual General Meeting of subscribers,† the Trustees have had under consideration the desirability of revising the Rules under which the Fund is operated. Whilst the Fund is controlled by and exists for the benefit of the members of the British Institution of Radio Engineers, it is controlled by the subscribers and not by the Institution. It is felt, therefore, that the stage has been reached where the Fund should have separate legal identity. Hitherto, consideration has been given to the possibility of recommending to subscribers that incorporation should be sought under the Companies Act 1948 for the Fund to be known separately as "The British Institution of Radio Engineers' Benevolent Fund", or alternatively, the subscribers might agree to a Trust Deed being formed.

There are several factors which have to be taken into account before the present Trustees make a firm recommendation, but under the Charities Act 1960 the Fund must be registered with the Charity Commissioners. The necessary steps have been taken in this connection and, subject to securing a conclusion of legal opinion, it is hoped to make some recommendations on the future Constitution of the Fund to the subscribers at the Annual General Meeting to be held on 24th October 1962.

Meanwhile, the Fund will continue to be operated by Trustees elected by the subscribers.

Members' support.—A record number of members —1,478—subscribed to the Fund during the year. The Trustees express thanks to new subscribers, as well as to regular subscribers, for their contributions. As shown in the Income Account, total subscriptions exceeded those for the previous year, but were still less than the contributions of two years ago, and considerably less than the record figure of £1,753 received in 1955.

For the twelve months ended 31st March 1962 just under 18% of the entire Institution membership subscribed to the Fund. A very special plea is made to all members to support their own Benevolent Fund and to help maintain the position of increasing investments which will help the revenue and enable the Trustees to meet future demands. For this reason, attention is again drawn, especially in the case of new members of the Institution, to the desirability of subscribers completing a seven-year deed of covenant.

Members who support the Fund annually by a subscription under standing bank order could greatly increase the value of their donations, without any additional expense to themselves, by completing a deed of covenant. The necessary form can be obtained from the Honorary Secretary.

Additional support.—The Trustees continue to appreciate the support of Electric and Musical Industries Ltd., the Radio Industries Club of London, and the Radio Industries Club of Manchester. During the year a donation was also received from the Clerk Maxwell Lodge No. 7382, which was greatly appreciated.

Grants.—No new requests for financial assistance were received during the year. Consequently the grants were limited to cases which have already been reported in previous Annual Reports. Many of these cases reached the stage where only a small measure of support was required, and the grants from the Benevolent Fund have therefore been considerably reduced to £167, compared with £430 in 1960. The Trustees, however, have been pleased to give advice to the dependents of members who have died in recent months but no call for financial assistance has been received so far.

Schools.—In the last Annual Report details were given of the excellent work of the three independent schools supported by the Benevolent Fund. Although there are no longer any children in the care of the Trustees attending these schools, the Trustees still give their support and continue their policy of purchasing bursaries. When the necessity arises in the future for the Trustees to provide education for children of a deceased or handicapped member, it will be possible to nominate these children for attendance at the school most suited to their age and ability. The three schools concerned are Reed's School, the Royal Wolverhampton School and the Royal Wanstead School. These

† *J.Brit.I.R.E.*, **23**, p. 97. February, 1962.

are independent schools which between them can provide boarding school education at primary, secondary, or grammar school standard up to the age of 18 years.

Other donations.—On behalf of subscribers the Trustees gave donations to the London Association for the Blind and the Royal Hospital for Incurables, Putney.

Accounts.—The amount of direct grants was the lowest for ten years. The purchase of bursaries was maintained at about the same figure. Comment has already been made on the total amount of subscriptions, and the interest received from investments is steadily increasing.

As shown in the Balance Sheet and Schedule, investments have now reached over £11,500 and the Fund continues to receive the benefit of income tax repayment in respect of both investments and subscriptions received under a seven-year deed of covenant.

Acknowledgments.—The administration of the Benevolent Fund is entirely voluntary and this applies in particular to that carried out by the Honorary Solicitor, Mr. C. Gray Hill, and the Honorary Auditor, Mr. R. H. Jenkins, who give their professional services and advice on legal and financial matters not only to the Trustees but to any members or dependents nominated by the Trustees. Their help and that of members who from time to time aid the Trustees in their work is sincerely appreciated.

Schedule of Investments as at 31st March, 1962

		£	s.	d.
£100	Associated Electrical Industries 6% Debenture Stock, 1978/83	98	10	0
£50	Associated Newspapers Ltd. 200 Deferred Shares of 5/- each, fully paid	166	4	6
£100	Bowater Paper Corporation Ltd. Ordinary Stock	290	17	4
£200	British Electricity 3% Guaranteed Stock 1968/73	155	19	6
£2,000	British Transport 4% Guaranteed Stock 1972/77	1,863	14	10
£200	Liverpool Corporation Mortgage Loan, 5¾%	200	0	0
£800	Commonwealth of Australia 5½% Loan 1977/80	788	2	7
300 Units	Commonwealth Unit Trust Fund	150	0	0
£4,000	4% Consolidated Stock	3,526	16	0
£1,000	Corporation of London 6¼% Stock 1971/72	970	0	0
£300	Borough of Middlesbrough 5½% Mortgage Loan	300	0	0
£200	5½% Exchequer Stock 1966	201	2	0
500 Shares	Falcon Trust	125	0	0
£200	Great Universal Stores Ltd. 4½% Cum. Pref. Stock	106	4	7
£300	Great Universal Stores Ltd. 7% Cum. Pref. Stock	247	17	5
£100	London County 6% Loan Stock 1975/78	99	4	4
£75	George Nott Industries Ltd. Ordinary Stock. 300 Units of 5/- each ..	368	18	7
500 Units	Orthodox Unit Trust ..	381	5	0
£200	3% Savings Bonds 1960/70	191	3	6
£200	3% Savings Bonds 1965/75	182	15	9
£1,500	3½% War Stock	1,157	15	9
		£11,571	11	8

(Market value as at 31st March, 1962 £10,051 . 14 . 2.)

The Income and Expenditure Account and the Balance Sheet for the Benevolent Fund is given overleaf.

THE BRITISH INSTITUTION OF RADIO ENGINEERS

BENEVOLENT FUND

INCOME AND EXPENDITURE ACCOUNT FOR THE YEAR ENDED 31st MARCH, 1962

1961 £		£ s. d.
431	*Grants and Donations*	167 15 0
330	*Purchase of Bursaries*	305 0 0
13	*Postage and Stationery*	14 12 3
769	*Balance, being surplus for the year carried to Reserve Account* ..	1,330 14 6
£1,543		£1,818 1 9

1961 £		£ s. d.
1,095	Subscriptions and Donations	1,302 18 10
448	Interest on Investments (Gross)	515 2 11
£1,543		£1,818 1 9

BALANCE SHEET AS AT 31st MARCH, 1962

1961 £		£ s. d.	£ s. d.
	RESERVE ACCOUNT		
	Balance as at 1st April 1961	10,578 3 8	
	Add Surplus for the year	1,330 14 6	
10,578			11,908 18 2
£10,578			£11,908 18 2

1961 £		£ s. d.	£ s. d.
	FIXED ASSETS		
10,220	Investments at Cost .. .. (see Schedule on page 197)		11,571 11 8
	CURRENT ASSETS		
264	Income Tax Repayment Claim	192 9 1	
37	Cash at Bank	58 2 6	
57	Amount due from The British Institution of Radio Engineers	86 14 11	
			337 6 6
£10,578			£11,908 18 2

For Trustees:—
Signed: A. A. DYSON
G. D. CLIFFORD (*Honorary Secretary*)
G. A. TAYLOR (*Honorary Treasurer*)

I have audited the above written Balance Sheet dated 31st March, 1962, in respect of the Benevolent Fund. I have received all the information and explanations I have required and in my opinion the Balance Sheet represents the true and accurate state of the Benevolent Fund.

42, Bedford Avenue,
LONDON, W.C.1.
12th July, 1962.

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

U.D.C. 621.395.002

Automatic Component Assembly in the Telephone Industry

By

D. HINCHCLIFFE,†

J. R. W. SMITH, M.Sc.†

AND

G. H. KING, B.Sc.†

Presented at the Symposium on "Recent Developments in Industrial Electronics" in London on 2nd–4th April 1962.

Summary: The paper describes an improved assembly and testing machine designed to have sufficient flexibility for the batch production of a variety of printed wiring boards. The machine is controlled by punched paper tape, the necessary encoded information being derived from specially arranged drawings and stocklists. The instructions are interpreted by digital type electronic circuits which initiate and monitor the movements of the various mechanical members. In addition to performing the assembly operation the machine can drill component fixing holes in the boards and test the components prior to assembly. For this latter operation programmed measuring circuits are used. Incorrect and out-of-tolerance components are automatically rejected and in addition the programme can cause actual test values to be recorded if desired. Standardization of component shapes and improved information handling facilities are needed for the wide application and continuous operation of such machines. Progress in these matters is discussed.

1. Introduction

Printed wiring was first used on a wide scale for the production of domestic radio receivers. To-day, most manufacturers have realized that printed wiring and transistor circuitry are complementary and are exploiting their possibilities to the full over the widest range of electronic applications.

The new techniques are particularly suitable for the type of equipment used for electronic switching and data handling. Most of the circuit elements used are transistors and small axial lead tubular resistors, capacitors and diodes, mounted on and interconnected by the printed wiring base board. This basic constructional pattern is now employed for the most diverse applications and almost any circuit can be obtained by varying the wiring pattern, the components and their positions, whilst retaining the two dimensional array and rectangular board shape.

An estimate based on the range of equipment manufactured by the A.T.E. group showed that there was a normal mass production requirement for 3000 boards of one type per week. In addition, however, there was a further requirement for 3000 boards a week, made from 230 different patterns. The estimated figures for 1962–3 showed an increase in the variety of patterns and in total output, namely 7000 boards per week from 400 different circuits.

The mass production economy, which derives from flowline production can only be realized when dealing with such variety if machines can be harnessed to handle the vast amount of manufacturing instructions. When the basic information is encoded into machine language it can be processed very quickly and operations such as stock control and the marshalling and issuing of components at the correct time are made practical.

The process can be carried further (with some additions to the basic information), by encoding the assembly instructions and using a machine to interpret them. Such a machine, providing it is sufficiently adjustable, is quickly set up for a new circuit arrangement and can thus maintain a continuous output.

There have been several attempts[1, 2, 3] to introduce machinery based on such a concept. The machine described here is somewhat different since it tests the components, drills the lead holes in the printed wiring boards and finally assembles the components to the boards. It is instructed by punched paper tape and can record component tolerances on an output tape.

2. General Description of the Machine

The machine will accept axial lead tubular components ranging in size from 0·1 in. to 0·5 in. diameter mounted on centres ranging from 0·6 in. to 2·0 in. The rectangular printed wiring boards can have a maximum size of 10 in. × 10 in. and the components may be positioned parallel to the board edges so that their fixing centres are located at the cross points of a 0·050 in. grid.

A perspective view of the complete machine is shown in Fig. 1. Each component type is mounted in

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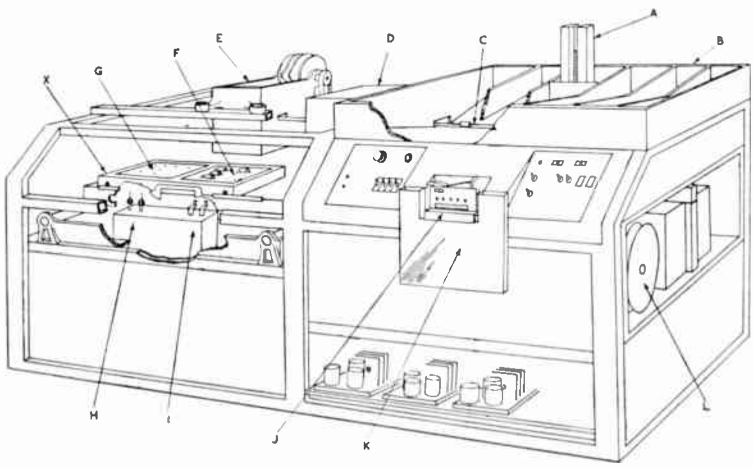


Fig. 1. View of machine with covers part removed to show main units.

More detailed views are given in Fig. 8.

a removable magazine A which holds up to 150 small components. A detachable framework B contains about 60 magazines. These magazines are loaded manually by feeding components, held by their bodies on adhesive tape, into the magazine from a reel. The adhesive tape is stripped away to leave the components in the magazine ready for release when required on to a moving transport belt C. The components are carried on this belt into a test station D. Correct components are allowed to continue down the belt into the insertion head E where the wires are sheared to correct length, formed and inserted through the holes in the printed wiring board. The board is held in an adjustable carrier or pallet, mounted at position F on the machine co-ordinate positioning tables X. The 0·052 in. diameter holes in the printed wiring board are drilled whilst the board is in pallet station G by the drilling unit H. The assembly occurs when the board is at station F and the wires are clinched over on to the copper foil circuit pattern by clinch unit I.

The control tape is fed into reader J and collected in the tape tank K. The output tape punch L is located on a shelf in the end of the machine. The framework B, printed wiring boards and control tapes are all loaded and unloaded manually. Apart from this the machine makes two drilled holes, a component test and a component insertion every three seconds.

3. Coded Instructions

Eight track punched paper tape is used for the program which is read into the machine by means of a step-by-step tape reader presenting one character at a time. The program is required to control several different parts of the machine, magazines, component measuring equipment, co-ordinate positioning tables, etc. This is simplified by arranging the information into blocks separated by an inter-block symbol #, and by identifying each block by its first digit or prefix. This prefix is used by the control to route the remainder of the block to the appropriate part of the machine. Figure 2 shows a short program which will cause the machine to assemble the

```
# # # # # #  7 NL
BOARD SP 24167 # 7 NL
D52 # 204 # 34-TAB # 56110050 # 6080 # 7 NL
R53 # 206 # 3234705 # 56125050 # 7 NL
R55 # 202 # 3242205 # 56170050 # •
```

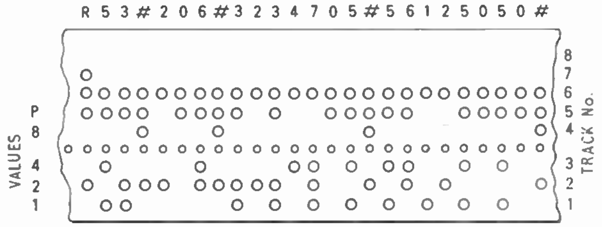
SYMBOLS UNDERLINED ARE WRITTEN ON MANUSCRIPT PROGRAM AND SUBSEQUENTLY TYPED. SYMBOLS NOT UNDERLINED ARE COPIED FROM MARGINALLY PUNCHED CARDS.

NL NEW LINE
SP SPACE
TAB TABULATE

CODE	MEANING	CODE	MEANING
#	INTER BLOCK	#	
#		3	PREFIX FOR BRIDGE
#	GENERAL RESET	2	RESISTANCE BRIDGE
#		3	10^3 TIMES
6	PREFIX FOR CENTRE DISTANCE (INSERTION HEAD SPACING)	4	4·7
		7	OHMS
0	HEAD SPACING	0	+5%
8	0·80″	5	TOLERANCE
0	FOR DRILLING AND INSERTION	#	
#		5	PREFIX FOR TABLES NORTH DATUM
7	PREFIX FOR PUNCH	6	DRILL TWO HOLES AND INSERT COMPONENT
NL		1	
R	COPIED ONTO OUTPUT TAPE	2	x COORDINATE 1·25″
5		5	
3		0	
#		5	y COORDINATE 0·50″
2	PREFIX FOR MAGAZINE	0	
0	MAGAZINE POSITION	#	
6	06 IN FRAMEWORK B	•	STOP

DIRECTION OF TAPE

R 5 3 # 2 0 6 # 3 2 3 4 7 0 5 # 5 6 1 2 5 0 5 0 #



TRACK 6 - NUMBERS TRACK 6+7 - LETTERS TRACK 7 - LETTERS

Fig. 2. Coding used and a short sample of actual tape.

three components shown in Fig. 6 on one printed wiring board, while at the same time drilling corresponding holes in another.

Each of the tape characters may have various meanings according to its position within a block of information and examples are shown in Fig. 2. This also shows how part of the program appears on 8-track punched paper tape. The code used follows closely British Standard 3480 : 1962, which is readily adapted for this type of work and can also act as a data processing code for the problems of stock control, etc., mentioned earlier.

4. Detailed Description of the Machine

4.1. *Control*

The mechanical members of the machine are cam driven and are thus synchronous with the camshaft rotation. By the use of electro-magnetic clutches and brakes, the control circuits can halt the camshaft at certain points thus enabling the machine as a whole to work asynchronously. In an analogous manner the control circuits whilst being controlled by and related to the timing of a multi-vibrator driven "clock", derive their master STOP and GO signals from the state of the machine.

The control circuits are built up from transistorized circuit elements. These are standard "bricks" developed and adapted from a 100 kc/s logic system produced for telephone exchange control, and are suitable for a wide range of applications. The bi-stable Eccles-Jordan or flip-flop circuit is used for information storage. Emitter followers and invertors are used where amplification or the invertion of signals is required. Diode gates are used to interconnect these circuits. Output circuits for operating lamps, relays and solenoids are made up from other standard "bricks" using power transistors. The timing or strobe pulses are derived from a multi-vibrator controlled master clock and ensure that all the Eccles-Jordan circuits change state by the next strobe time thus ensuring that the machine logic keeps in step.

The circuits are mounted on printed wiring boards, several circuits of one type being mounted on a board. These boards are supported on shelves and located in guide channels and plug directly into sockets mounted on the rack. Part of the wiring pattern at the edge of the board is gold plated, and used as contacts to provide connections to the rack sockets. The rack itself is mounted on sliding runners and the whole unit can be withdrawn well clear of the machine and tilted for easy access to both the printed wiring cards and the cable connectors.

4.2. *Outline of Operation*

A simplified timing diagram for the machine is shown in Fig. 3. From this it can be seen that many operations occur together but of course deal with different components. The tape reader will always read in information as fast as the machine can digest it, used information being overwritten in the store.

A schematic diagram illustrating the mechanical elements of the machine and the connections to the control unit is shown in Fig. 4. A typical sequence of events when the program tape (Fig. 2) is put into the reader and the machine started is as follows. The tape leader consists of a number of inter-block characters # which are used to reset all the control toggles. The first block, prefix 7, contains the board number which serves as a label. This is copied on to the output tape and can subsequently be used for progress control, etc. The next block prefix 2, contains the magazine number of the first component. This information is stored and used to pulse the appropriate magazine electro-magnet A (Fig. 4). This in turn operates the magazine escapement levers B. One component is allowed to fall on to a ramp and thence to the transport belt, upon which it is carried into the test station where it is stopped by a sliding gate C. The third block of information on the tape, prefix 3, is routed to a common bridge store and is then used to set up the range, value and tolerance of the appropriate measuring equipment. When the optical detector D signals the arrival of the component in the test station, the control operates solenoid E which removes pawl F and permits motor G to drive the test station camshaft H via a friction clutch. Pairs of spring-driven probes are thus allowed to move together over the belt to grip the component wires. The component is thus connected to the measuring

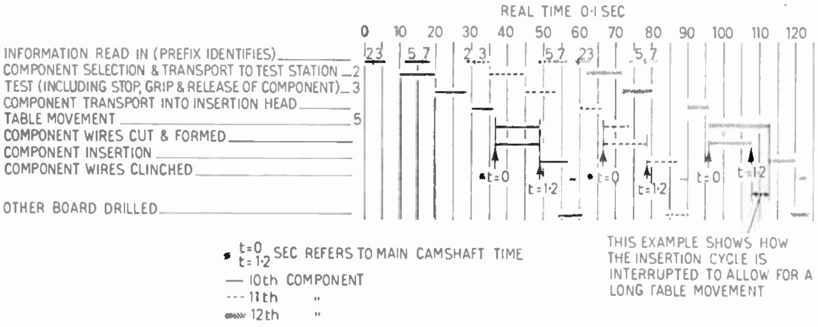


Fig. 3. Simplified timing diagram for machine.

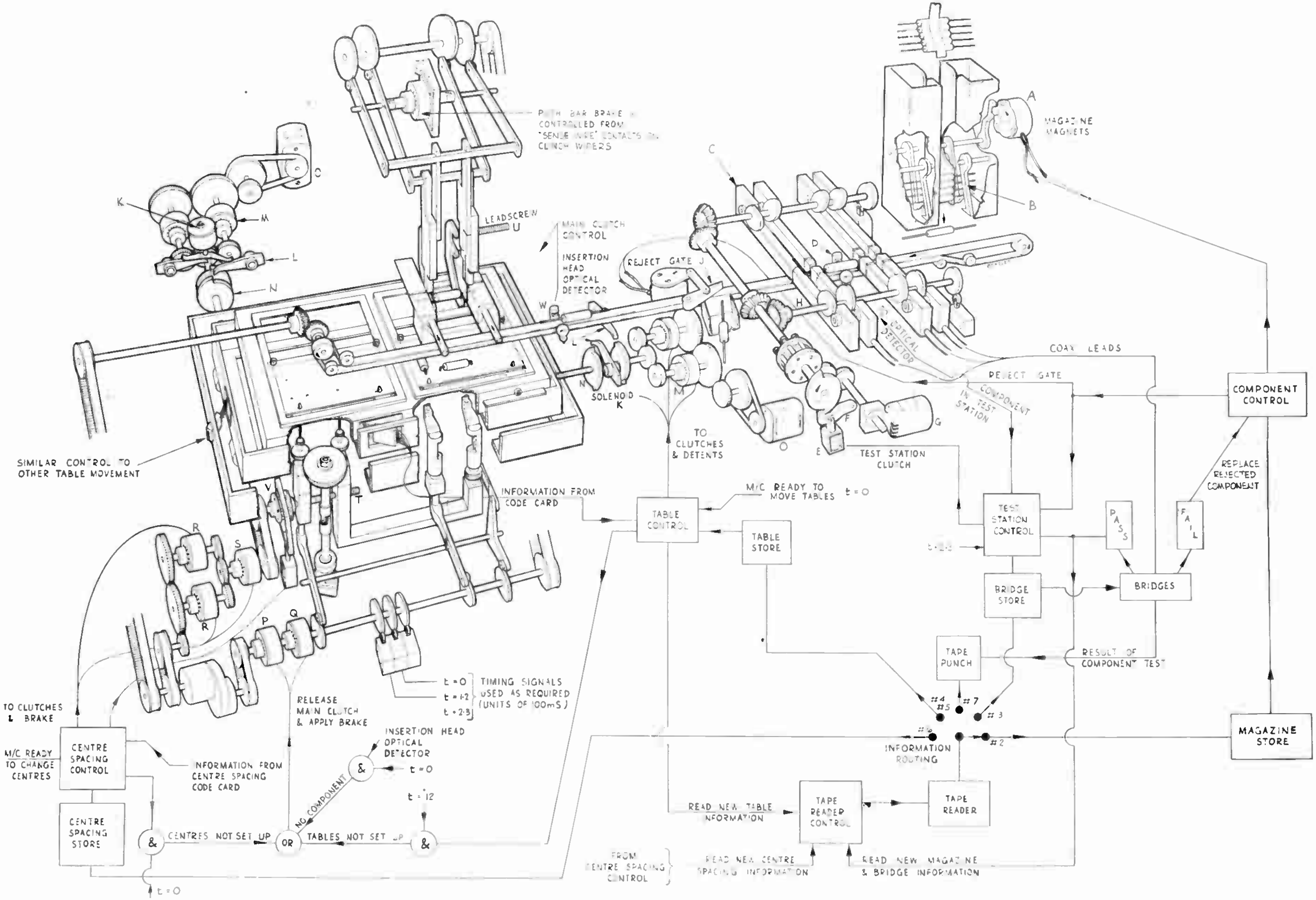


Fig. 4. Schematic diagram showing the machine elements and their connections to the control circuits.

circuits and the electrical test is carried out. If it is faulty the component is released from the test station and rejected by gate J. A further component is obtained and tested, using the information which is still stored. Only when a component has finally passed the test is the tape reader permitted to read magazine and bridge information blocks for the next component.

The next block of information, prefix 5, contains the drill and insert instruction and the table co-ordinates. This block is stored, but not acted on before $t = 0$ when the drill and insertion head camshafts have moved all machine parts to a safe position clear of the tables. The solenoid K and the clutches M are energized raising pawls L clear of ratchet wheels N, allowing motors O to drive the table lead screws. Table position is obtained from gold-plated flush moulded linear digitizers, coded at 0·050 in. intervals. In order to prevent false reading of the digitizer when changing from one interval to the next, an optical detector is used to provide a momentary blanking signal from a flag on the lead screw. The digitizer uses a binary decimal code and parity check. This code matches the program tape code so that signals from the brushes can be compared with those in the table store. When identity is achieved the stopping action is initiated. This happens soon after the tables enter the 0·050 in. stopping zone. The solenoid K drives the pawls L via a spring arm into contact with the periphery of ratchet wheels N. At the same time the drive is removed by releasing clutches M. According to the direction of rotation of the lead screw one of the ratchet wheel faces is stopped by its pawl. The lead screw continues to rotate due to its inertia and winds up a spring connecting it to the ratchet wheel, this spring eventually reverses the lead screw rotation, the spring energy being absorbed by a viscous damper and the system finally halts with both pawls locked against the ratchet wheel stopping faces.

The tables move at 1 in/s and if they reach their new positions within 1·2 seconds the insertion cycle can continue without delay. Since most printed wiring boards have closely packed components the steps usually take ¼ second. When a movement of several inches is required the main insertion head camshaft is stopped and the drive disengaged at $t = 1{\cdot}2$ seconds by the clutch and brake unit PQ. The insertion cycle can proceed no further until the tables are in position.

A new block of table movement information cannot be read until the tables have been positioned correctly by the previous data. The block, prefix 6, which comes next, defines the insertion head spacing. This information can only be obeyed at $t = 0$ seconds to avoid damage to machine and components being assembled. The head spacing is changed by energizing the electromagnetic clutches R which drive the screws T and U, thus moving the insertion head, drill head and clinch heads into their new positions. A digitizer and brush system similar to that used on the tables measures the distance moved. Stopping is effected by releasing clutches R and applying brake S. This halts the lead screw very near to the required stopping point but a final reset to the exact 0·050 in. position is provided by the solenoid operated bar V. Downward movement of this bar aligns a pair of pins projecting from the face of a disc attached to the leadscrew.

The insertion head can accept a new component before all the mechanical members have returned to the start position. At $t = 2{\cdot}3$ seconds a timing signal, derived from a cam on the main camshaft, operates solenoid E again, via the test station control, thus allowing the test station camshaft H to open gate C. The component will then be carried by the belt past the optical detector W into the insertion head arriving at $t = 0$. A gate (Fig. 5(*a*)) stops the component. The insertion cycle is started by the signal from the optical

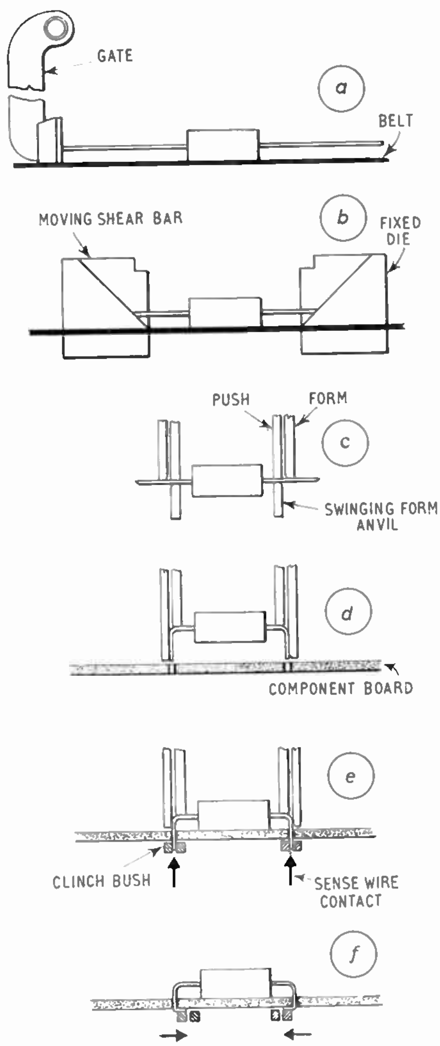


Fig. 5. Stages in component insertion.

detector, provided that the insertion head is in its correct positions as mentioned above. Side walls (not shown in the diagram) are raised from the belt to allow a pair of shear bars to move across the belt, pushing the component wires against fixed shear dies (Fig. 5(*b*)). At this stage the wires are trimmed to their final length, which varies according to the body diameter. Automatic compensation for this is provided for by the 45 deg inclination of the shear blades. The component is then moved further forward, being held by the wires between pressure pads and the moving shear bars. These halt above a forming anvil (Fig. 5(*c*)) where the component wires are pushed down and held. The forming bars bend the wires and continue to the board to provide a guide way for the wires (Fig. 5(*d*)). These are then pushed through the holes in the printed wiring board by the continued downward movement of the pushbars (Fig. 5(*e*)). The anvil is hinged and moves away whilst this operation takes place. The pushbars are arrested by brake X (Fig. 4) which is operated when the correct length of component wire projects beyond the board under surface. This is detected by sense contacts fixed to each of the two anvils which clinch the wires against the board.

This signal also serves to inform the control circuits that the component has been correctly formed. If not, further movement of the main camshaft is prevented by applying brake Q.

4.3. *Component Testing*

A check on electrical parameters ensures that:

(a) The magazines are loaded with the correct components.

(b) The magazines are placed in their correct locations.

(c) Faulty and out-of-tolerance components are eliminated.

(d) Polarized components, e.g. diodes are correctly orientated.

The actual component tolerance can be punched into the output tape. It is considered that this information is likely to be useful for prototype boards, or for the evaluation of faults which may occur in subsequent batches.

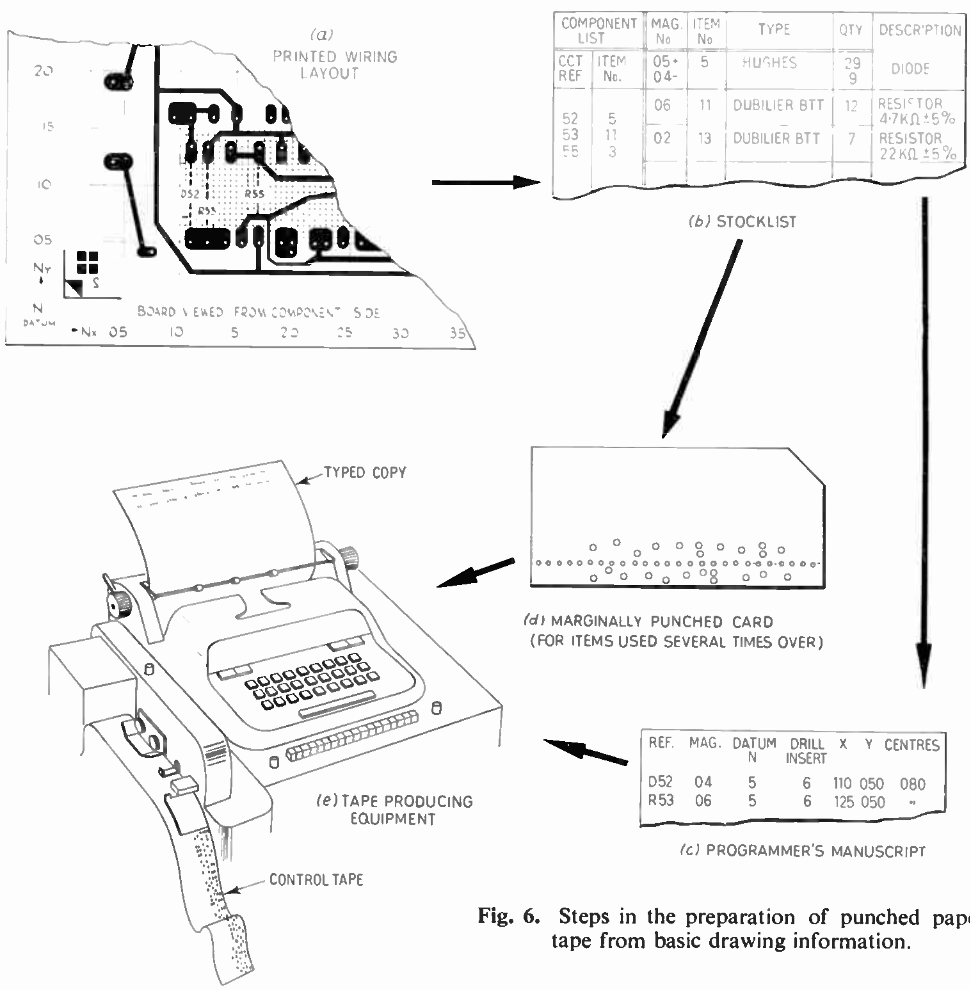


Fig. 6. Steps in the preparation of punched paper tape from basic drawing information.

After the first few boards of a batch are completed the possibility of finding an out-of-tolerance component is reduced since items (a) and (b) above have been checked.

The present machine will measure capacitances ranging from 10 pF to 0·99 μF set to two significant figures. Tolerances can be set and measured up to ±29% in 1% steps. Electrolytic capacitors can be measured from 0·1 μF, a measurement of leakage current and/or effective resistance can be made and the polarizing voltage applied can be controlled. Capacitors of incorrect polarity are rejected. Resistors within the range of 10 ohms to 990 kilohms can be measured with tolerances and setting as for capacitors. A check can also be made to ensure that a diode is working and that the polarity is correct.

The bridges used for these measurements differ from those conventionally used by having all switching operations performed by reed relays and having standards arranged in binary decades. The value to be measured is set up on the standards in binary decimal form from the input paper tape characters. The component is then measured to see whether it is above or below the nominal value, using a.c. excitation on the bridge and a phase sensitive detector. The value is then altered in the appropriate direction by the allowed tolerance. Phase reversal indicates a satisfactory component. The actual tolerance is then measured and punched on the output tape.

The testing techniques used here have been developed from equipment previously described.[4]

5. Programming the Machine

During the development of the machine close contact has been maintained with the equipment designers and also with the drawing office. The system of drawings evolved for the production of printed wiring boards has been made suitable, at no extra cost, for the derivation of information required by the machine. The standardization of component fixings at the intersections of grid lines spaced 0·050 in. apart has simplified not only the machine design and the encoding of component positions on the punched paper tape but also conventional production methods.

Reference has already been made in section 3 to the coding used. Figure 6 illustrates the various steps taken in producing the program tapes from the master printed wiring layout and stocklist. The grid lines and distances from a fixed datum are accurately printed on stable plastic film sheets at twice full scale. The printed wiring pattern is laid down on this using adhesive tape, the component fixing pads being accurately located at the grid intersections. A photograph of this master layout is printed on paper and the component references and positions pencilled in (Fig. 6(*a*)). From this and the stocklist (Fig. 6(*b*)) the programmer prepares a manuscript (Fig. 6(*c*)) using the code explained in Fig. 2. At the same time marginal punched cards are prepared for those components used in several different positions on the board. These are passed through the tape-producing equipment during the translation of the manuscript to paper tape. This saves the manual repetitive punching of identical information and speeds the encoding operation, which has to be done twice by different operators to check for errors. Programming for a 50 component board takes approximately 1½ hours.

6. Availability of Suitably Prepared Components

The component magazines of the machine can be quickly loaded when the components are supplied body-taped as shown in Fig. 7. The adhesive tape can be stripped away to leave the components neatly stacked in the magazine. About 2500 small components can be conveniently supplied on a long tape rolled on a paper tube fitted with end cheeks to protect the component leads during transport. It is necessary that the components leads should be substantially straight and that changes in body diameter due to ovality and taper be kept to a minimum. Typical tolerances required are illustrated in Fig. 7.

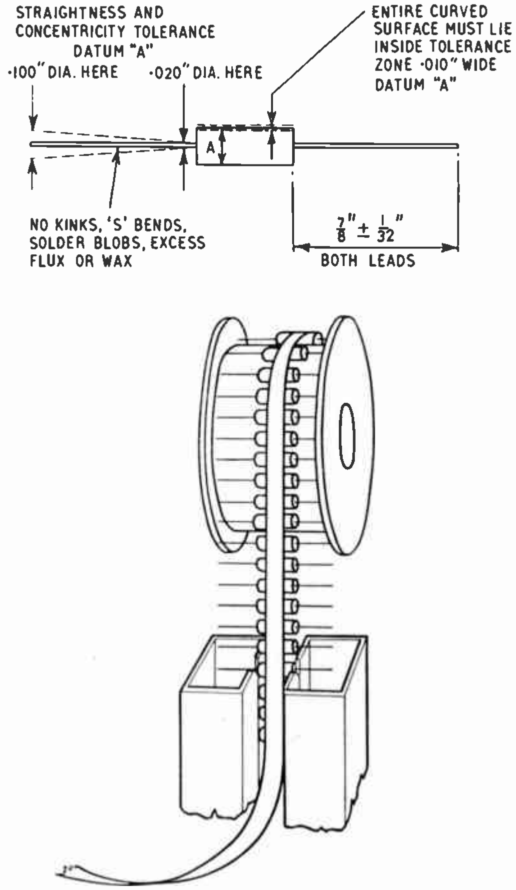
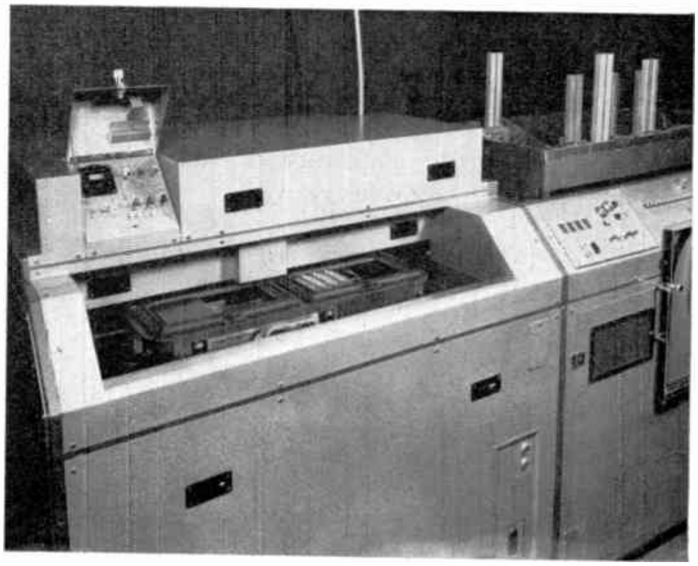
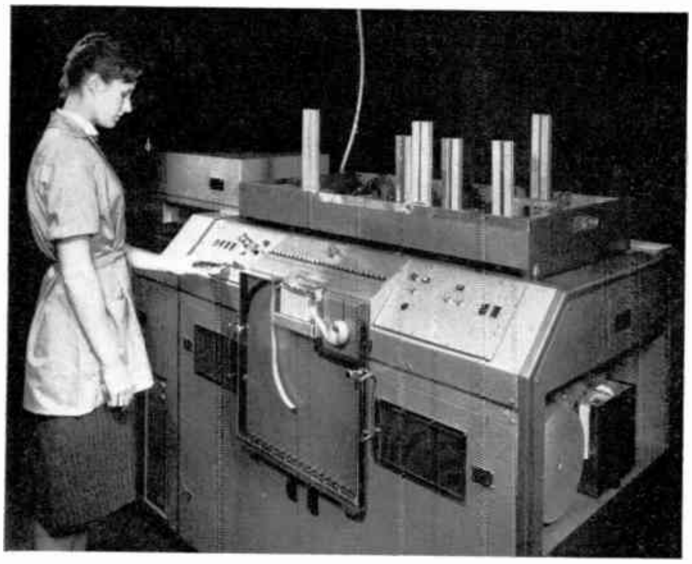


Fig. 7. Dimensional and packaging requirements for the components.

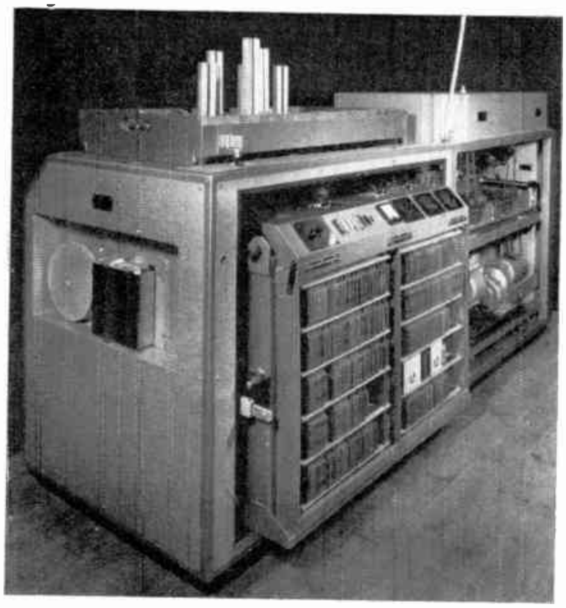
The printed circuit boards are held in adjustable pallet frames. The operator is shown removing a drilled board. An assembled board can be seen in the right hand pallet.



General view of the complete machine.



The operator is here depressing the start key on her control panel. The component magazines are jacked into the store frame which can be lifted off and quickly replaced by another. The output tape reperforator is housed in a recess at the end of the machine.



The printed circuit cards used in the control computer can be easily removed and the rack itself can be tilted and withdrawn on telescopic runners for inspection purposes.

Fig. 8. The Automatic Component Assembly Machine.

At least four component manufacturers can supply components body-taped and to the required limits and many thousands of such components have been obtained. The extra cost involved should not be greater than $\frac{1}{20}$ penny per component. Costs at present vary greatly depending on the machinery and manufacturing methods used by the component supplier. There is no reason to suppose that any additional charge need be made if this method of packaging were widely used. Some supplies obtained at no extra cost have already confirmed this contention. We could process the components ourselves using machinery currently available but this method, though cheaper at present in some cases, is not a satisfactory long term solution.

7. Economics

The present machine is not designed to show its maximum economy when making large numbers of the same circuit, since information handling for mass production presents few problems. The machine performance should be compared with the manual assembly methods normally employed when small batches of boards have to be made. Here the cycle time for drilling the holes, preparing and assembling the components, including the assimilation of information is at least 30 seconds. The machine has a cycle time of 3 seconds and is thus ten times as fast as manual methods. If the components are prepared in the factory using lead straightening and cropping machinery it has been estimated that a saving of £5,000 per annum on labour can be expected. Against this must be set depreciation.

A saving in direct labour costs is however not the only criterion used to assess the value of machinery. The attainment of manual dexterity to assemble components economically and sight drill holes without making scrap takes time. The absence of such trained operators has a serious effect on production whereas less manual skills are needed to operate machinery and moreover it can work for longer hours when required. Machines usually produce better and more uniform products and they use less floor space.

These factors are somewhat difficult to cost. This applies also to the value of testing each component immediately prior to assembly and also to the value of the test record.

8. Conclusions and Future Trends

The study of the automatic assembly of printed wiring boards has led to the adoption of a modular layout for the components and a high standard of dimensional accuracy. The procedures used have simplified the layout and drawings of printed wiring boards; the resulting standardization and accuracy have helped to make the boards easier to make by conventional methods. These are the conclusions after producing well over 1000 layouts.

The present machine is capable of development and some increase in speed can be anticipated. Simpler, cheaper and much faster machines could, however, be built if component outlines were standardized and designed for mechanical handling.

Nowadays there are few faulty components, but nevertheless difficulties do occur during functional testing. Often this is due to a chance accumulation of tolerances or to incorrect specification. Little is yet known of the benefits of testing components and recording the results when making high quality equipment. The data from the present experiment should prove valuable, and could be used by circuit designers, to relate actual to theoretical performance, and also by engineers responsible for quality and production control.

For the present machine to produce a variety of assemblies economically it must be fed with the correct components at the right time. This should prove a useful test for any information handling system and provide data and a stimulus for those seeking methods to control the batch production of a large variety of assemblies under one roof.

9. Acknowledgments

Thanks are due to Mr. J. Lawton, Director of Research, British Telecommunications Research Ltd., for his continued interest in this work and for permission to publish this paper.

We wish to thank all our colleagues who have participated in this joint project and in particular Messrs. D. Gee, J. Lucas and J. Moss.

10. References and Bibliography

1. G. W. Gamble, C. J. Godwin and F. S. Feldheim, "Punched cards control job-lot assembly system", *Electronics*, **28**, No. 11, pp. 122–8, November 1955.
2. W. M. Hancock and J. C. Souter, "Mechanized assembly of carrier equipment", *Western Electric Engineer*, April 1957, pp. 34–8.
3. S. B. Korin and F. B. Spencer, "Programmed servo speeds short-run production", *Electronics* **32**, No. 10, pp. 54–6, 6th March, 1959.
4. T. C. Cardwell, J. R. W. Smith and G. H. King, "An experimental transistor-controlled component selection and testing machine", *Proc. Instn Elect. Engrs*, **107B**, No. 36, November 1960, pp. 608–14 (I.E.E. Paper No. 3219M).
5. *Transactions of the Institute of Radio Engineers on Production Techniques*, notably **PGPT-2**, April 1957 and **PGPT-3**, April 1958.
6. E. Davies, "The application of printed wiring to development and small batch production with particular reference to television equipment", *J. Brit.I.R.E.*, **20**, pp. 265–79, April 1960.

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POINTS FROM THE DISCUSSION

Mr. K. M. McKee (*Associate Member*): Having some experience in the automatic assembly of components, I think the authors are to be congratulated in developing a fully programmed type of machine, probably the first in this Country.

Although it may not appear difficult, one of the major problems in designing such machines is in the handling and feeding of standard electronic components. Components are a very different proposition to handle mechanically than, say, bars or sheets of metal, or tins of fruit. The great majority of components were not designed for automatic feeding and the tolerances on external dimensions are often wide.

In this connection, I remember trying to feed a certain type of ceramic capacitor. Although intended to be an axial lead type of component with leads extending from either end, occasionally one of the leads protruded from the centre of the body. Incidentally, these were not used by the telephone industry. It was really rather pathetic to watch an assembly machine very carefully and deliberately cutting, forming, inserting and clinching-over a lead that was not there.

In their paper, the authors do not include information on the performance of their machine in this respect. I was wondering if they could give some indication of the insertion efficiency that they have been able to achieve, in terms of the number of satisfactory insertions per hundred components—excluding of course, those rejected for electronic defects.

The Authors (*in reply*): We overcome much of the difficulty of handling components by locating and holding them by the wires only and, more important, by maintaining this grip throughout the critical insertion stage. Moreover component diameter variations are automatically provided for by the inclined shear anvils. Nevertheless we have encountered some difficulties due to eccentrically disposed leads. In general, however, these eccentric leads merely result in excess wire projecting at right angles from the board after clinching and it can easily be clipped off.

The machine at present is still undergoing proving and reliability trials whilst making production boards. It is still too early to assess the ultimate performance which is being improved all the time. To date however over 10 000 components have been inserted into production boards. Less than 20 components and no boards have been damaged on insertion during these early trials and during the last 1000 insertions only about 10 diode wires have needed attention. This "dressing" is done quite simply by the girl who fits the transistors.

Mr. Harcharan Singh (*Graduate*): I would like to know the authors' opinion of the relative merits of the Dynasert (American) multistation type of automatic assembly machine and their machine.

My second question concerns with the economic aspects of this machine. Is this sort of machine economical for batch sizes of 10 to 50? What is the programming time?

My third question is: Does this machine handle components with two radial leads? What is the possibility of handling single-ended components like transistors etc.? Some components have to be held mechanically to the board by fixings additional to their leads. How can this facility be provided and is the complication involved in providing this facility justified in the opinion of the authors?

For soldering the leads seem too long after bending over. May not soldering produce short circuits?

The Authors (*in reply*): The Dynasert "in-line" machine and our machine are designed for different production requirements. Dynasert is intended for mass production. A 30-station machine when working continuously can assemble a 30-component board in about 3 seconds, but it takes a long time to set up the line. The machine described here is intended primarily to make savings in set-up time and preparation time on small batch production work. On this class of work the actual insertion time is often overshadowed by the time taken for the operators to learn a new placement pattern particularly if the batch size is not more than 50 boards.

We certainly expect the machine to prove more economical than manual methods for small batches of boards. In our organization a large annual production of a board is often made in relatively small batches of 10 to 50 at say fortnightly intervals. Thus whilst the programming time for a 50-component board is typically 1½ hours the cost of this operation is spread over a large number of boards.

The machine inserts axial lead components only and cannot handle either radial leads or single ended components. Additional fixings are seldom needed, when they are they would be manually applied.

It would be impractical and undesirable to complicate the mechanics of the machine further to provide any of the extra facilities mentioned by Mr. Singh. The boards are, however, mounted on pallets and we could envisage a further slave machine, run from the same control and accepting the same pallet, assembling the transistors for example.

The leads are not in fact too long after clinching. The turned-over horizontal portion of the lead does not overlap a 0·150 in. diameter pad.

U.D.C. 621.385.11.014.15

The Space-Charge Controlled Focus of an Electron Beam

By

D. L. HOLLWAY, B.E.E., M.Eng.Sc., D.Sc.(Eng.). †

Summary: A table is given of solutions of the space-charge equations governing the defocusing of electron beams having circular symmetry.

It is shown that the approximation,

$$(r_s/r_i) = 5{\cdot}9 \times 10^4\{(z_s/r_i)\,(I/V^{1\cdot5})^{0\cdot5}\}^{2\cdot5}$$

where r_s and r_i are the spot and initial beam radii respectively, z_s the screen distance, V the beam potential in volts and I the beam current in amperes, may be used for most beam design problems.

1. Introduction

The spreading produced by space-charge repulsion in an electron beam is often the most important factor limiting the current density in a focused spot. For the important case of a beam having circular symmetry, moving in a field-free space, beam profiles, graphs and charts have been published to assist designers.[1, 2, 4]

In a recent paper Moss,[3] examining the boundary between space-charge and thermal-velocity spreading, has made use of a normalized curve relating the smallest obtainable spot radius, the initial beam radius, screen distance and perveance.‡

As the space-charge limit is of practical importance, not only in the design of cathode-ray tubes but also of microwave devices, counters and other applications of electron beams, it is desirable to express the space-charge limit not only in graphical form but as a simple explicit equation which may be rearranged readily as a function of any variable and differentiated. The space-charge restriction then may be included in an expression for the overall performance of a device. This is an advantage when the optimum shape or dimensions are being sought.

In the following sections a table of numerical solutions of the complete space-charge equation is presented and compared with a simplified approximate expression intended for use in electron-beam tube design.

2. Numerical Solutions of the Space-Charge Equation

When an electron beam having circular symmetry is focused to a spot having the smallest radius r_s obtainable at a given screen distance z_s from the lens, the beam cross-section passes through a minimum and expands before reaching the screen.[1] If the beam is less strongly focused, i.e. if the initial convergence is reduced below the optimum value, the minimum cross-section may be moved forward to the screen; but the spot so formed will be larger than before.§

Usually only the optimum focus condition is of interest in beam design and it is not necessary to find either the position or radius of the minimum cross-section.

It has been shown[2] that, for optimum focus, the spot radius r_s is related to the initial radius r_i and the minimum radius r_m by the equations

$$2\int_0^{\sqrt{\ln(r_i/r_m)}} e^{x^2}\,dx - \frac{r_i/r_m}{\sqrt{\ln(r_i/r_m)}} = \frac{r_s/r_m}{\sqrt{\ln(r_s/r_m)}} - 2\int_0^{\sqrt{\ln(r_s/r_m)}} e^{x^2}\,dx \qquad \ldots\ldots(1)$$

$$\frac{z_s}{r_i} = k\frac{r_m}{r_i}\left\{\frac{r_i/r_m}{\sqrt{\ln(r_i/r_m)}} + \frac{r_s/r_m}{\sqrt{\ln(r_s/r_m)}}\right\} \qquad \ldots\ldots(2)$$

where $k = 5{\cdot}739\times10^{-3}/(I/V^{1\cdot5})^{0\cdot5}$

I = beam current in amperes

V = beam potential in volts, assumed to be constant between lens and screen.

By eliminating r_m between eqns. (1) and (2) a relationship is obtained between the required dimensions r_s, r_i, z_s and the beam perveance $I/V^{1\cdot5}$. The earlier solutions were found by numerical and graphical methods, but in view of the renewed interest in space-charge defocusing it was decided to program the digital computer SILLIAC to prepare a table of solutions having higher accuracy. In Table 1 are shown sets of concordant values of r_i/r_m, r_s/r_m, r_s/r_i and the corresponding values of $\sqrt{(\text{beam perveance})}\times(z_s/r_i)$. It is interesting to note that eqn. (1) is symmetrical. This results from the symmetry of the

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‡ This normalized curve was first published in 1952[2] and was derived independently by Schwartz.[4] When allowance is made for a difference in units, both curves are in full agreement.

§ The contours of beams focused in this way may be reduced to a single profile—Spangenberg's[7] "universal beam-spreading curve"—by normalizing with respect to the minimum radius.

beam profile on either side of its plane of minimum radius. When the spot and initial radius are equal the minimum plane falls midway along the beam; but all other values of (r_s/r_i) form pairs in Table 1, equally spaced above and below the line $(r_s/r_i) = 1$. Both members of a pair refer to the same beam profile, but with r_s and r_i interchanged. This is illustrated by the curve (a) in Fig. 1, drawn from Table 1. For example, the ordinate at $(r_s/r_i) = 0{\cdot}1$ is 0·0051 and this relatively small spot indicates that the minimum plane occurs close to the spot. On interchanging r_s and r_i, $(r_s/r_i) = 10$, the new ordinate is $0{\cdot}0051 \times 10$ and the same profile represents a highly divergent beam with the minimum plane close to the objective lens or electron gun.

Table 1

r_i/r_m	r_s/r_m	r_s/r_i	$\frac{(z_s/r_i)}{(I/V^{1\cdot5})^{0\cdot5}}$
54·60	1·030	0·0189	0·00350
44·81	1·038	0·0232	0·00363
36·97	1·048	0·0283	0·00378
30·65	1·059	0·0345	0·00393
25·53	1·072	0·0420	0·00410
21·38	1·088	0·0509	0·00429
17·99	1·106	0·0615	0·00449
15·22	1·128	0·0741	0·00470
12·94	1·153	0·0891	0·00494
11·05	1·182	0·1070	0·00520
9·488	1·216	0·1282	0·00549
8·187	1·256	0·1534	0·00580
7·099	1·302	0·1833	0·00615
6·187	1·354	0·2189	0·00653
5·419	1·415	0·2612	0·00696
4·771	1·486	0·3115	0·00743
4·221	1·568	0·3715	0·00796
3·753	1·664	0·4433	0·00856
3·353	1·775	0·5294	0·00923
3·012	1·906	0·6329	0·00999
2·718	2·060	0·7577	0·01086
2·562	2·165	0·8450	0·01143
2·3491	2·3491	1·0000	0·01242
2·165	2·562	1·183	0·01353
2·060	2·718	1·320	0·01433
1·906	3·012	1·580	0·01578
1·775	3·353	1·889	0·01743
1·664	3·753	2·256	0·01930
1·568	4·221	2·691	0·02143
1·486	4·771	3·210	0·02386
1·415	5·419	3·829	0·02664
1·354	6·187	4·569	0·02984
1·302	7·099	5·455	0·03354
1·256	8·187	6·518	0·03782
1·216	9·488	7·799	0·04280
1·182	11·05	9·345	0·04862
1·153	12·94	11·22	0·05544
1·128	15·22	13·49	0·0635
1·106	17·99	16·26	0·0730
1·088	21·38	19·65	0·0842
1·072	25·53	23·82	0·0977
1·059	30·65	28·94	0·1138
1·048	36·97	35·29	0·1332
1·038	44·81	43·16	0·1567
1·030	54·60	52·99	0·1852

3. Electron Beam Design Equations

For design purposes eqns. (1) and (2) may be replaced by a simpler approximate expression[2] arranged to denote,

(*a*) the greatest allowable beam perveance for a given spot size and screen distance:

$$(I/V^{1\cdot5}) = 1{\cdot}5 \times 10^{-4}(r_s/r_i)^{0\cdot8}/(z_s/r_i)^2 \qquad \text{......(3a)}$$

(*b*) the maximum screen distance for a given spot size and perveance:

$$(z_s/r_i) = 1{\cdot}23 \times 10^{-2}(r_s/r_i)^{0\cdot4}/(I/V^{1\cdot5})^{0\cdot5} \qquad \text{......(3b)}$$

(*c*) and (*d*) the smallest spot size:

$$(r_s/r_i) = 5{\cdot}9 \times 10^4\{(z_s/r_i)(I/V^{1\cdot5})^{0\cdot5}\}^{2\cdot5} \qquad \text{......(3c)}$$

$$(r_s/z_s) = 5{\cdot}9 \times 10^4(z_s/r_i)^{1\cdot5}(I/V^{1\cdot5})^{1\cdot25} \qquad \text{......(3d)}$$

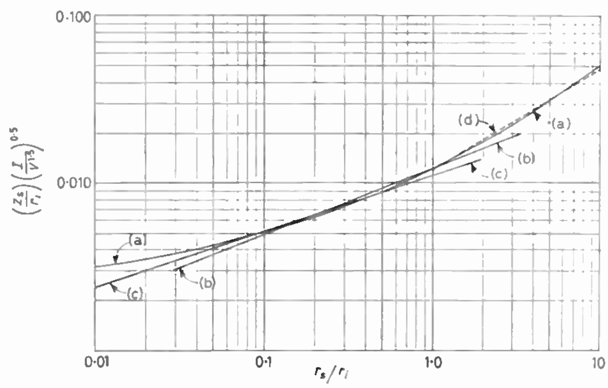

Fig. 1. The beam parameter, normalized screen distance × √perveance, shown as a function of the normalized spot radius.

(*a*) From exact solutions of the space-charge equations (1) and (2).

(*b*) Equation (3). This is the preferred form for beam design.

(*c*) Equation (4).

(*d*) Equation (3) with r_s and r_i interchanged. (Equation (5).)

The solutions of eqns. (1) and (2) given in Table 1 and Fig. 1 (*a*) may be used to indicate the range in which eqn. (3) provides a satisfactory approximation. The agreement between (*a*) and the straight line Fig. 1 (*b*), plotted from eqn. (3) and the error curve Fig. 2 (*e*), shows that the simplified form may be used for all problems in which the spot radius is greater than one-twentieth, and less than twice the initial beam radius. The majority of beam space-charge problems fall in this range.

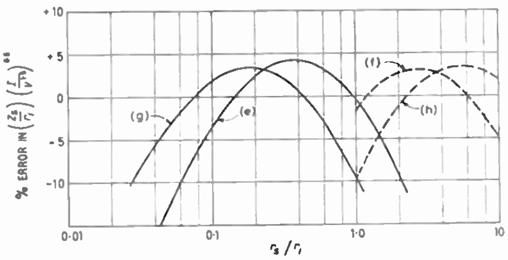

Fig. 2. Error curves showing the useful ranges of the approximations.

(*e*) Equation (3).

(*f*) Equation (3) with r_s and r_i interchanged. (Equation (5).)

(*g*) Equation (4).

(*h*) Equation (4) with r_s and r_i interchanged.

In many applications it is necessary to keep the spot radius smaller than the initial radius and for these the following expression may be found more convenient than eqn. (3):

$$(r_s/r_i) = 7{\cdot}1 \times 10^5\{(z_s/r_i)(I/V^{1{\cdot}5})^{0{\cdot}5}\}^3 \quad \ldots\ldots(4)$$

Equation (4) corresponds to the line (*c*) in Fig. 1, which differs from the true curve (*a*) by the error shown in Fig. 2 (*g*). The useful range of eqn. (4) is

$$0{\cdot}02 < (r_s/r_i) < 1{\cdot}0$$

The symmetry of Fig. 1 (*a*), discussed earlier, makes it possible to apply eqn. (3), or eqn. (4), to highly divergent beams producing spots much larger than the initial beam radius. This is done simply by interchanging r_s and r_i. Equation (3a) then becomes

$$(I/V^{1{\cdot}5}) = 1{\cdot}5 \times 10^{-4}(r_s/r_i)^{1{\cdot}2}/(z_s/r_i)^2 \quad \ldots\ldots(5)$$

corresponding to the dotted line Fig. 1 (*d*). Error curves for eqn. (5) and for eqn. (4) interchanged, are shown in Fig. 2 (*f*) and (*h*) respectively. Both agree closely with the true curve Fig. 1 (*a*), but in practice spots larger than $(r_s/r_i) = 2$, the upper limit of eqn. (3), are rarely needed and for all lower values eqns. (3a–d) may be used without alteration.

Although the term "spot" is used, these expressions are not restricted to the low-current beams used in oscilloscopes. In other beam tubes r_s may be the radius of an aperture at a distance z_s from the gun. Equation (3a) then gives the greatest beam perveance which may be used without intermediate focusing electrodes.

Only space-charge defocusing has been considered in this note; in practice thermal velocity spreading[3,5,6] and lens aberrations cause departures from the condition of laminar flow assumed in the derivation of eqns. (1) and (2) and so reduce the spot current density. Thermal spreading should be considered particularly when the space-charge influence is small, as indicated by a low value of r_s/r_i.

4. References

1. B. J. Thompson and L. B. Headrick, "Space-charge limitations on the focus of electron beams", *Proc. Inst. Radio Engrs*, **28**, pp. 318–24, July 1940.
2. D. L. Hollway, "The optimum space-charge-controlled focus of an electron beam", *Aust. J. Sci. Research*, (Series A), **5**, pp. 430–436, 1952.
3. H. Moss, "The cathode loading limit in circular beam electron devices", *J. Brit.I.R.E.*, **21**, pp. 35–9, January 1961.
4. J. W. Schwartz, "Space-charge limitation on the focus of electron beams", *R.C.A. Rev.*, **18**, pp. 3–11, March 1957.
5. M. E. Haine, "A contribution on the triode system of the cathode ray tube electron gun", *J. Brit.I.R.E.*, **17**, pp. 211–6, April 1957.
6. D. B. Langmuir, "Theoretical limitations of cathode-ray tubes", *Proc. Inst. Radio Engrs*, **25**, pp. 977–91, August 1937.
7. K. R. Spangenberg, "Vacuum Tubes", page 444 (McGraw-Hill, New York, 1948).

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INSTITUTION NOTICES

Birthday Honours List

The Council of the Institution has congratulated the following member whose name appeared in Her Majesty's Birthday Honours List:

Sidney John George Burt on his appointment as an Ordinary Officer of the Civil Division of the Most Excellent Order of the British Empire.

Mr. Burt, who was elected an Associate Member of the Institution in 1949 and was transferred to full Member in 1957, has been Principal of Hong Kong Technical College since 1952. His association with the College has been continuous, in successively more responsible posts, since 1938, apart from four years when he was a prisoner-of-war.

Brit.I.R.E. Prize for R.A.F. Apprentices

The second award of a Brit.I.R.E. Prize for the apprentice scoring the highest educational marks in each Entry of aircraft apprentices at No. 1 Radio School, R.A.F., Locking, has now been made. The Prize for the 93rd Entry has been awarded to Corporal Aircraft Apprentice G. W. Ash. Corporal Aircraft Apprentice Ash was also awarded prizes in English and General Studies. The Prize, details of which were announced in the August *Journal*, has a value of £5.

British Conference on Automation and Computation

The Institution has accepted an invitation from the Council of the British Conference on Automation and Computation, extended on the suggestion of the representatives of The Institution of Electrical Engineers on the Council, and with the unanimous support of the Executive Committee of the B.C.A.C., to become a Member Society of the B.C.A.C.

As its two representatives on the B.C.A.C. Council, the Institution has appointed Mr. Andrew St. Johnston, B.Sc. (Member) and Mr. William Renwick, M.A., B.Sc. (Member). Mr. St. Johnston is vice-chairman of the 1963 Convention Committee and has recently been nominated for election to the Council of the Institution. Mr. Renwick is chairman of the Computer Group Committee.

The Annual General Meeting of the representative members of B.C.A.C. will be held on Tuesday, 2nd October at 3.30 p.m. at the Institution of Electrical Engineers. It will be followed at 5.30 p.m. by the second B.C.A.C. Annual Lecture. Dr. B. V. Bowden, M.A., M.I.E.E., Principal of the Manchester College of Science and Technology, will deliver the lecture which is entitled: " Automation—The Next Phase. Can Managers be Automated? " Admission to the lecture will be open to members of all the Member Societies of the B.C.A.C.

The Indian Advisory Committee

The President of the Institution, Admiral of the Fleet the Earl Mountbatten of Burma, K.G., will give a reception in Delhi on Saturday, 10th November, 1962, for the members of the Indian Advisory Committee and other senior members of the Institution.

Joint I.E.E.-Brit.I.R.E. Meetings on Medical Electronics

As announced on page 444 of the June *Journal*, the Committee of the Medical Electronics Discussion Group of the Institution of Electrical Engineers and the Medical and Biological Electronics Group of the British Institution of Radio Engineers have been authorized to collaborate in their activities. The two Committees recently met and have arranged a number of common meetings during the 1962–63 Session. The joint meetings for the first half of the Session are as follows:

Monday, 29th October

"Data Processing in Medicine"

Dr. S. Rosenbaum and Dr. L. C. Payne

To be held at the I.E.E., Savoy Place, London W.C.2.

Wednesday, 21st November

"Automatic Biochemical Analysis and Particle Counting"

M. I. Henderson and Dr. J. F. Marten

To be held at the London School of Hygiene and Tropical Medicine, Gower Street, London W.C.1.

Friday, 7th December

"Masers and Lasers and their possible application to Medicine and Biology"

Opening speakers to be announced.

To be held at the I.E.E., Savoy Place, London W.C.2.

British United Provident Association

The annual renewal date for the Institution's Group of the B.U.P.A. is 1st November next. Members of the Group who wish to transfer their Scale or enter into the General Practitioner Scheme are reminded that this can only be arranged at the renewal date. Advice should be sent to the Secretary of the Institution not later than 8th October.

Applications from members wishing to join the Institution's Group can be accepted at any time. Full details of the Scheme can be obtained from the Group Secretary, 9 Bedford Square, London, W.C.1. Members who already subscribe to B.U.P.A. individually may transfer their registrations to the Brit.I.R.E. Group and have the advantage of 20% reduction in subscription rate. Requests for such transfer should be sent direct to the B.U.P.A. offices.

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The Application of Rapid Access Photographic Techniques to Radar Display Systems

By

S. R. PARSONS, B.A.†

Presented at a meeting of the Radar and Navigational Aids Group in London on 14th February 1962.

Summary: This paper describes a system whereby the cathode-ray tube of a radar display is photographed, and the exposed film rapidly processed and projected so that a large bright high contrast theatre-type presentation of the radar display is obtained. The picture is renewed automatically every few seconds. Either front or rear projection can be employed with a horizontal plotting table or a vertical screen. Mention is made of the use of colour film. Examples of the application of this system to air traffic control and marine and harbour radar are given and the operational advantages of such a system in these fields are discussed. In particular the 16 mm rapid processor and projector system installed in the S.S. *Canberra* is described.

1. Introduction

The display of radar information is, as is well known, achieved in its most usual form by intensity modulation of the time base of a cathode-ray tube which is rotating in synchronism with the aerial. Since by this means the radar data are only renewed once every revolution of the aerial, continuity of observation is achieved by using a phosphor with long persistence characteristics.

It has long been appreciated, however, that this type of presentation suffers in many applications from several operational disadvantages. The chief among these are:

(*a*) In order to preserve contrast, the display has to be viewed in very low ambient light conditions.

(*b*) The maximum available size of cathode-ray tubes restricts the number of people who can easily view the display simultaneously.

(*c*) It is not easy to annotate or plot on the display directly.

(*d*) It is fatiguing for an observer to watch such a display for long periods of time particularly due to the visible rotation of the time-base sweep.

It is the purpose of this paper to discuss a system which is designed to overcome these disadvantages by using photographic techniques to produce a large, bright, high contrast, theatre-type presentation of the radar data.

2. The 35 mm Rapid Photographic Processor and Projector

The basic requirement for producing a large bright display of radar data using photographic techniques is to have means whereby the film can be processed automatically within a few seconds. Once such means are available, then by the use of an intermittently-operated film transport mechanism, the film that has been exposed to the cathode-ray tube through the camera lens can be moved to the processing position where it is developed, washed and dried, and then moved to the projection position for viewing. If this process is continued film-frame by film-frame then a sequence of projected pictures of the radar display will be produced, each picture being up to date, within a few seconds, with the latest radar data.

Figure 1 shows a schematic representation of a 35 mm rapid processor and projector designed originally for the Ministry of Supply. The film gate has three stations, the camera station, processing station and projection station, each one film-frame apart. The film lies stationary in the gate during the processing cycle. In this time a fresh film-frame is being exposed in the camera station to the cathode-ray tube while the previous film-frame to be processed is being projected in the projection station. At the end of the processing cycle, the film transport mechanism is activated and moves the film forward by one film-frame. This cycle is repeated until the film in the casette is used up. The film casette will hold 1000 ft of 35 mm film and using the fastest processing time of 3½ seconds, this means that the machine will operate for 6 hours continuously before the film has to be renewed.

2.1. *The Processing Station*

The processing station consists of a pot in which are arranged a number of jets which spray the developer, fix and wash solutions and drying air on to the film sequentially. The jets are of the Venturi type and are operated by compressed air so that the solutions are applied in the form of a fine atomized spray.

† S. Smith & Sons (England) Ltd., Kelvin Hughes Division, Dagenham, Essex.

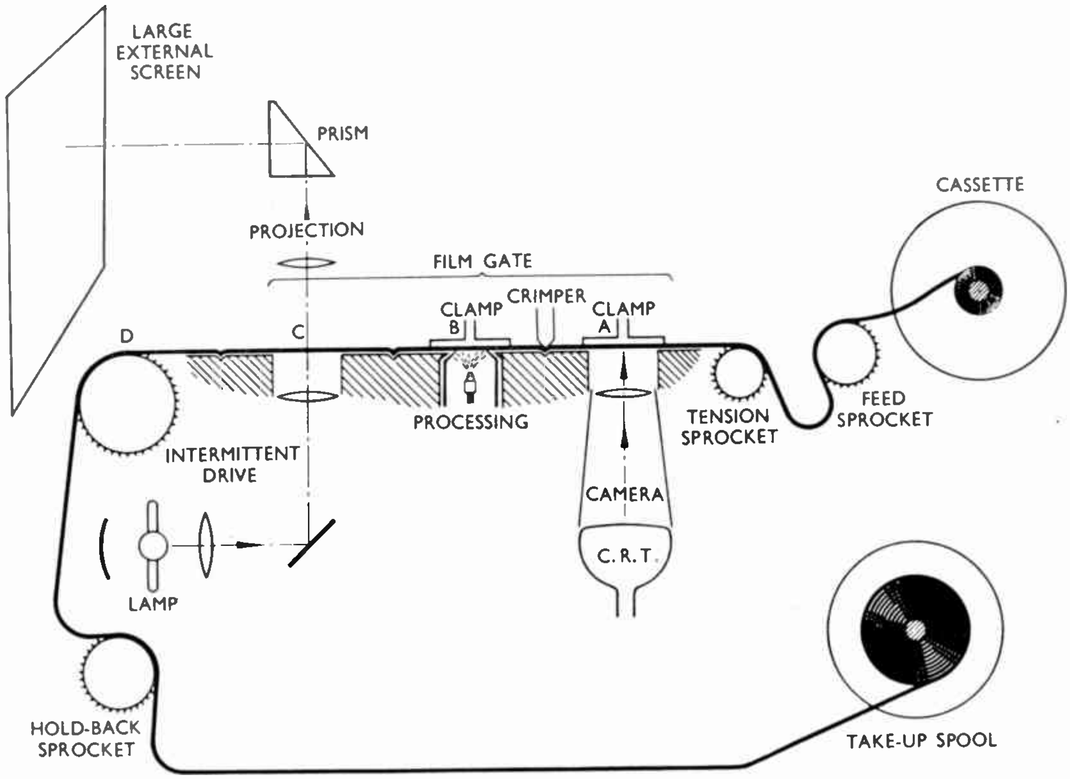

Fig. 1. Schematic representation of the 35 mm rapid photographic processor and projector.

This method has several advantages.

(i) The liquids are switched on by switching compressed air to the jets in sequence by means of fast operating solenoid valves thus overcoming problems of sticking and corrosion which would arise if the liquids themselves were switched sequentially into a single jet.

(ii) The high velocity of application of the atomized spray to the emulsion surface provides very effective agitation which in conjunction with the continuous application of fresh solution is responsible for the constant high quality of the processed film.

(iii) The ability to switch the liquids rapidly does away with the need for washing the film after the application of each solution.

The processing spray is preheated so that its temperature is about 35°C when it impinges on the film. This temperature is achieved by thermostatically controlling the temperature of the compressed air at 200°C.

The processing pot and jets are made of special material such as tantalum or Hastalloy "C" to prevent corrosion by the chemicals.

2.2. *The Projection Station*

The time for which the film remains in the projection station can be varied from 3½ seconds up to several minutes. Thus means must be found for keeping the film cool and in precise focus during this time. This requires that the projection aperture is fitted with an accurate bloomed-glass register plate against which the film is located by means of cool compressed air. The film then remains in optical contact with the glass, is cooled by the impingement of the air, and is finally fully dried.

Various focal length projection lenses can be used so that some flexibility is obtained in the choice of projected picture size and throw distance from the projector to the screen.

2.3. *Film Crimper*

One major problem which had to be overcome in the design of the gate unit was the fact that the projected light, which can be of the order of 6000 lumens, passes through the film less than 4 in. from the camera aperture and less than 2 in. from the processing aperture. Unless suitable precautions are taken this means that the film becomes completely fogged.

Research into this problem showed that the light was travelling along the film base by multiple reflections and the solution was to put a sharp kink between the film frames by means of a crimper blade, the angle of the kink being arranged with respect to the critical angle so that any light in the film base must leave at the kink.

2.4. *Photographic Performance*

Normal operation of the equipment produces conventional negatives which may have a gamma between 0·5 and 3·5 (depending on the processing cycle), a fog level of about 0·05 and a maximum density of 3.

It is possible to achieve positive processing by using a bleach instead of the fixer solution. In this case the minimum processing time is about 7 seconds in order to achieve a usable contrast for projection.

The resolution of the overall system, including camera lens, emulsion, processing and the projection lens is of the order of 50 photographic lines/mm.

2.5. *Operation and Maintenance of the Equipment*

The equipment is designed to operate 24 hours per day and need only be stopped to reload with film or for a weekly maintenance of about half an hour.

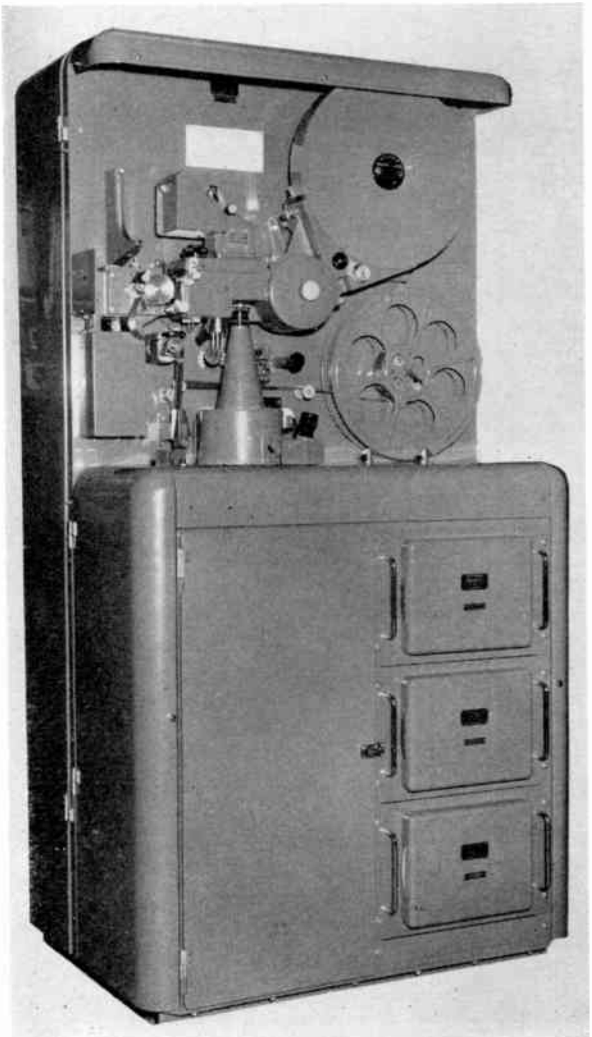

Fig. 2. The 35 mm rapid photographic processor and projector.

The chemical bottles are fitted with nozzles and inverted in the apparatus so that the nozzles dip into reservoirs which will contain enough solution for about half an hour's operation. Thus these bottles can be removed for replenishment without interrupting the operation of the equipment. The concentrated chemicals are supplied in containers of such a capacity that when they are emptied into the bottles, the correct concentration is obtained by filling up the bottles with ordinary tap water, thus avoiding the necessity for making any volumetric measurements. The use of tap water is made possible by including in the wash solution a small quantity of a disodium salt to remove the effect of various degrees of hardness of ordinary tap water.

A system of warning lights coupled with an audible warning will automatically draw attention to various conditions such as chemicals low, film running out, a film break or a fault in the compressed air supply. A film break or failure of the compressed air automatically shuts off the equipment thus avoiding permanent damage.

Figure 2 shows a complete 35 mm processor and projector mounted over a cabinet containing the cathode-ray tube and its associated electronics.

3. Applications to Air Traffic Control

One of the prime means of obtaining information for the purpose of air traffic control is by the use of radar. The main problem which arises is to discover the best method by which this information can be presented to the controllers so that they can exercise control rapidly and efficiently in circumstances which are becoming increasingly complex.

Because of this increasing complexity, a great deal of effort is being devoted to analysing and evaluating integrated air traffic control systems. It is not within the scope of this paper to discuss the many controversial aspects of such integrated systems but merely to illustrate how rapid-access photographic techniques could be applied to air traffic control if in any overall systems concept there was found to be a need for a large theatre-type "general situation map" presentation.

The 35 mm rapid photographic processor and projector, known for short as the 35 mm RP3, can produce a bright, high contrast picture of the radar information up to a displayed diameter of 15 to 20 ft either by front projection on a vertical screen, or by front or rear projection on a flat horizontal plotting table. Figure 3 shows the result of using the 35 mm RP3 to produce a general situation map on a horizontal plotting table. This was installed at Indianapolis airport for evaluation purposes and the illustration shows the controllers tracking aircraft and

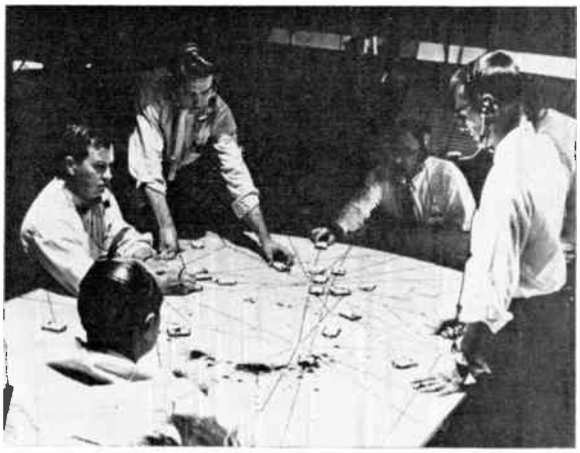

Fig. 3. Operational use of a 35 mm RP3 at Indianapolis Airport.

annotating them by means of discs which can be tracked on top of the actual aircraft echoes.

In this type of application where the speed of rotation of the radar aerial is about 10 rev/min or one revolution every 6 seconds, the film repetition rate can be synchronized so that the film transports once per aerial revolution. It will be appreciated that in these circumstances the information seen on the projected picture will be a minimum of 6 seconds late and a maximum of 12 seconds late depending on whether the data are painted on the cathode-ray tube just before or just after film transport has taken place. This is inevitable due to the step-by-step nature of the operation of the 35 mm RP3 whereby the film after exposure must be processed before being projected. The delay which occurs between the recording of the information and its presentation is often raised as a serious objection to the system. It can only be said that operators who have used it have stated that with a little practice they find no difficulty in allowing for this delay in their assessment of the data.

A second difficulty which arises from synchronization of the film transport with aerial rotation is the fact that the film transport takes a finite time of about 1/25 second during which the film cannot be exposed to the cathode-ray tube. This means that at a rotation rate of 10 rev/min there will always be a blank sector in the same position of about 2·4 deg. This can be partially overcome by arranging for the film transport to be slightly out of step with the aerial rotation so that the blank sector is stepped round through 360 deg.

Figure 4 shows an arrangement whereby the radar picture is projected on to a semi-transparent screen which can be edge illuminated. The picture can be annotated from behind by writing with a chinagraph pencil and when the edge illumination is switched on, the writing is clearly seen against the radar information. Furthermore, as is seen in Fig. 5, the screen and its annotation can be easily televised and the information taken by a closed television system to any number of remote positions. It is also apparent that, due to the high contrast of the original projected picture, the televised version suffers little deterioration.

Thus the use of a 35 mm RP3 equipment with air surveillance radar gives to an air traffic control system the ability to present a bright theatre-type display of the radar data in the form of a general situation map, on which plotting can take place either by markers or with chinagraph pencil, and this display can be readily televised and repeated in any number of remote positions. It is also worth noting that due to the high quality of the film processing, a permanent film record is obtained which can be stored without deterioration for many years. Such a record can be very valuable for analysis and for training purposes.

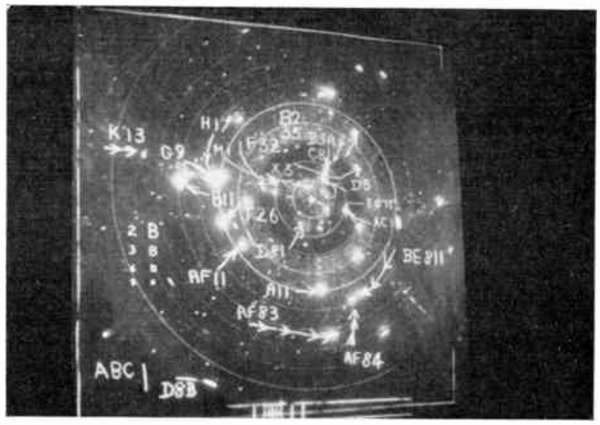

Fig. 4. An air surveillance radar picture on a semi-transparent screen which is edge illuminated to show up the annotation on the back of the screen.

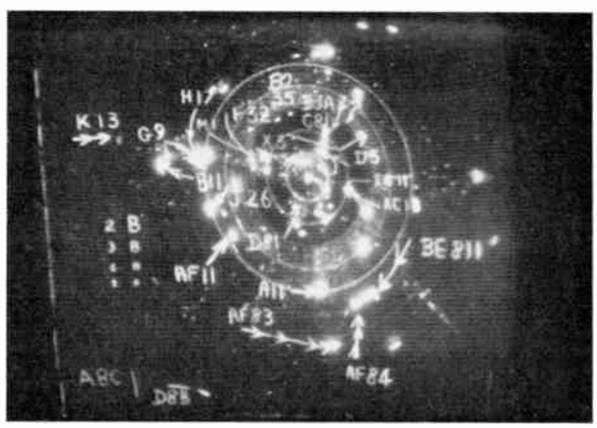

Fig. 5. The result of televising the screen shown in Fig. 4 on a closed-circuit system.

3.1. *Colour Processing*

A recent advance in rapid access techniques is the use of colour film by means of which a coloured record can be obtained in a processing time of 20 seconds.

The colour film has two layers, one sensitive to blue light and containing a red dye, and the other sensitive to green light and containing a green dye. Processing is of the reversal type so that exposure to blue light will produce a green image and exposure to green light a red image, while exposure to both blue and green light simultaneously will produce a white image. These images are produced on a dark background which is most suitable for observing colour. One method of operation is to use a cathode-ray tube with a phosphor having a spectral sensitivity in the blue and green bands. Means are then provided for electrically switching either a minus blue or a blue or a neutral filter between the cathode-ray tube and the camera. During the 20 second exposure time three categories of radar data can be displayed on the cathode-ray tube sequentially and the appropriate filter switched in for each category. By this means at the end of the exposure time, the three categories of radar data will have been integrated on the film and after processing will appear in their appropriate colours.

An alternative but more complex mode of operation is to use three cathode-ray tubes each with the appropriate spectral responses, and imaged on to the film simultaneously. By this means the three categories of radar data can be displayed and photographed simultaneously.

4. Applications to Marine Radar

In order to appreciate the possible operational use of rapid access photographic techniques in the marine radar field, it is necessary to review briefly the present types of marine radar display.

The signals received by a marine radar, when displayed on the cathode-ray tube, represent the position of coastlines, ships, buoys etc. relative to the ship to which the radar is fitted. Thus when the ship is in motion, the tracks on the display of other ships are relative to own ship considered stationary. Since the aerial beamwidth of a 3 cm radar is not sufficiently narrow to display the aspects of other ships, it is not possible, without introducing own ship's course and speed as a vector on a separate plot, to determine other ships' courses and speeds through the water. Thus the only immediate information available from a relative motion display is whether or not a potential collision situation exists as judged by the constant bearing criterion. The best action to be taken can only be assessed by either manual plotting or by having sufficient experience to be able to carry out plotting in one's head. Furthermore when own ship alters course, the whole relative display rotates if it is stabilized to ship's head, thus introducing a confusing discontinuity in the information being presented. This can be overcome by stabilizing the picture to the compass heading but then the positions of echoes on the display do not correspond in an easily recognizable manner to the actual positions of the targets relative to the observer's frame of reference, namely the fore and aft line of the ship.

If however the display is compass stabilized and the time-base origin is moved across the cathode-ray tube in the direction of own ship's course and at a speed which represents own ship's speed for the range in use, then other ships' tracks will represent their true courses and speeds through the water (neglecting the effect of current and tides) and any manoeuvre by own ship will in no way effect these tracks. In effect the radar data, which are essentially relative data, are being processed by using a computer which automatically introduces on the display own ship's speed vector.

The main features of Relative and True Motion Displays can thus be summarized briefly as follows:

(*A*) *Relative Motion*

(i) Other ships' tracks give immediate potential collision information but plotting is required to find their true courses.

(ii) When own ship manoeuvres a confusing discontinuity occurs in the information unless compass stabilization is used.

(*B*) *True Motion*

(i) Other ships' tracks give immediate information of their true courses but plotting is required to assess potential collision situations.

(ii) Own ship's manoeuvres do not affect the position or tracks of other targets.

It will be appreciated from this summary that some form of plotting is required both in the relative and true motion case if all the information inherent in the display is to be used.

Two methods of plotting are presently available to users of radar on merchant ships. The first is to employ the conventional method of transferring sequential range and bearing measurements of each target to a separate plot, a somewhat tedious and time-consuming operation. The second is to use a reflection plotter, where, by using a half silvered mirror over the cathode-ray tube, it is possible to project marks made by a chinagraph pencil on the plotting surface on to the surface of the display. In this second case, the display and plot has still to be shielded from ambient light and cannot be viewed normally by more than one or two people at a time.

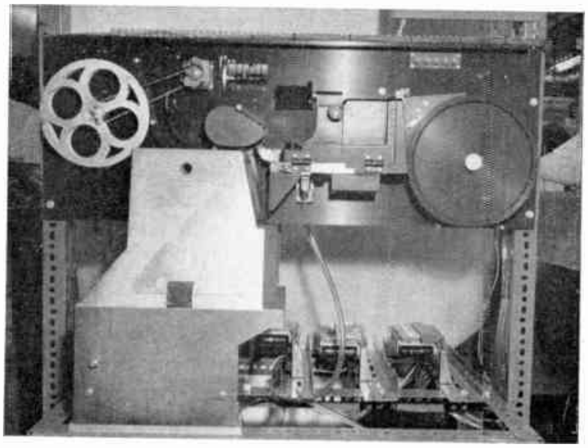

Fig. 6. The 16 mm rapid photographic processor and projector.

Ideally on a merchant ship, where the staff available for radar observation and plotting is very limited, the requirement is for a large bright display on a flat surface, giving a chart-like presentation of the radar data, so that plotting can be carried out directly on top of the radar picture using conventional chart techniques. This can be achieved as a result of the development of the 16 mm RP3, which due to its small size and compactness, can be readily integrated with a standard marine radar display into a deck-mounted bright display console.

4.1. *The 16 mm Rapid Photographic Processor and Projector*

The 16 mm RP3 design is based entirely on the experience gained from the many years of operation of the larger 35 mm version. Due to the smaller size of components inherent in the use of 16 mm film it has been possible to fit all the sub-assemblies on a main frame, whose dimensions are 3 ft by 1 ft 6 in. The 1 kW xenon projection lamp is housed in a cast case and an ellipsoidal mirror is used to image the arc on to the film in the projection aperture thus eliminating the need for an expensive condensing lens system.

The film casette holds 400 ft of film which, under operating conditions on board ship where a 14 seconds film repetition rate is normally used, will last approximately 15 hours. The cost of film and chemicals works out at about ¼d. a frame, which for the same operating cycle of 14 seconds is about 5s. an hour.

Figure 6 illustrates the main frame and lamphouse of a 16 mm RP3 and Fig. 7 shows a prototype deck-mounted relative motion bright display console wherein the 16 mm RP3 has been combined with a standard radar display. The console is completely self-contained except for the supply of compressed air and can be installed with a conventional radar system to produce a 24-in. diameter rear projected bright display. The display electronics, which feed a 3-in. cathode-ray tube under the camera lens, are seen in the right-hand door and the chemical bottles are seen mounted in the left-hand door. The radar and 16 mm RP3 controls appear along the front of the console just below the projection screen.

4.2. *The Radar System Installed in the P & O-Orient Liner "Canberra"*

The P & O-Orient liner *Canberra* is the first ship in the world to be equipped with a 16 mm RP3 bright display radar console. This console forms part of a comprehensive navigational console designed especially for the *Canberra* to the owners' specification and is illustrated in Fig. 8.

The console consists of two true motion radar displays and a chart table with an echo sounder and Decca Navigator mounted at the rear. The radar unit in the centre is a conventional deck-mounted 16 in. true motion display with a reflection plotter and the two right-hand sections form the bright display unit containing a 16 mm RP3 and another set of true motion display electronics which feed a flat-faced 3 in. cathode-ray tube situated under the camera of the photographic unit. The controls and true motion computer for the bright display are seen on top of the right-hand end section. Behind the central radar display are a zig-zag clock, set to give signals every 6 min for plotting purposes, and the speed and distance indicators of a Sal pressure-type log.

In the forward part of the bridge is situated a pedestal mounted 12-in. relative motion display which can be switched as a slave to either of the console displays.

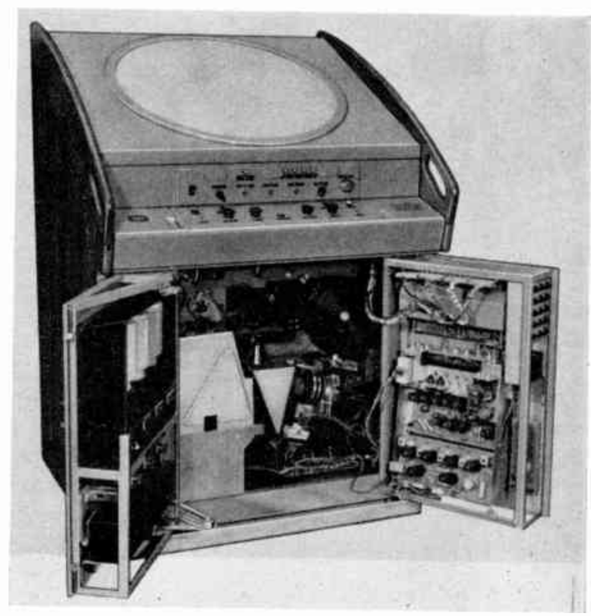

Fig. 7. A shipborne relative motion bright display console.

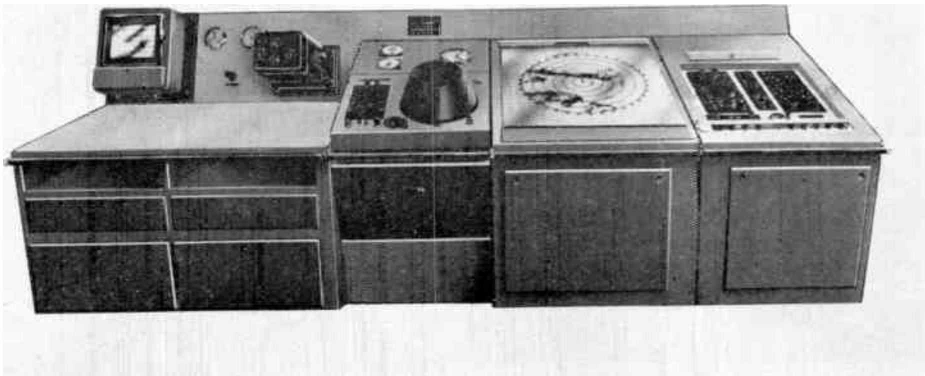

Fig. 8. The navigational console on the P & O-Orient liner S.S. *Canberra*.

The two console displays and the slave are connected to two aerial and transmitter units and the two complete radar systems are supplied from two 1 kW generators driven by a common 3-phase motor and phased in such a manner that mutual interference is virtually eliminated. A comprehensive interswitching arrangement enables all the units of the two systems to be interchanged and also allows for all the displays to be connected to one aerial and one transmitter.†

The panel at the extreme right-hand end of the navigational console displays by means of lights the manner in which all the units are interconnected at any given moment.

4.3. *Operational Aspects of the "Canberra" Bright Display Unit*

The bright display system is capable of producing a large, chart-type presentation of the radar data on a 24 in. rear projection screen which can be viewed easily under daylight conditions without the need for screening. Plotting can be carried out with a pencil directly on the radar picture with the aid of conventional chart instruments and the display can be viewed by several people simultaneously.

The rate at which the picture is renewed can be chosen to be 3½, 7, 14, 28 or 56 seconds and in all these instances the rate is controlled automatically. The film can be left exposed to the cathode-ray tube for longer times by manually operating a film transport switch. Automatic plotting can then be achieved by leaving the film exposed to the radar data for, say, 6 minutes. In these circumstances, if the true motion mode is being used, the film on projection will show 6-minute integrated tracks of own and other ships. These tracks are then immediately available for computing relative information and also can be used to compute the speed of other ships' since their lengths will be one-tenth of the speeds in knots.

A switch is also available for choosing either negative or positive processing and this choice can be made at any time without interrupting the operation of the equipment. Positive processing is available chiefly for night operation since the presence of the dark background considerably reduces the light level on the bridge. Alternatively a negative picture can

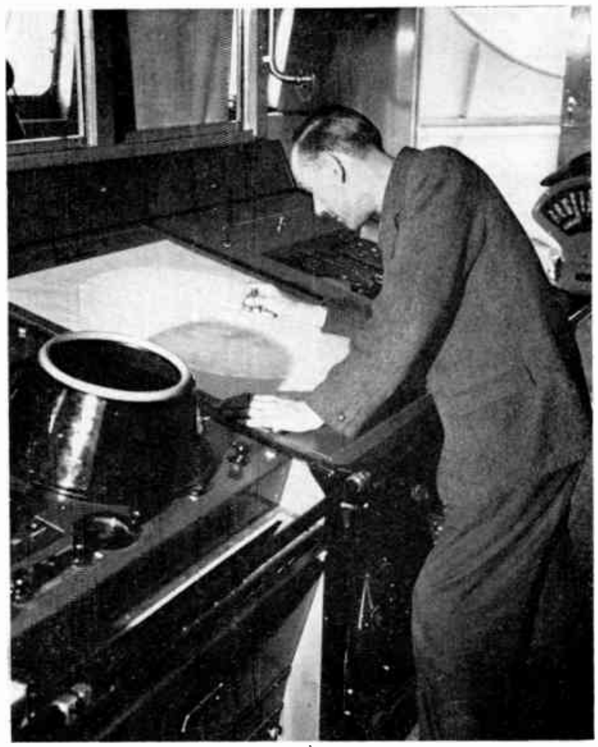

Fig. 9. The plotting screen of the bright display console on the *Canberra*.

† A. Harrison and D. Chamberlain, "Integrated radar systems with special reference to S.S. *Canberra*", *J. Brit.I.R.E.* (to be published).

Fig. 10. A bright radar display of the Thames Estuary at Southend showing chart comparison.

be used at night and dimmed by introducing a coloured filter in the projection system. It has been found on the *Canberra* that the latter is to be preferred.

Due to the fact that the bright display can be used like a chart, great care is taken to ensure accurate linearity of the projected picture. In particular a lens had to be devised which could be placed on the surface of the 3-in. cathode-ray tube to correct for the errors in linearity inherent in the use of a flat-faced tube.

A simple telescopic device is incorporated in the console so that the cathode-ray tube may be viewed directly for setting-up purposes when the radar is first switched on. This overcomes the difficulty that if the projected picture is used for this purpose the result of varying the controls is not seen for several seconds.

A special paper is used for the projection screen and this is housed in a roll at the top of the console and is drawn down over plate glass and connected to another roller at the front. The rollers are motor driven so that fresh paper is automatically available on demand. Figure 9 shows a close-up view of the plotting screen.

4.4. *Applications to Harbour Radar*

The application of the rapid processor and projector to harbour radar displays is in many ways analogous to its application to air traffic control. In a harbour control system the advantage of a large bright theatre-type presentation is obvious. Annotation using either chinagraph pencil or disc markers can be used and additionally by suitably adjusting the size of the projected picture, the radar can be matched to a standard chart. Figure 10 shows a front projected picture of the stretch of the Thames at Southend using a 35 mm RP3 equipment photographing a 9-in. radar display installed in the Kelvin Hughes research station at the end of Southend Pier.

5. Conclusions

The use of rapid access photographic techniques for the production of large, bright, high-contrast radar displays has proved over the years to be practicable for both land-based and shipborne radar equipment. This is mainly due to the high degree of reliability that has been achieved coupled with simplicity of operation.

It is acknowledged that the system has some disadvantages, in particular the fact that stocks of film and chemicals must be available for its operation, but if the operational advantages of the type of display it produces are wanted, then it is difficult to see for some time how purely electronic means can replace it for quality of presentation.

6. Acknowledgments

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The Physical Meaning of Formulae for Excess Noise in Composition Resistors

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Summary: It is shown that generalization of Hettich's formula for excess current noise in resistors leads to a physical interpretation of the coefficient in Bernamont's formula and in the "technical" formula. It is shown further that these coefficients can be represented by the simple product of certain electrical and geometrical factors. The validity of the theory developed is confirmed by experiment and an application of the results to the reduction of current-noise is noted.

1. Introduction

The noise in excess of thermal noise, generated by direct current in composition resistors, has been the subject of many papers.[1–12] These papers, however, do not discuss the physical meaning of the various coefficients in the noise formulae. Bernamont[1, 2] first established the following relation between the r.m.s. electromotive force E of the noise and the direct current I_0 flowing through the resistor:

$$E = KI_0^{\alpha}B \qquad \ldots\ldots(1)$$

where K is a factor defining the noise of a given resistor, B is a factor depending on the frequency response of the system, and α is an exponent which is forced to be close to unity.

On the assumption $\alpha = 1$ and the usual relation between I_0 and the steady voltage V_0 across the resistor, the following "technical" formula was stated and generally used for purposes of measurement and specification[10]

$$E = \mu V_0 \qquad \ldots\ldots(2)$$

According to this, the noise coefficient of a given resistor was conventionally defined as the ratio of the r.m.s. electromotive force of the excess noise to the direct voltage applied to the resistor, for a given frequency response of the system.

In the following discussion, the factor B will be omitted, assuming it to be included in the noise coefficient, as was done in eqn (2).

Formula (2) is useful for the comparison of noise in resistors of the same resistance, but it gives no information on the physical meaning of the coefficient μ and it can be misleading if one tries to use it to compare resistors of different values or to calculate the resultant noise in series or parallel combinations of resistors. In fact, formula (2) when written in the form $E = \mu I_0 R$ and μ is regarded as a constant of the material, appears to contradict the law of addition of the power of random fluctuations which requires that the noise e.m.f. varies as $\sqrt{R}$. Formula (2) would then require that either the noise in different resistors is correlated or that μ is not a constant of the material, but depends on other physical properties. The latter supposition was adopted by Hettich[8] who pointed out the dependence of the excess noise on the geometry of the resistor. His development was based on the assumption of randomness of noise e.m.f.'s generated in each element of a resistor. Introducing the concept of r.m.s. noise e.m.f generated in a resistor of unit length and cross-section (E_0), he calculated the resultant e.m.f. of a resistor of cross-section S and length l on the basis of the addition of uncorrelated fluctuations, and obtained

$$E = E_0\sqrt{\frac{l}{S^3}} \qquad \ldots\ldots(3)$$

In this paper, Hettich's work is extended and applied to Bernamont's formula and the "technical" formula. At the same time, the physical meaning of the various noise coefficients and their dependence on certain electrical and geometrical factors becomes clear.

2. Theory

If e_0 is the r.m.s. electromotive force generated by unit direct current in a unit cube of material, then on the basis of eqn (1) with $\alpha = 1$,

$$E_0 = e_0 I_0 \qquad \ldots\ldots(4)$$

can replace E_0 in eqn (3). On the other hand, the specific resistance ρ of the material the resistor is given by

$$\rho = RS/l \qquad \ldots\ldots(5)$$

and combination of eqns (3), (4) and (5) leads to

$$E = (e_0/\sqrt{\rho})\sqrt{R}(I_0/S) \qquad \ldots\ldots(6)$$

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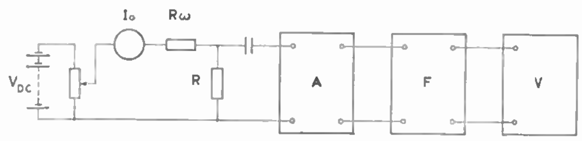

Fig. 1. Experimental arrangement for measuring current noise.

This form indicates the physical meaning of the coefficient K in eqn (1). It depends on the characteristics of the material (through $e_0/\sqrt{\rho}$), the resultant value of the resistance (through $\sqrt{R}$) and the applied current density (through I_0/S). The factor $\sqrt{R}.I_0/S$ shows that the resultant noise in any combination of resistors is the sum of the values of noise power of the individual resistors, as can be done in the case of simple thermal noise.

3. Experimental Results

To prove the validity of the assumption that the elementary noise contributions are uncorrelated, eqn (6) was checked by experiment by varying R and S. The measuring circuit is shown in Fig. 1. The direct current through R was adjusted by a wire-wound variable resistor R_w that gave rise to no appreciable noise in excess of its thermal noise. The current-noise generated in R was amplified by the low-noise amplifier (A), passed through the filter (F) and indicated on the true r.m.s. voltmeter (V).

To vary R while keeping S constant, the resistor was composed of n substantially identical resistors R_0 connected in series. The results obtained are shown in Fig. 2, which confirms that the r.m.s. noise varies as $\sqrt{R}$.

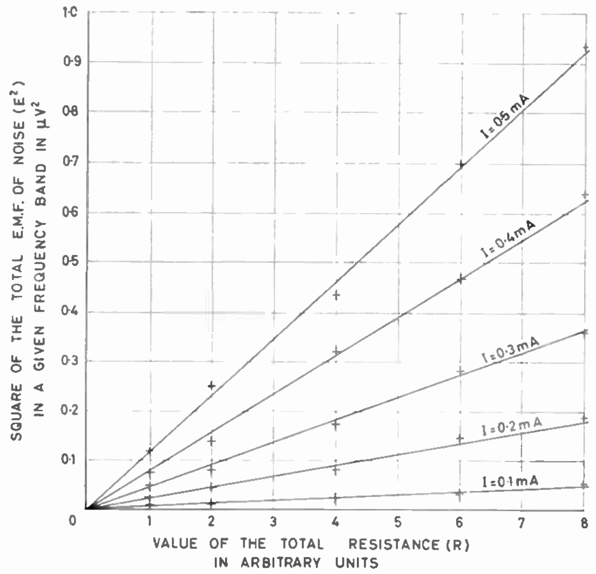

Fig. 2. Relation between noise and total resistance.

To vary the current density while keeping the resultant R constant, the resistor was composed of a series-parallel combination of n^2 substantially identical resistors R_0. The resulting cross-section S was then nS_0, where S_0 is the cross-section of each resistor. The results are shown in Fig. 3, which confirms that the r.m.s. noise varied as $1/S$ when R is maintained constant.

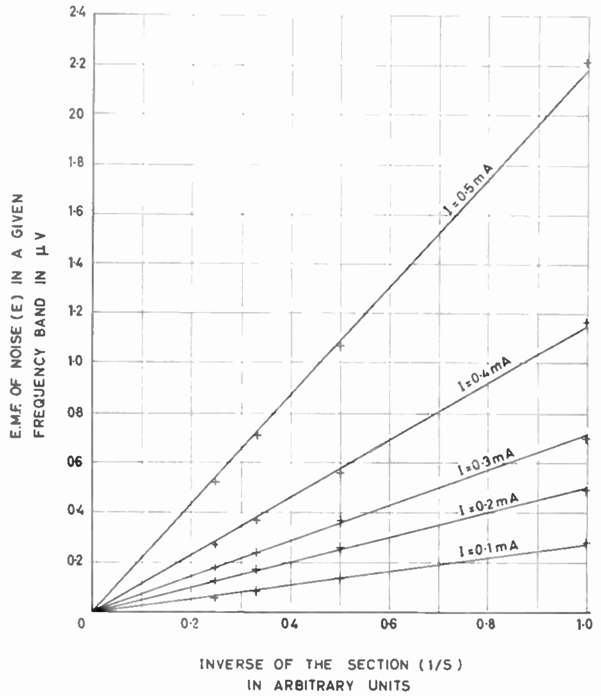

Fig. 3. Relation between noise and cross-section.

4. Conclusions

Having demonstrated experimentally that eqn (6) is valid, this equation can be introduced in the "technical" formula (2). Thus

$$E = \frac{e_0}{\sqrt{\rho}} \cdot \frac{1}{S\sqrt{R}} V_0 = \frac{e_0}{\rho\sqrt{lS}} \cdot V_0$$

The product lS equals the volume Q of the resistor, so one can write the coefficient μ in eqn (2) in the form

$$\mu = (e_0/\rho) \,.\, (1/\sqrt{Q}) \qquad \ldots\ldots(7)$$

The first factor in this depends only on the material of the resistor and its state, while the second factor depends only on the volume of the material. Thus all resistors made of the same material and having the same volume should have the same coefficient μ. It is seen also that the current-noise can be reduced by using a series-parallel combination of resistor, having the same resultant resistance as that of an individual element.

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Very Low Noise Transistor Amplifiers in the U.H.F. Band using the Parametric Conversion Mode

By

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Summary: The need for amplifiers with low noise and high gain in the ultra high frequency band led to the use of semiconductors in parametric amplifiers. Because such amplifiers are reciprocal devices, they must be used with isolators. This paper describes a new method of using available high-frequency transistors to achieve high conversion gain with extremely low noise figures in a small and simple non-reciprocal u.h.f. amplifier which avoids the expense of "varactor" diodes and isolators.

1. Introduction

The high frequency performance of a transistor can be determined from the frequency at which the gain drops to unity.[1] In the straightforward application of transistors in conventional circuits, useful gain is obtained at frequencies up to about 700 Mc/s only when existing types of transistors are used. In this paper, new circuits are described in which transistors are operated as parametric frequency converters in which the effects of the undesirable input phase-shift and the base spreading-resistance are avoided. The actual performance of the transistor has an upper limit of frequency determined only by the transit-time of minority carriers across the effective base width. As a result of the oscillator condition the noise figure and the conversion both attain optimum values.

2. Basic Theory of Operation

The cut-off frequency of high-frequency transistors is determined mainly by the phase-shift of the equivalent R-C delay line at the input. The intrinsic base spreading-resistance $r_{bb'}$ is the dominant factor in this relation. The maximum frequency of oscillation f_{max} is expressed in terms of $r_{bb'}$ by:

$$f_{max} = \sqrt{\frac{f_\alpha}{8\pi C_c r_{bb'}}} \qquad \text{......(1)}$$

The frequency f_α is determined by the delay line which consists of the emitter diffusion-capacitance, the barrier-layer capacitance and the emitter diffusion-resistance, as shown in Fig. 1. In this

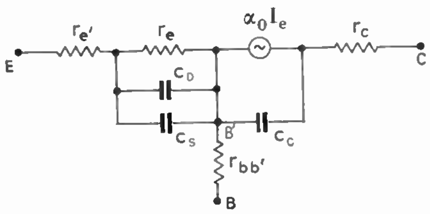

Fig. 1. Normal equivalent circuit of a *p-n-p* transistor in common base configuration, showing emitter diffusion capacitance, barrier-layer capacitance, the emitter diffusion-resistance, the collector barrier-layer capacitance and intrinsic base-spreading resistance $r_{bb'}$.

$r_{e'}$ = emitter spreading-resistance (about 12 ohms).

r_e = emitter diffusion-resistance (26 (mV)/I_e (mA), for 20° C).

r_c = collector spreading-resistance (0·5 to 40 ohms).

C_D = emitter diffusion-capacitance = 39 ($W^2/2D$) I_e where W is the width of the base in µm, D is the diffusion constant of holes in a *p-n-p* transistor and I_e is the emitter current.

C_S = barrier-layer capacitance (30 pF).

C_c = collector capacitance (about 0·5 to 1·5 pF).

The input cut-off frequency is given by

$$f_0 = \frac{1}{2\pi r_e C_E} \qquad \text{......(2)}$$

in which C_E is the total emitter capacitance. In the grounded-base circuit the diffusion capacitance is effectively negative and can be made to cancel the barrier-layer capacitance. By these means C_E can be made effectively zero for a particular value of the emitter current, the input impedance becomes purely resistive and f_0 is not limited by C_E. A transistor in this condition is referred to as being "current-tuned" because the condition is achieved for one special value of the emitter current only (see definition of C_D). It is operated in a frequency band in which the value of C_c is nearly sufficient to produce self-oscillation by feedback direct to the inner base point marked B′ in Fig. 1. In this condition, no high-frequency current flows in the base lead; hence $r_{bb'}$ does not appear in the modified equivalent circuit shown in Fig. 2.

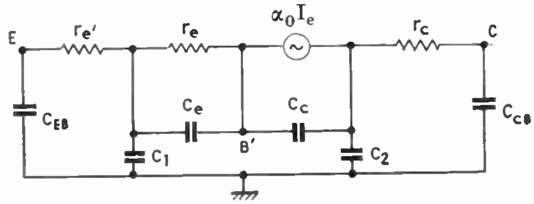

Fig. 2. Modified equivalent transistor circuit neglecting the influence of both input frequency behaviour and the intrinsic base-spreading resistance.

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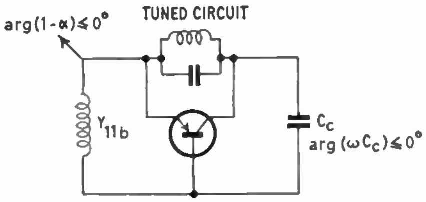


Fig. 3. Transistor in a tuned circuit with feedback to produce a negative impedance.

Next, consider a transistor in the circuit of Fig. 3 in which the transistor is matched to the resonant element. The impedance between the terminals EC in Fig. 2 can be calculated, with the result[2]:

$$Z_{EC} = \frac{(1-\alpha)}{j\omega C_c} + R_v \qquad \ldots\ldots(3)$$

where $R_v = r_e + r_{e'} + r_{c'}$.

Minority carriers are assumed to move across the base by drift, reaching the collector in a time τ.

Hence

$$\alpha = e^{-j\omega t}$$

and eqn. (3) becomes

$$Z_{EC} = \frac{1-e^{-j\omega t}}{j\omega C_c} + R_v \qquad \ldots\ldots(4)$$

or:

$$Z_{EC} = \frac{\tau}{C_c}\frac{\sin\omega\tau}{\omega\tau} - j\frac{(1-\cos\omega\tau)}{\omega\tau} + R_v \qquad \ldots\ldots(5)$$

In the range of $\omega\tau$ between π and 2π, the resistive component of the first term is negative, and provided R_v is small enough, Z_{EC} can become negative over part of the corresponding frequency range. With this, oscillation can be maintained in a resonant circuit of sufficiently high Q connected between E and C. A transistor maintaining oscillation in this way is said to oscillate in the transit-time mode.

3. Experimental Transistor Converters

3.1. *Transistor Operated Close to the α-cut-off Frequency*

The circuit of the converter that was first tested is shown in Fig. 4, and the external appearance is shown in Fig. 5.

The high frequency transistor is operated as a negative feedback oscillator[5] in which the oscillating frequency (less than f_{max}) is determined mainly by the coaxial line resonator or any other form of resonator which may be used. The amount of feedback, and therefore the conversion gain, is controlled by the adjustable capacitor between the emitter and the collector. According to the theory of feedback amplifiers, the output impedance is transferred by this capacitance to the input as a negative resistance with an inductance. To achieve this condition properly, the input impedance should be measured to ensure that it is set to the correct value. This can be done most conveniently with a ZG Diagraph which displays the impedance directly. It is also necessary to use an electronically-regulated supply which ensures constancy of the voltage between the emitter and the base, once it has been set to give the required emitter current.

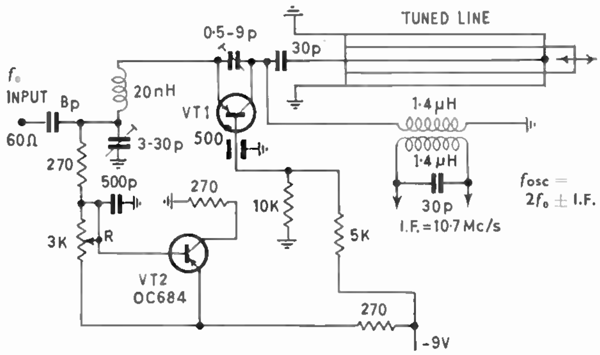


Fig. 4. Circuit of a relatively simple mixer producing high gain at low noise figures. VT1 is the transistor given in Table 1.

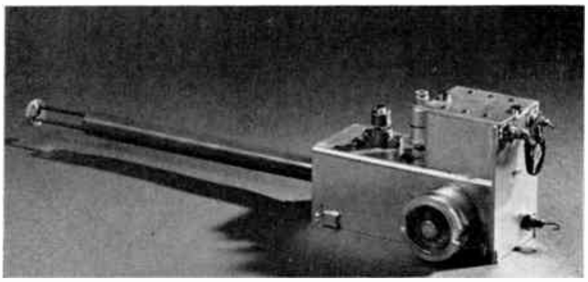


Fig. 5. Mechanical construction of the circuit of Fig. 4, showing the coaxial input, the tuned line, the variable resistor to set emitter current, the input trimmer, and the measured transistor.

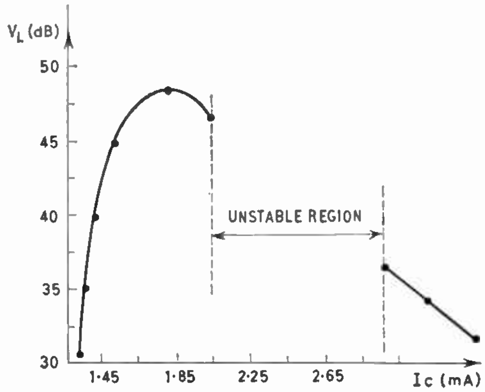


Fig. 6. Power amplification plotted against emitter current for an operating frequency of 350 Mc/s for the transistor AF 106. The region between the dashed lines represents unstable i.f. operating conditions.

Under this condition, the input side of the transistor can be considered as a "varactor" with a relatively high resistance ($r_{e'}+r_e+r_c$) in series. Because we are dealing with an oscillating feedback circuit, this series resistor appears negative. Provided the input frequency and the oscillating frequency differ by only a small relative amount (the intermediate frequency) the input circuit then has a high effective Q at both these frequencies. This condition can also apply to harmonics of the oscillating frequency, as will be shown later.

Amplification is produced because, for properly adjusted circuit conditions, the input circuit has a high effective Q and, as with any parametric amplifier, it is resonant within the required band as the reactance is varied from negative to positive by the oscillation which varies C_D by modulating the emitter current. Because the intermediate frequency appears at the input circuit, this also can be amplified by the transistor. Table 1 gives results obtained with various transistors at various frequencies. In each example the bandwidth was 500 kc/s and the intermediate frequency was 10·7 Mc/s.

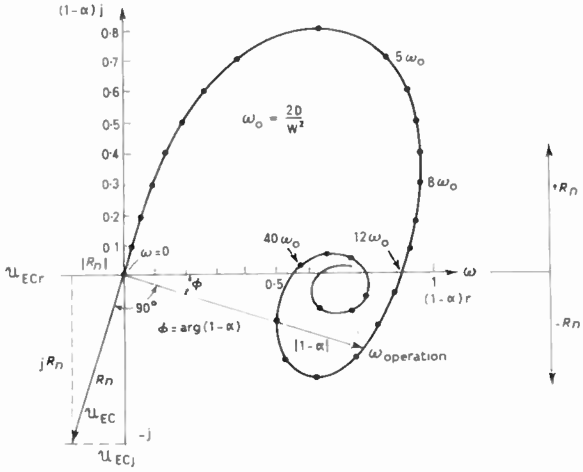
Table 1

Frequency (Mc/s)	Transistor (VT1) Type	Amplification (dB)	Noise Figure (dB)
88–100	OC615 *pnip*	88	3
,,	AF114 POB	88	3·2
†200	OC615 *pnip*	83	3
†400	,, ,,	46	5
†600	,, ,,	25	8
† ,,	AF102 MESA	46	6
,,	AFY11 ,,	70	5
,,	AF122 DRIFT	47	7
,,	AF106 MESA	50	6
† ,,	AF129 ,,	30	8
1000	AF106 ,,	48	7
,,	AFY11 ,,	60	7
,,	BSY21 PLANAR (*npn*)	55	5·5
†2000	BSY21 ,,	35	6
† ,,	2N709 ,,	45	5·5
† ,,	2N700 MESA	30	11

† Transit-time conversion with $f_{osc} \geq f_{max}$.

3.2. *Circuit with Separate Pump Oscillator*

The circuit described in the previous section employed a single self-oscillating transistor as the frequency converter, which has certain disadvantages. To avoid these disadvantages, a circuit using a separate pump oscillator has been tried, operating in a frequency band in which equations (3) and (5) are satisfied. To determine this frequency band, the curves shown in Fig. 7 have been determined by measurement. They show the behaviour of different types of transistors operating at various emitter



(*a*)

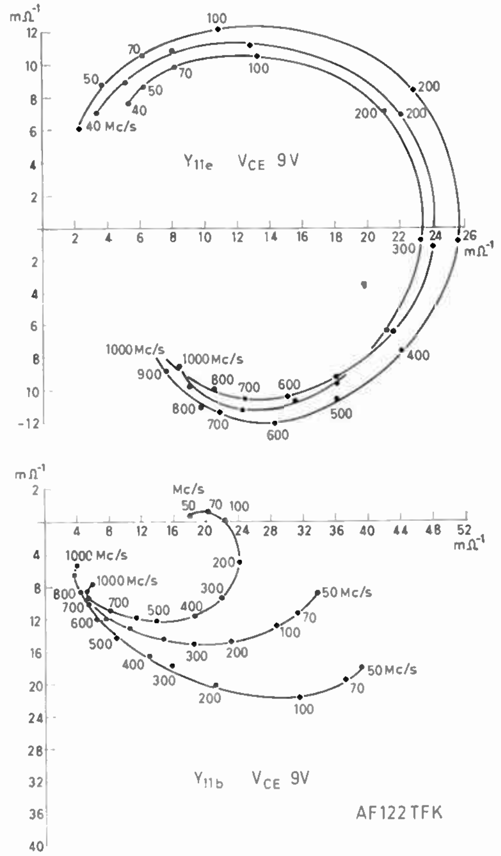
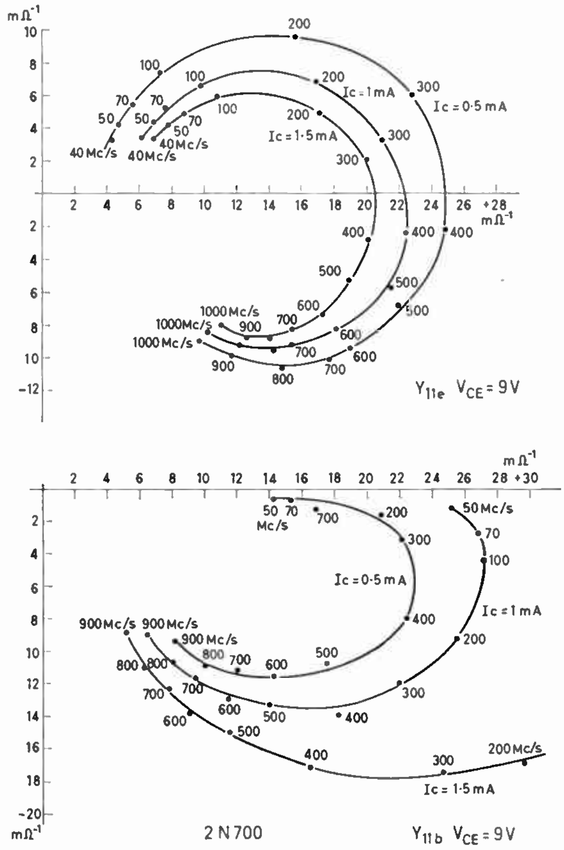
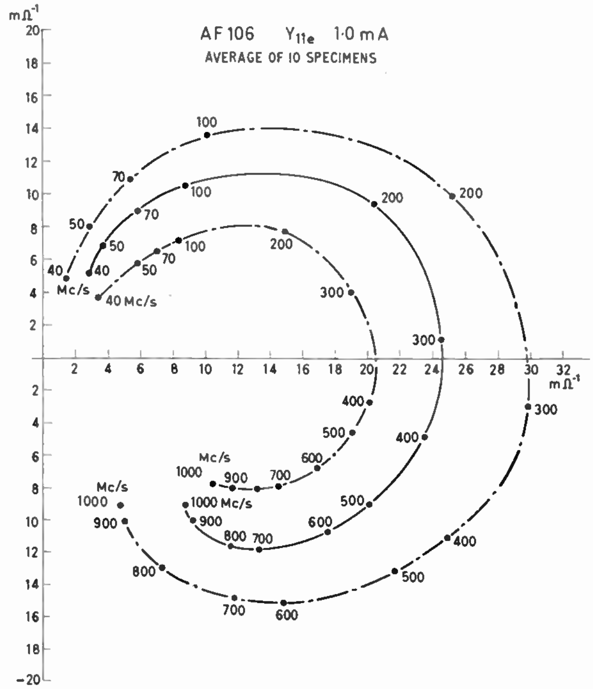


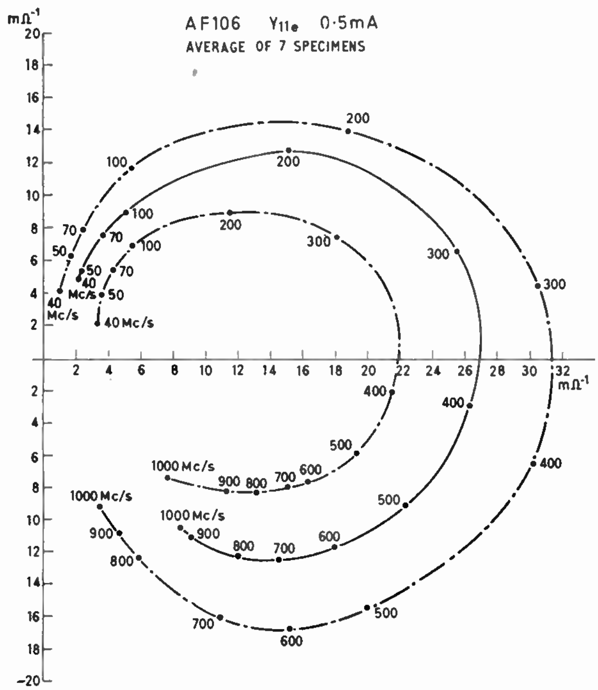
Fig. 7.



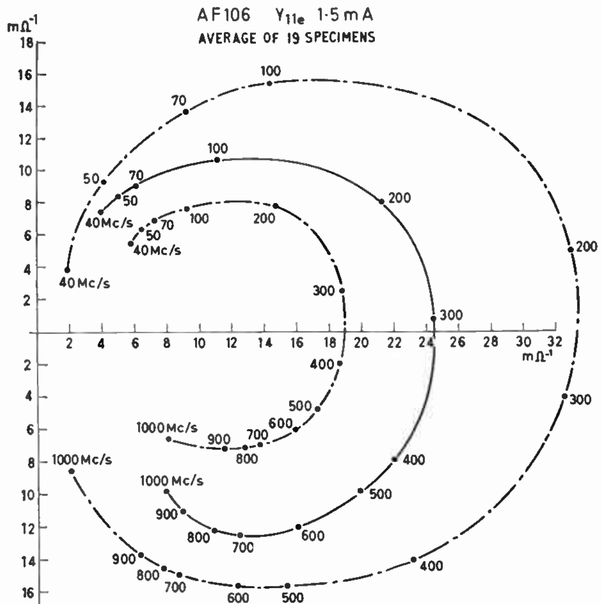
(*c*)



(*e*)



(*d*)



(*f*)

Fig. 7. (*a*) Theoretical curve of $(1-\alpha)$ in both the real and complex part, (*b*) to (*f*). Input characteristics for different transistors for different emitter currents and circuits (e = grounded emitter b = grounded base).

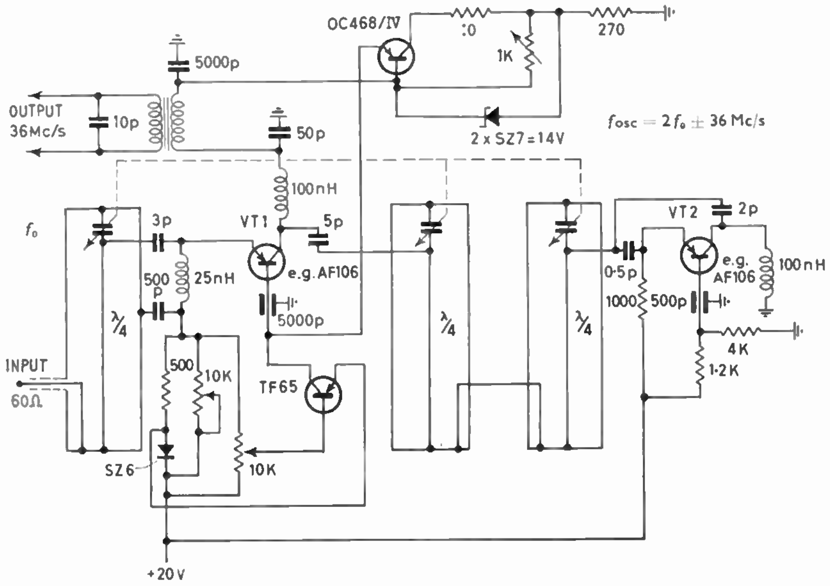


Fig. 8. The circuit of an experimental u.h.f.-tuner covering 400 Mc/s to 1200 Mc/s (or higher) using coaxial tuning elements. The input frequency is converted by a pump oscillator operating in the transit-time mode to an output i.f. of 36 Mc/s. The first coaxial cavity is λ/2 to the oscillator frequency and λ/4 to the input frequency.

currents. Figure 8 shows the circuit of the experimental low-noise head amplifier suitable for frequencies between 400 Mc/s and 5000 Mc/s and employing normal and epitaxial transistors. Use is made of the voltage dependence of the transistor capacitance C_c. To ensure satisfactory operation of this current tuned condition and the maintenance of a sufficiently steady

Table 2

Frequency (Mc/s)	Transistor Type (VT1 and VT2)	Power Gain (dB)	Noise Figure (dB)
4000	BSY21	15	5
,,	AFY11	8	9
5000	BSY21	11	5·8
3000	2N709	18	5
,,	BSY21	20	4·5
,,	AFY11	10	7
2000	AF106	25	4
,,	AFY11	22	6
1000	AF102	27	3·5
,,	AF106	25	3
,	AF122	22	3·5
,,	BSY21	40	2·5
400	AF102	32	2·3
,,	AF106	30	2·3
,,	AF122	30	2·5
,,	BSY21	45	2

collector voltage, two electronically-regulated sources are required. These supplies make use of transistor type TF 65 and OC 468, the operating voltages of which are set by means of silicon Zener reference diodes. The pump oscillator uses a transistor VT2 operated in a harmonic generation mode. Use of a separate pump oscillator allows freedom in the adjustment of the collector capacitance C_c to achieve a self-oscillating condition for the transistor VT1. This produces a high Q for both the input circuit and the collector circuit. As with the first example (Sec. 3.1.) the circuits are tuned to the frequencies required. The bandwidth and the power of the pump oscillator are proportional.

This method can be used as a non-reciprocal parametric amplifier, the pump frequency being half the input frequency, as well as for direct conversion to the intermediate frequency.

In the experimental converter, the intermediate frequency was 36 Mc/s, the bandwidth was 7 Mc/s and the pump oscillator power was 20 mW. The results obtained are given in Table 2.

Only the transistor type BSY21 could be made to operate at 5000 Mc/s because of difficulty with the other types in connecting the transistor to the external circuit without introducing excessive lead inductances. In some cases the transistors were used without their housing to reduce the unwanted distributed inductances and capacitances.

4. Conclusion

It has been shown experimentally that it is possible to make high-gain, low-noise amplifiers or frequency converters which can operate satisfactorily in the frequency range 400 to 4000 Mc/s, using conventional types of transistors.

5. Acknowledgments

I should like to thank Dr. Rüchardt of the development department of Siemens Semiconductor factory and Dr. Engbert of the semiconductor division of Telefunken for their valuable help in enabling me to make the necessary measurements. The firms of Valvo (Philips) and Intermetall (Clevite) have provided high-frequency transistors which enabled the investigation to be carried out on the broadest basis.

6. References

1. J. Lindmayer and R. Zuleeg, "Determining transistor high-frequency limits", *Electronics*, **32**, No. 34, pp. 31–34, 21st August 1959.
2. J. F. Gibbons, "An analysis of the modes of operation of a simple transistor oscillator", *Proc. Inst. Radio Engrs*, **49**, pp. 1383–90, September 1961.
3. V. W. Vodicka and R. Zuleeg, "Transistor operation beyond cut-off frequency", *Electronics*, **33**, No. 35, pp. 56–60, 26th August 1960.
4. R. Zuleeg and V. W. Vodicka, *Proc. Inst. Radio Engrs*, **48**, pp. 1785–6, October 1960 (letter).
5. Ulrich L. Rohde, "Parametric amplification with transistors", *Wireless World*, **67**, pp. 498–9, October 1961.
6. Ulrich L. Rohde, "Der Transistor als parametrische Diode", *Funkschau*, **9**, pp. 222–4, May 1962.
7. W. Shockley, "Negative resistance arising from transit-time in semiconductor diodes", *Bell Syst. Tech. J.*, **33**, pp. 799–826, July 1954.
8. George H. Heilmeier, "Millimeter wave generation by parametric methods", *Proc. Inst. Radio Engrs*, **48**, pp. 1326–7, July 1960.
9. D. L. Hedderly, "Parametric amplification by charge storage", *Proc. Inst. Radio Engrs*, **49**, pp. 966–67, May 1961 (letter).
10. R. Lowell and M. J. Kiss, "Solid-state microwave power sources using harmonic generation", *Proc. Inst. Radio Engrs*, **48**, pp. 1334–5, July 1960.
11. Yohan Cho, "Parametric-excited resonator using junction transistor", *Proc. Inst. Radio Engrs*, **49**, p. 974, May 1961 (letter).
12. D. J. Hamilton, "Maximum avalanche multiplication in *p-n* junctions", *Proc. Inst. Radio Engrs*, **48**, pp. 1787–8, October 1960 (letter).
13. R. L. Pritchard, "Frequency variations of junction-transistor parameters", *Proc. Inst. Radio Engrs*, **42**, pp. 786–99, May 1954.
14. R. Hearn, R. J. Bennett and B. A. Wind, "Some types of low noise amplifier", *J. Brit.I.R.E.*, **22**, pp. 393–403, November 1961.
15. J. Lindmayer and C. Wrigley, "On parametric amplification in transistors", *Proc. Inst. Radio Engrs*, **49**, pp. 1335–6, August 1961.
16. Ulrich L. Rohde, "Pushing transistors above their frequency limits", *Electronics*, **35**, No. 25, pp. 46–49, 22nd June 1962.

Though not all the above references are quoted in the paper, those not mentioned either summarize similar results or give alternative explanations of the subject.

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An X-ray Television System with Image Storage and Automatic Exposure-Release

By

A. J. SEYLER†

Summary: The design of an x-ray television system containing an electronic recording storage tube is described. The sequence of storage tube functions and x-ray exposure is automatically controlled by a central timing device and all time intervals are synchronized with the vertical scanning period of the television system. By actuating a single exposure release button when a new image is required, erasure of the previous image and storage of the new one are completed within half a second. During this interval the x-ray source is energized for not more than one quarter of a second but generally less. Continuous display times of useful pictures of up to 30 minutes were obtained. Apart from the single-shot operation provision is made for automatically repeating the exposure at intervals variable between 2 and 6 seconds. In this cycling mode slowly varying phenomena and surgical manipulations may be observed in quasi-motion. Any number of ordinary television display units may be supplied with composite television signals from the output of the storage unit and one such device may be permanently set-up for still or moving photographic recording of the images.

The unit is presently undergoing tests for quantitative evaluation of its performance and for the investigation of its medical potential. One objective for further development is already under consideration, i.e. the exploitation of the potential of the storage tube for the storing of four images. Thus when required two images obtained in two planes of the object could be stored simultaneously with those of a previous exposure which would be retained for reference.

1. Introduction

In recent years television has found ever-increasing usage as a means of presenting x-ray images, thus affording more convenient ambient lighting and viewing conditions than was hitherto possible. Equipment has been or is being asembled in a number of industrial and medical institutions in which either conventional television cameras with and without previous image intensification or specially designed pick-up devices are employed for this purpose.

Common to all these x-ray–television assemblies is the fact that x-ray radiation has to be applied to the object to be displayed for as long as it is desired to observe the image. This continuous x-ray exposure, although at relatively low energy levels, is a radiation hazard which, to protect the patient (in medical applications) and even more so the radiologist, it is desirable to reduce wherever possible. It has been recognized and previously suggested[1, 2, 3] that, if a television signal obtained from a short x-ray exposure could be stored and displayed for any length of time, this radiation hazard could be reduced substantially. Three categories of storage devices suitable for this purpose have been or are being developed either for television type displays of radar and other data or specifically for the storing of television picture signals. These are viewing and recording storage tubes[1, 4, 6] and magnetic tape or drum stores.[6] Provided the device employed has the spatial and contrast resolution required for x-ray images and for the specific purpose of either industrial or medical application, the choice of the particular device is governed only by convenience and availability. Once this choice is made the system design involves primarily the ancillary control and timing equipment by which x-ray, television and storage are functionally integrated into one composite system. It is the purpose of this paper to describe such a system design which the author carried out for the Department of Surgery of the University of Melbourne and which was given the name VISTODAX (VIdeo STOred Discontinuous Automatic eXposure).

The basic system specification called for an experimental equipment assembly which would be suitable for investigating the medical potential of stored x-ray television images in diagnostic and surgical applications for ascertaining the reduction of the x-ray radiation hazard resulting from the use of image storage and for deriving the technical and operational requirements for the development of industrially produced devices of this nature.

2. Choice of the Storage Device

Under the given circumstances the choice of the storage device was affected more by the local

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environmental conditions than by purely technical considerations. Because of the absence in Australia of industrial organizations engaged in the development of storage devices, the device to be used had to be one which was already in commercial production elsewhere and thus one for which sufficient technical data were available and for which the supply of future replacements was assured.

Largely as the outcome of military efforts, a number of viewing as well as recording storage tubes were being offered by overseas manufacturers at the time. Since several standard television display units were already installed in the television laboratory of the Department of Surgery, a recording storage tube from which a number of ordinary display units could be supplied with suitable picture signals, appeared preferable. This choice would offer the additional advantage that the actual storage device and its associated control equipment could be placed anywhere outside the actual area in which the medical activities took place, and also that display units could be installed in seminars, consultants' rooms etc. wherever and whenever the televised x-ray images were to be shown. Moreover, if desired, photographic records of the displayed images could be taken without interfering with the medical procedure.

The recording storage tube to be chosen should permit the reading-out of the stored picture over periods, say, up to ten minutes without significant loss of picture quality. Furthermore, the tube should have as little as possible deteriorating effect on the picture signals obtainable from a 625-line television system. A tube satisfying most of these conditions and readily available in 1959 (when the plans for this project were made) was the type QK 685 (Raytheon Manufacturing Co., Waltham, Mass. U.S.A.) which was primarily designed for scan-conversion of high-definition radar signals and slow-scan television signals.

This is a single-gun tube and hence requires sequential writing and reading. During the writing mode of the tube, charges are deposited on a coated storage grid by the magnetically focused and deflected electron beam scanning this grid in typical television raster fashion. The electron beam current is modulated with the signals to be stored and thus a spatial charge pattern is generated by the beam impinging on the grid with sufficient energy for secondary emission to take place. For reading-out, the storage grid is biased below cathode potential, hence the scanning beam electrons will pass through the storage grid to the signal electrode, the beam-density being controlled by the previously generated spatial charge pattern. Thus a correspondingly varying current is obtained at the signal electrode. Since, at least theoretically, no electrons should be landing on the storage grid during reading, the deposited charge pattern should persist until intentionally erased and changed. However, in practice some ions still present in the tube as well as electrons will be captured by the grid and thus degradation of the contrast and resolution of the stored picture will slowly become apparent after prolonged reading.

To change the stored picture, the storage grid is scanned with an unmodulated electron beam, first under the same conditions as for writing, i.e. white is written-in. In this mode which is called "erase" the original charge pattern is equalized. The storage grid is then biased below the secondary emission potential and the scanning beam charges the grid uniformly to cathode potential. This mode is called "prime".

Consequently, for each exposure, the storage tube has to be sequentially operated through the four modes "erase", "prime", "write", "read". The minimum number of scans required for the first three modes depends on the setting of beam current and storage grid potential, but is a minimum of one picture period for erasing and writing, and of some seven to ten periods for priming, if the grid is scanned with a standard television raster of 625 lines and 50 frames interlaced 2 : 1.

It is claimed that a resolution of up to 1000 television lines can be obtained across the full diameter of the raster, if dynamic focus and optimum write-read conditions are used. Contrast resolution, limited mainly by spurious shading signals, should be better than ten steps between black and white, the dynamic range being primarily dependent on the state of the storage grid after erase and prime.

The main disadvantage of this tube (and for that matter of all presently-available recording and viewing storage tubes) is the time required for changing from one picture to the next, i.e. for erase and prime, although for the QK 685 this would be less than half a second. For most of the intended applications, however, this changeover-interval was considered acceptable.

Having made this choice of the storage device the remainder of the integrated VISTODAX system design was more or less determined in principle.

3. System Components and Functions

Since the storage tube accepts standard television signals as input, it is of no significance to the actual configuration of the system by what method television signals are generated from x-ray images.† For the particular experimental system, equipment was avail-

† The VISTODAX system concept may be generally used in any application where a prolonged display of pictures is desired which may be obtained from short exposures to visible or invisible light, or from any other source of radiation, or as result of a selection out of a continuous source of television signals for the "freezing" of any phase of motion etc.

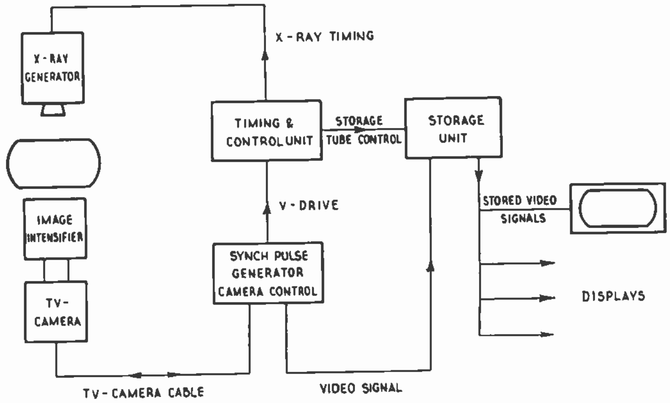

Fig. 1.

VISTODAX system configuration.

able which consisted of an x-ray intensifier optically coupled to an industrial vidicon type television camera with associated camera control unit and synchronizing pulse generator. Mobile x-ray units were available from the X-ray Department of the Alfred Hospital, Melbourne. The basic system then has the configuration shown schematically in Fig. 1. Apart from the x-ray television equipment, the system contains the storage unit and a master timing and control unit (t.c.u.). This latter unit controls all those functions which are typical for the system concept.

Operationally, it was desirable to facilitate the choice of two modes of system functions:

(a) single-shot exposure

(b) repetitive exposure ("cycling").

In the single-shot mode an exposure and subsequent storage were to be made whenever it was required to have a new x-ray image. On the other hand, in the cycling mode, exposures were to be automatically repeated at fixed intervals, only the start and finish of the cycling operation being controlled manually. In both cases the actual exposure involves the switching of the storage tube through the four states and the switching of the x-ray source. The sequence of these switching functions was to be carried out automatically once the exposure was initiated by the pressing of a "start" button. The timing of the switching functions and generation of appropriate control signals is the purpose of the t.c.u. In order for the inevitable switching transients not to cause spurious signals in the stored and displayed pictures, the transitions between the states of the storage tube were synchronized with the vertical suppression intervals of the television signal, the vertical drive pulses from the television synch. pulse generator serving as primary timing reference.

Since minimizing the x-ray radiation was one of the main aims of the system, the timing of the x-ray generator is included in the sequence of events controlled by the t.c.u. For this purpose a slight modification was made in the control circuit of the x-ray machines used such that, when the machine was switched to "fluoroscopy", the x-ray generator was energized only when a relay-controlled switch in the t.c.u. was closed. Thus it was made possible to ensure that x-ray energy was only radiated for the short interval required to generate and write into the storage tube the television signals representing the x-ray image.

In the cycling mode the timing sequence of the actual exposure remains the same, but the instant of exposure is controlled from another timer in the t.c.u. which is set to the length of the desired interval between exposures, i.e. to the length of the display (reading) interval. This mode is intended for the quasi-moving display of x-ray images of events which move only slowly. In other words only "frozen" phases of movement are recorded and shown, thus obviating a continuous exposure to x-ray radiation for the whole time. Thereby it was desirable to be able to vary the cycling period in order to match it to the movement of events as well as to the limitation of human vision. The former condition governed the longest interval, whereas the latter, together with the interruption of the display during the switching of the storage tube, determined the shortest interval between exposures in the cycling mode.

The complete automatization of the switching sequence involved in the exposure, including the switching of the x-ray source, is the main aspect of the VISTODAX system concept, resulting in the minimization of the x-ray radiation hazard for any x-ray television assembly, in the shortest possible changeover break between stored images, and in the practicability of the cycling mode of operation. Furthermore, considering the environment in which the system was to be used, the simplification attained by this automatization with regard to the human operator requirements was of particular importance.

It is obvious to the engineer skilled in the art that the actual instrumentation of these functional principles may be carried out in a number of ways and that

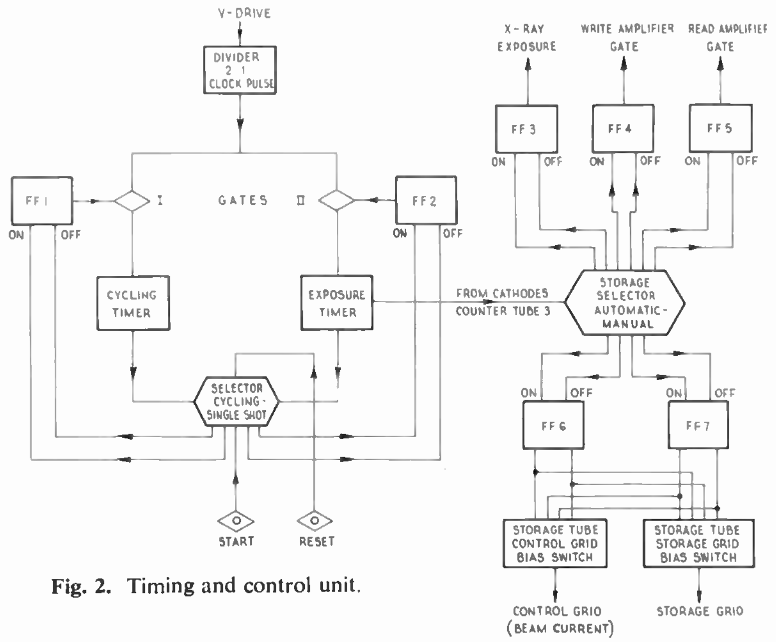

Fig. 2. Timing and control unit.

several permutations of system as well as circuit configurations are conceivable.

The subsequent description of the techniques employed in the experimental system will therefore be relatively brief and should be regarded as an example only. Moreover, since the type of equipment by which the television signals are generated from x-ray exposures is insignificant for the system concept (though not for the x-ray doses, picture quality and convenience of operation), this description will primarily concern the timing and control unit and the specific circuits associated with the switching of the storage tube.

4. Timing and Control Unit

The actual components of the t.c.u. are depicted in Fig. 2.

All switching functions are synchronized with the vertical suppression interval, but their timing is required to be in multiples of picture periods only. Therefore, the master clock pulse is generated by a 2 : 1 divider driven by the vertical pulse of the television synch. pulse generator. This clock pulse train of 25 pulses per second controls two timer circuits, one for the timing of the cycling intervals and the other for the timing of the sequence of functions required for each exposure. Both these timers consist of gas-filled stepping counter tubes (Dekatrons), and pulse-shaping circuits of standard design as recommended by the manufacturers of such tubes. The clock pulses are supplied to the timers through electronic gates I and II which are switched by flip-flop circuits (FF1 and FF2). The mode of operation of the t.c.u. is chosen by means of the selector switch "cycling-single shot". Since the single shot timing

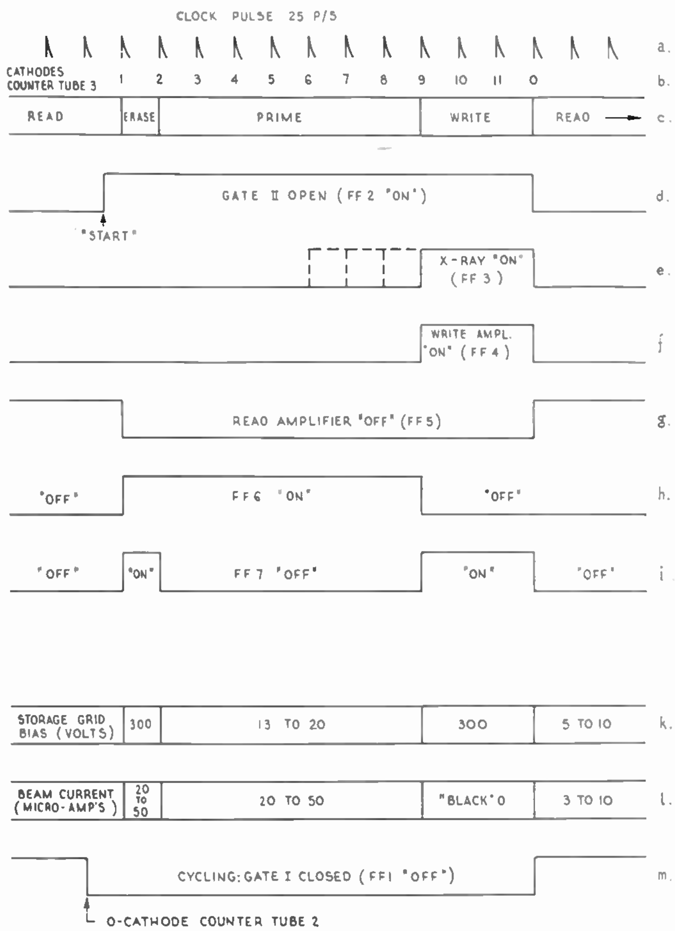

Fig. 3. Timing sequence.

sequence, determining the storage tube and exposure switching functions is also repeated in the cycling mode, the former will be described first with reference to Fig. 3.

In order to establish correct initial and quiescent conditions of all circuits after the switching-on of the equipment, a "reset" switch is provided by which the equipment is switched into the reading mode. In that condition both timer gates are closed and no clock pulses can reach the stepping counter tubes. If now, with the mode selector switch in single shot position, the "start" button is actuated, a start pulse switches FF2 "on" and this opens gate II. The first clock pulse after the start pulse then commences the stepping of counter tube 3, a 12-cathode tube, in the exposure timer. Gate II remains open until the count reaches 0-cathode again from which an "off" pulse is fed to FF2 thus closing the gate and interrupting the flow of clock pulses until a new start signal is given (*d*). The pulses obtained at the cathodes of the counter tube 3 (*b*) then trigger a series of flip-flops (FF3–FF7) by which the system functions are switched. (By a more sophisticated arrangement it may be practicable to reduce the number of flip-flop circuits; however for reasons of experimental flexibility a certain amount of redundancy was accepted thus providing greater independence of circuit functions.)

FF6 and FF7 provide the driving signals for the switching of the storage grid and beam current (control grid) of the storage tube through the four states, in accordance with (*c*), (*h*), (*i*), (*k*) and (*l*). One clock-pulse interval is provided for "erase", seven for "prime" and three for "write". The seven scans for priming were found to be just sufficient, but require a critical setting of the storage tube parameters.[4] It would be desirable to increase this interval, which can be done by reducing the writing time. The initial choice of three scans for that interval was governed by the resulting improvement of the signal to noise ratio. When the x-ray source was set to the minimum feasible current, x-ray quantum noise became visible in the television image. If then only one scan was used for writing (which is practicable) the quantum noise is "frozen" in the displayed image and appears as a granular spurious signal. However, when using a number of writing scans, due to the integration on the storage grid, the stored random noise increases only with the root of the number of writing scans, whereas the signal increases linearly. From this point of view the choice of three writing scans represents an initial compromise between x-ray exposure and picture quality. Subsequent experiments may prove the practicability of obtaining the same or even better picture quality by increasing the x-ray tube current but reducing writing time (keeping the total x-ray energy constant). Thus the priming time could be increased which would afford a less critical operation of the storage tube and would possibly give a better dynamic range of the stored signals because of the more complete priming of the storage grid.

FF3 provides the driving signal (*e*) for the x-ray switching relay. It was found in preliminary tests that full video signal amplitude at the output of the x-ray television assembly was not obtained instantaneously. This may be primarily due to the time-constant of the x-ray generator, but may also result from the shorter time-constants of the image intensifier and vidicon camera chain. In order to accommodate such delays the timing of the x-ray on-pulse may be advanced relative to the commencement of the write period by up to three clock pulse intervals (120 ms) by means of a selector switch.

The write amplifier contains a gating tube (E91H) which is controlled from FF4 (*f*) so that signals can reach the input to the storage tube only during the writing interval. Thus interference or other spurious signals, which may originate in the peripheral television equipment during the reading and other switching intervals are effectively suppressed.

Alternatively, the gating tube (E91H) in the reading amplifier is closed during the whole exposure switching sequence by a signal from FF5 (*g*). Hence, the screen(s) of the display units connected to the output of this amplifier are black for the period (of 480 ms) during which the content of the storage tube is changed. However, the gate suppresses only the video part of the output signal, whereas the synchronizing signal supply is maintained to the display units. This is particularly important for the cycling mode, because otherwise the display raster would become non-synchronous during the changeover period and cause annoying initial rolling of the displayed picture.

When the mode selector switch is set to "cycling" the start pulse is removed from the input to FF2 and instead connected to FF1. FF1 opens gate I and thus clock pulses are supplied to the cycling timer. This contains two stepping counter tubes. The first one is a straight divide by twelve counter, its output pulse (480 ms) being used to drive counter tube 2 the twelve cathodes of which are individually accessible (as for counter tube 3). By means of a switch the pulse from any of the cathodes 1 to 11 can be fed back through a simple shaping circuit as reset pulse to cathode 0 and thus the count can be preset. Every time the beam of counter tube 2 reaches cathode 0, gate I will be closed (by FF1) and gate II opened (by FF2) and an exposure sequence will be initiated. At the end of the sequence cathode 0 of counter tube 3 opens gate I again while closing gate II and the picture is displayed during the count of the cycling timer which may be from $\frac{1}{2}$ to approximately 6 seconds after which time another exposure is made. This cycling continues until stopped by pressing the "reset" button or by throwing the mode selector switch into the "single shot" position.

As shown in Fig. 2 the inputs to FF3 to FF7 are routed through a storage selector switch. This is a 10-pole 5-position switch which enables the equipment to be switched through the four states of the storage tube either manually or automatically. In the position "automatic" the sequence is operated as described above and in accordance with Fig. 3, the cathodes of counter tube 3 being connected directly to the required flip-flops. In the four remaining positions of the switch the respective inputs of the flip-flops are connected to the start pulse so that, after setting the switch into the desired condition of the storage tube (i.e. erase, prime, write, read), the respective flip-flop conditions are obtained by pressing the start button. This way it is possible to set storage grid bias and beam current to the values specified for the correct operation of the storage tube in any one of the four states. Since only the drive of the flip-flops is changed by the manual switching operation, this facilitates at the same time the checking, under static conditions, of their functions and the measuring of the voltages applied to gates, switches, relays etc., operated by the flip-flops directly or indirectly.

5. Some Circuit Details

Only those circuits which may be considered of a more specific nature will be discussed in detail, whereas for the remainder performance specifications will be given from which the detailed design may be easily deduced.

5.1. *Flip-Flop Circuit*

As may be seen from Fig. 2 altogether seven flip-flop circuits were used in the experimental system. For reasons of standardization a single basic configuration was adopted for these circuits—depicted in Fig. 4.

Since the flip-flops are acting as switching devices operated from the output pulses of the stepping counter tubes an independent "on/off" type trigger circuit is required, although each of the two trigger inputs had to accept pulses of equal positive polarity. ("On/off" refers to the state of V1.) Therefore an inverting stage was incorporated in the input circuit for the "off" trigger (V3). Apart from the trigger pulses, the flip-flops were also to be triggered by reset action to establish initial conditions of all control functions. It is apparent from Fig. 3 that all but FF5 are reset "off". Normally V3 is non-conducting due to its cathode being held positive relative to the grid by the bleeder circuit to B+. This bias is removed in the reset "off" condition, V3 conducts and applies a negative voltage to the grid of V1 cutting this off (if it was conducting) and thus causing V2 to conduct. For the reset "on" of FF5, a positive voltage is applied to the grid of V1 through the series resistor of 2·2Ω turning V1 hard on and turning V2 off. To prevent "off" pulses from feeding back into the "on" input an isolating diode is provided which at the same time serves as an anode current path for V3.

The actual flip-flop circuit is of the cathode-coupled type and thus an independent trigger input grid is obtained. No speed-up capacitor is used in the coupling circuit A1—G2 since no very fast turn-over of the circuit is required and the circuit becomes less sensitive to spurious pulses which could cause false operations. In order to obtain positive and negative control potentials from the flip-flops, the circuit is made floating between +325 V and −250 V, the cathode swinging nominally between zero and +20 volts for V1 "on" and "off" respectively. Thus approximately +20 V is sufficient to trigger the circuit, an amplitude readily obtained from the counter tube cathodes. Since these cathodes have high source impedance resistors of 100 kΩ are connected in series with the

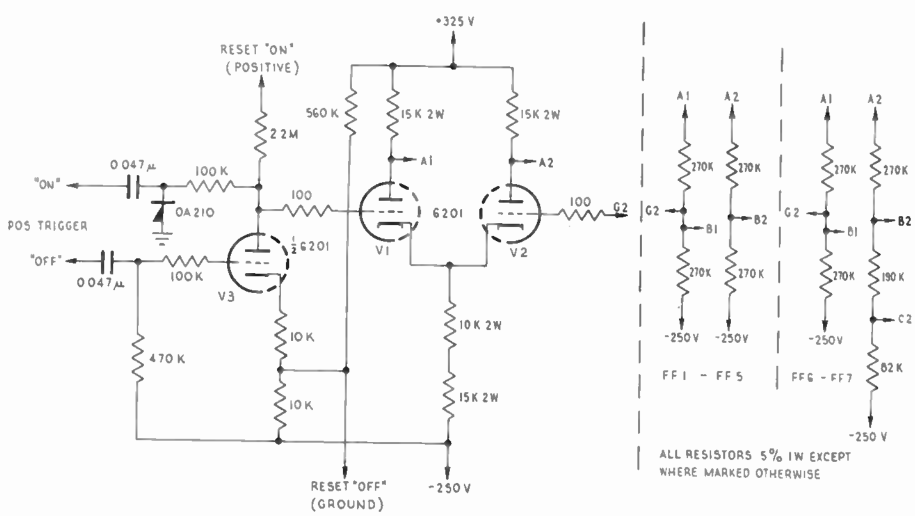

Fig. 4. Standard flip-flop circuit.

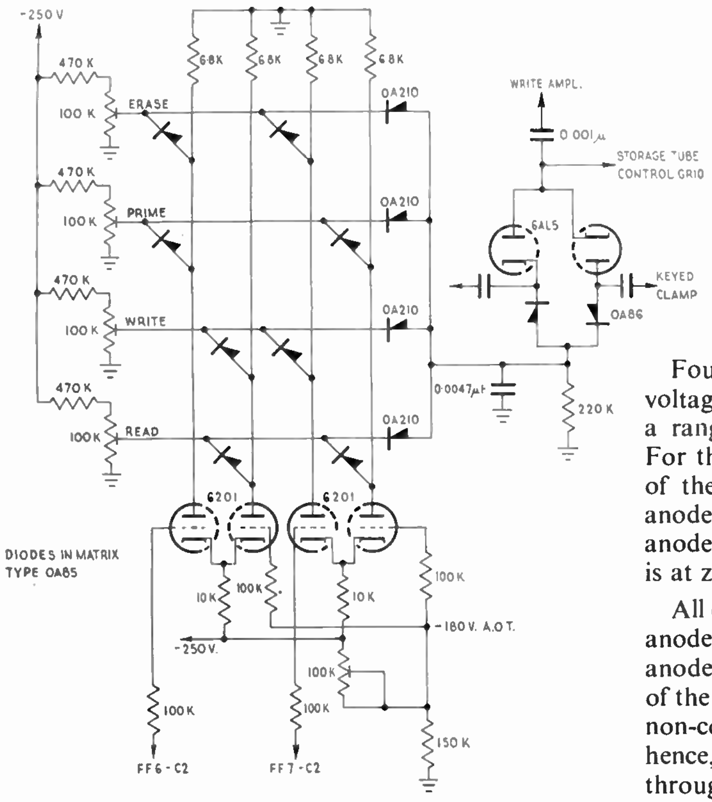

Fig. 5. Storage tube control-grid bias switching.

trigger inputs of the flip-flop to prevent undue loading by possible grid current of V1 or V2, particularly when several flip-flops are connected to the same cathode.

The driving voltages for the circuits controlled by the flip-flops are then taken off at suitable points of the voltage divider chains between the anodes of V1 and V2 (A1 and A2) and −250 V as shown in Fig. 4, marked by the letters B and C which are indexed 1 and 2 depending on the anode to which the respective divider is returned. These letters correspond to those shown in the subsequent circuits. The circuit operation of the flip-flop has proved stable and uncritical throughout the operation of the experimental equipment and the control voltages obtained exceed the actual requirements in most cases, thus providing a satisfactory margin for changes of valve characteristics and for the ageing of components.

5.2. *Storage Tube Control-grid Bias Switch*

As shown in (*l*) of Fig. 3 the beam current setting of the storage tube varies for the different operating modes. This current is controlled by the bias voltage applied to the control grid of the tube, which is switched by means of a diode matrix switch having four inputs and one output, as depicted in Fig. 5. The actual switching voltages are obtained from two long-tailed pairs which are controlled from the appropriate tapping points of the divider chains of FF6 and FF7.

Four preset potentiometers supply the grid control voltages for the four storage tube modes variable over a range of between −5 and −50 V approximately. For the controlling flip-flop "on" the left-hand valve of the associated long-tailed pair is conducting, its anode being at approximately −55 V, whereas the anode of the right-hand valve, being non-conducting, is at zero volt, and vice versa for the flip-flop "off".

All diodes of the matrix connected at any time to the anode of a conducting switching valve are open (the anode being in all cases more negative than the cathode of the diode) and the ones connected to the anode of a non-conducting switching valve are conducting, and, hence, are connecting the respective bias line to ground through 6·8 kΩ resistors. Thus for the states of FF6 and FF7 as indicated in (*h*) and (*i*) of Fig. 3, all but one of the four bias lines are grounded in any one of the four switching combinations. In order to obtain the required isolation of the output of the switch from the switching matrix, high inverse resistance silicon diodes are used as series diodes.

Since at the same time the control grid of the storage tube is modulated by the signal to be stored (in the writing mode), the beam current control bias is applied as reference bias to a keyed clamping circuit connected to the control grid and the write amplifier output.

5.3. *Storage Grid Bias Switch*

It was mentioned in Section 2 that for the four storage tube modes the storage grid potential has to be above or below the critical secondary emission level for erase/write and prime/read respectively. This changing of the storage grid bias is accomplished by means of the switching circuit shown in Fig. 6. Since there is a large potential difference between the erase/write level and the prime/read levels a combined relay and electronic switching circuit was chosen for this function.

In order to complete the switching during the vertical suppression interval the relay had to be of the high speed type. This relay is energized by the anode current of a valve which is switched on or off by FF7, such that for FF7 "on" the single-pole single-throw contact operated by the relay is closed, applying a

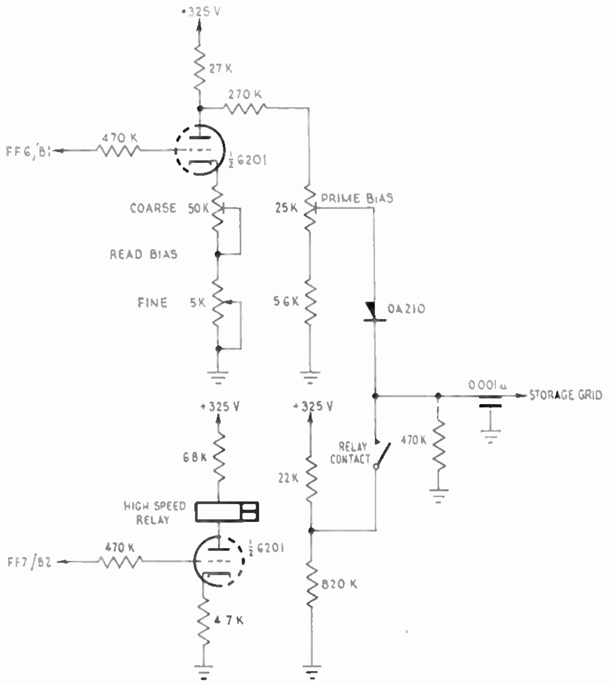

Fig. 6. Storage-grid bias switching.

voltage of +300 V to the storage grid. This in turn disconnects the low voltage prime/read bias circuit by opening the series diode through which that circuit is connected to the storage grid. Thus the relay contact together with this diode form a single-pole double-throw switch.

Whereas for the erase and write modes the storage grid is at the same bias level, its potential for the prime mode must be above and for the read mode below cathode potential the actual voltages being approximately +20 and +10 V respectively. In these modes FF7 is "off" and thus bias is supplied through the diode-"contact" of the single-pole double-throw switch. The changing of the bias levels for prime and read is carried out by switching the current through a part of the voltage divider between h.t. and earth from which the bias voltage is derived. In the prime mode FF6 is "on", the control tap B1 becomes negative and thus the control valve supplying that current becomes non-conducting. The setting of the potentiometer connected to the anode of the series diode together with the other resistors of the voltage divider than determines the prime bias level. When during the read mode FF6 is "off" the control valve becomes conducting and an additional current flows through the 27 kΩ resistor of the voltage divider. This reduces the voltage at the anode of the series diode (and thus the bias of the storage grid) below that in the prime mode. This read bias is then determined by the actual configuration of the voltage divider *and* the current through the control valve. The latter is adjustable by two variable resistors in the cathode of that valve, one being preset (coarse) and the other (fine) providing an optimizing manual control. The contrast of the picture obtained during reading is critically dependent on the read bias. Furthermore during prolonged reading periods, when the contrast tends to decrease, the readjustment of the read bias may substantially improve the picture quality. Therefore the facility of manual fine control of the read bias was found to be a desirable feature.

5.4. *Gating Circuits*

Two types of gating circuits are required in the equipment: one for the gating of the clock pulses which are supplied to the timing counters, the other for the gating of video signals in the write and read amplifier respectively. For both types of gates E91H valves are employed.

The pulse gates (Fig. 7 (*a*)) are designed as AND gates, i.e. output is only obtained when grid 3 and grid 1 have a positive signal input. No pedestal resulting from the gating waveform on grid 3 can appear in the output of the gate, because the cathode is held above grid 1 potential by the fixed cathode bias, except when clock pulses are applied. Grid 3 is controlled from the appropriate flip-flop in accordance with the timing sequence (Fig. 3 (*d*) and (*m*) respectively). A limiting diode prevents this grid from exceeding cathode potential and an integrating capacitor reduces the rise and fall transients of the gating waveform, which may otherwise generate spurious trigger pulses by capacitive coupling into the output circuit.

In contrast to the pulse gates, the video signal gates are operated as linear amplifier stages during the "on" state of the gate to meet the linearity requirements of the video amplifiers. Consequently, the gating waveform would cause a pedestal waveform to appear in the output. This would cause overloading transients in the subsequent video amplifier stages. Since the complement of the gating waveform is available from the controlling flip-flops a simple circuit configuration could be adopted to suppress this gating transient. As shown in Fig. 7 (*b*) each video signal gate consists of two gating valves operating into a common anode load resistor. The left-hand valve acts as the actual gate, whereas the right-hand one acts as a "dummy" supplying a direct current only when the video gate is cut-off. The control circuits switching grid 3 of each valve are identical and are connected to complementary taps in the respective flip-flops. Whereas grid 1 of the video gate receives the video signal to be gated, that of the dummy gate is returned to ground. In order to balance the no-signal anode currents a variable resistor is provided in the cathode of the dummy gate. Only short switching pulses appear in the output of the gate, due to the finite rise and fall times of the complementary gating waveform. These, however, falling

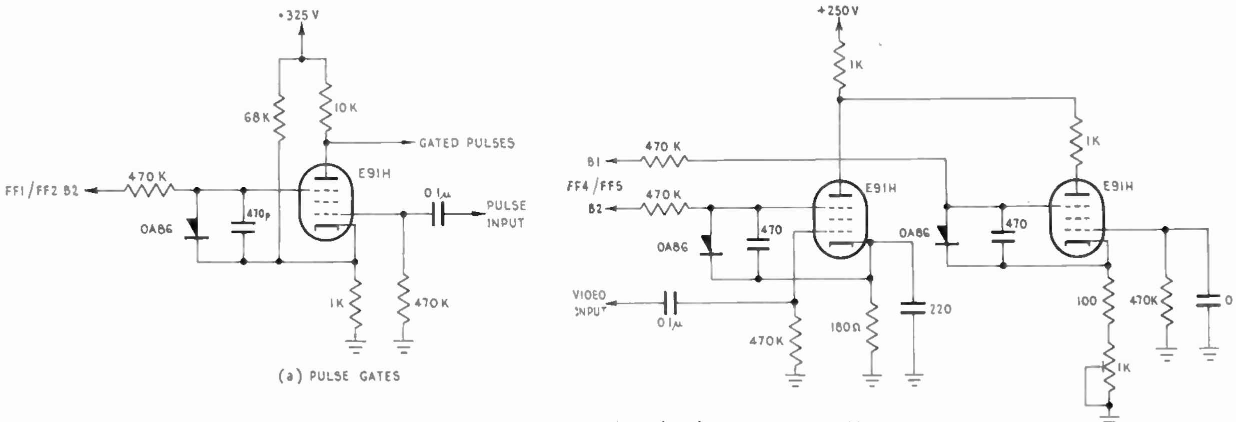

Fig. 7. Gating circuits.

into the vertical suppression intervals, do not interfere with the output signals of the amplifiers. To reduce capacitive loading of the video gate output by the anode-capacitance of the dummy valve a decoupling resistor is incorporated between the two anodes.

5.5. *Video Amplifiers*

The storage unit contains two video amplifiers; one, for supplying video signals, generated by the television camera chain, to the storage tube ("write-amplifier"), the other, for the processing of video signals obtained from the reading-out of the storage tube and for distribution to a number of television picture display units ("read-amplifier").

Apart from the gating circuit described in Section 5.4, there is nothing unusual about these amplifiers, in fact, the write amplifier has basically the same requirements as an amplifier supplying signals to a television picture tube, whereas the read-amplifier bears a great resemblance to amplifiers used in television camera control units or monoscope and flying-spot television signal generators. Therefore it is not proposed to enter into a detailed circuit description of the amplifiers used in the unit, rather only their general features will be discussed.

The write-amplifier accepts composite television signals having standard amplitude of 1 V peak synch. to peak white into 75 ohms and negative synch.-polarity. It is required to supply up to 20 V peak white signal amplitude into the control grid of the storage tube which is d.c. controlled by a keyed clamp (Fig. 5). Amplitude control is provided by a 75-ohm potentiometer in the amplifier input circuit. Because signal polarity is to be preserved four amplifier stages (including the video gate) are used, giving ample gain margin to obtain the overall bandwidth of 8 Mc/s (at 70% response) by simple cathode peaking circuits.

The read amplifier is designed on the basis of 0·2 μA peak signal current from the storage tube into a load of 50 kΩ shunted by 20 pF capacitance of the signal electrode to all other tube elements. As for most camera amplifiers, signal polarity reversal is required, if the amplifier is to supply a composite video signal with synch. negative. Apart from the gating stage, suppression and synch. signal insertion as well as amplitude control circuits are provided. Four output cathode followers supply a minimum 1 V peak-peak composite video signal into 75 ohms. To these outputs four display units, or more, if loop-through arrangements are made, may be connected. An input cascode stage (E88CC) and high gain-bandwidth pentodes (E180F) provide low internal noise, and an overall bandwidth of 7 Mc/s (70% response) with some 100 : 1 response lift at 6 Mc/s on test with the output circuit of the storage tube removed. Three keyed clamping stages are used to restore black level at critical points of the amplifier and at the grids of the output cathode followers (6CK6), the cathodes of which are d.c.-coupled to the loads.

From the tests so far carried out, it was found desirable to incorporate in future a fast-acting automatic gain control in the write amplifier, in order to simplify operation when the signal from the camera chain varies in peak amplitude, due to changes of the object from which the x-ray television images are obtained. However, experimentation is still required to develop the best method of establishing the reference for the gain control circuit.

Regarding the read amplifier, provision of a versatile "gamma" control circuit appears desirable in order to match the grey-scale of the reproduced pictures optimally to the requirements of the subject-matter depicted.

5.6. *X-ray Control*

The timing of the x-ray exposure was to be controlled synchronously with the switching of the storage tube in order to minimize the x-ray radiation hazard.

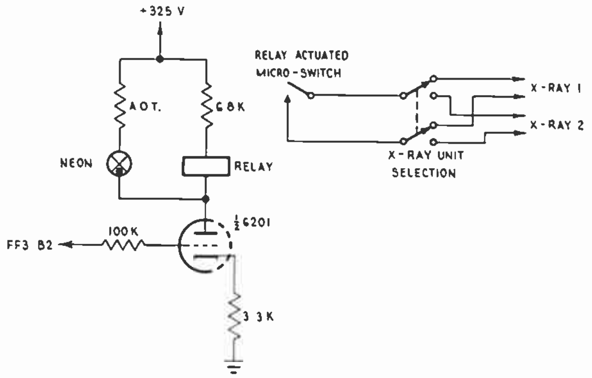

Fig. 8. X-ray unit control.

For this reason the x-ray machine used in conjunction with the described system is modified as described in Section 3. The high tension supply to the x-ray tube is thus switched on by the x-ray control circuit contained in the t.c.u. and depicted in Fig. 8. A micro-switch actuated by a type 3000 Post Office Relay (10 000 ohm) which is energized by the anode current of a control valve serves as x-ray timing switch. The control valve itself is switched from FF3 which in turn is triggered from the sequence timing counter, (Fig. 3 (*e*)), for x-ray exposure to occur only when the storage tube is ready to accept a new television signal.

For monitoring and warning of the operator a neon indicator lamp in parallel with the relay shows when the relay is energized and thus when x-ray may be switched "on" (provided the x-ray machine is connected). In some applications it was desirable to use two complete x-ray television assemblies, e.g. when x-ray images were required in two planes. For such cases a double-pole double-throw switch is incorporated by which the appropriate x-ray unit is selected. This selector switch will in future be combined with the television camera selector switch in the camera chain so that the respective x-ray television assembly is selected as a whole in one switching action.

5.7. *General Design Aspects*

Apart from the circuits discussed in more detail in the last section, some more general aspects of the circuit design associated with the storage unit may be mentioned for completeness.

The storage tube requires magnetic deflection and focusing for which a standard television receiver yoke and deflection circuits are used in the experimental unit. However, for the protection of the tube additional scan-fail circuits are included which interrupt the beam current, whenever either scanning amplitude falls below a preset threshold value.

Manual focus control is provided by controlling the anode current of a pentode serving as constant current source for the focus coil. Generally any deflection yoke for deflection angles of 30 deg or more and, including focus coil, not longer than 4 inches having an internal diameter of 1·5 to 2 in. may serve for this purpose. To prevent detrimental effects from spurious external magnetic fields, the tube and deflection system are enclosed in a Mu-metal shield. In the course of development of the circuitry associated with the storage tube, a dummy tube having a phosphor screen instead of the storage grid proved very convenient.

Electronically-regulated power supplies were found essential and are used throughout. All d.c. supplies were made as free of residual ripple as practicable. This is particularly important for the voltages supplied to those elements of the storage tube which are switched during operation since, in order for these to change potential within a vertical suppression interval, only short time-constant decoupling circuits can be used at the electrode terminals themselves, which can give only protection against spurious pulses and r.f. interference picked-up in the wiring.

Because of the generally high ambient interference level encountered in a large hospital (from e.g. diathermy, x-ray, and other medical electronic devices) extreme precautions had to be taken for the shielding of sensitive circuit components (particularly the read amplifier input stages). In addition r.f. filters were inserted into the mains supply and x-ray control leads, which may transmit interfering signals into the otherwise completely shielded unit.

Control lights for all power supplies, fuses and metering facilities, including an elapsed time indicator for storage tube operation, were considered essential for this type of equipment.

Mechanically, this experimental prototype is of necessity less compact than a thoroughly developed device and occupies a cubicle of 48 × 20 × 24 inches. The circuits are divided into functional subunits in the form of removable standard 19-inch rack units which are interconnected by a plug-in wiring harness and, where necessary, by coaxial cables. The whole cubicle rests on castors for easy transportation.

6. Objectives of Future Development

Due to the limitations of resources and local experience with video storage devices, the objectives of the original project were in the first instance limited to a feasibility study and qualitative demonstration of the system's concept.† This being accomplished, a programme of more systematic investigations is now in progress with the aim of establishing

† Demonstrations were first given in August 1960 to delegates of the Victorian Cancer Congress, Melbourne, to members of the Medical Staff of the Alfred and Royal Melbourne Hospitals and to the Anti-Cancer Council of Victoria. These were reported in the Australian and Overseas Press at the time.

quantitative data on x-ray dosage, image quality and general system performance, the results of which, it is hoped, will be published in due course. Furthermore the scope of medical applications in routine diagnostic work and research which has been outlined by Berci[7] is being investigated in clinical tests.

However, the work carried out and the experience gathered so far already suggest a number of objectives for future development which may be outlined here as a matter of completeness.

In certain operations it is necessary to have x-ray images of the object in two orthogonal planes. This has previously been accomplished by using two x-ray television assemblies† and storing and displaying one image after the other. Since in the present arrangement the storage of one image implies the erasure of the previous one, the surgeon has to rely on his memory for comparing the two. This is a serious disadvantage. The same problem arises if the comparison of two temporally sequential conditions is necessary. However, due to the high spatial resolution capability of the storage tube employed, it is practicable to store up to four images on the storage grid at any one time and still obtain some 500 television lines resolution for each of those.‡ Each individual image would be written into the storage tube separately in the same way as outlined before, except that the scanning raster size was reduced by half in each linear dimension and that for each exposure the raster position would be shifted to the required quadrant. This requires the incorporation of horizontal and vertical shift coils in the deflection system, the current through which would be switched by a four-position quadrant switch which itself could be coupled with the camera selector switch. Once the images were stored, reading selection could be instantaneous by switching back and forth between quadrants without actuating the exposure cycle. If a simultaneous display of all four stored images was desired, this could be achieved by reading with a raster size covering the whole storage grid area being centrally positioned. However, in this case vertical and horizontal resolution would be halved unless the bandwidth of the read amplifier and display units and the number of scanning lines were increased. Although such changes are technically feasible, the reduction of resolution may be acceptable in most cases, where such a simultaneous display was more in the nature of a qualitative survey of a given situation; particularly if for detailed inspection this could be supplemented by the reading of individual images with full resolution. The consequences of this facility cannot yet be fully appreciated until the necessary equipment modifications have been made.§

† The television equipment in use is designed for alternatively switching several television cameras to the same central camera control unit by means of a push-button camera selector switch.

‡ Personal communication to the author by Mr. A. S. Luftman of Raytheon.

These involve, apart from the modification of the deflection system for switched raster positioning, the addition of dynamic focus modulation in order to obtain maximum and uniform spatial resolution over the whole area of the storage grid. Furthermore, it would appear necessary that focus current be automatically switched during the storage sequence to optimize the conditions for writing and reading. (The desirability of this feature was already observed in the present single image operation, but is less critical there and a good compromise focus setting can generally be obtained, because of the superior capability of the storage tube relative to that of the remainder of the television system.)

Besides these functional objectives, developments in semiconductor devices during recent years make it now practicable to convert most of the timing and control as well as the video amplifier circuits from valve to transistor circuits. This conversion would substantially reduce the bulk and power consumption of the equipment and further improve its reliability, a factor which is of considerable importance for equipment used in medical applications.

7. Conclusion

By combining into an integrated system an electronic recording storage device with an x-ray television assembly generating television signals representing x-ray images, it was possible to obtain a prolonged display of such images immediately following a short x-ray exposure. The sequence of equipment operations including the timing of the x-ray source is automatically controlled from a central timing and control unit, such that the changing of the stored and displayed image is completed within an interval of half a second after actuating a single push-button. During this interval the x-ray source is energized for from 120 to 240 milliseconds. Apart from this "single-shot" operation, provisions are made for automatically repeated exposures at preset intervals from between 2 to 6 seconds. This "cycling" mode of operation is most useful for the observation of slowly moving events without requiring a continuous exposure during the whole time. All time intervals are synchronized from a television synch. pulse generator and occur in multiples of television picture intervals of 40 milliseconds. Thus the sequence switching functions could be made to coincide with the vertical suppression interval of the television signals and spurious switching transients prevented from appearing in the displayed pictures.

§ It will be obvious that such a system arrangement could also be accomplished with a multiple track magnetic drum store[6] once it became available.

The choice of the recording storage tube was primarily governed by its high resolution capabilities which are superior to those of the 625 line television system used. Additional factors influencing this choice were that it was in commercial production and that practically any number of ordinary television display units could be supplied with picture signals from the device.

In the equipment assembly described the storage device was supplied with television signals from an industrial vidicon camera chain the camera of which was optically coupled to a 5-inch image intensifier. A typical x-ray television presentation with this equipment using a mobile x-ray source, required for an image of a human femur (phantom) 3 mA x-ray tube current at 80 kV for a distance of 30 inches between x-ray source and image intensifier plane. Thus for an x-ray exposure of maximally 0·25 sec. required for storage, an input energy of 0·75 mA sec. at 80 kV was required. Display times of from 10 to 30 minutes after such an exposure could be obtained, whereby the main limitation was, for the storage tube employed, the deterioration of contrast in the central picture area due to the appearance of an ion spot after about 10 minutes; but by manipulation of the reading control and contrast settings this could be neutralized to a large extent, if an acceptable and useful image was desired for longer periods.

The equipment as described was intended in the first instance for an experimental feasibility study of the potential usage of such devices in medical x-ray diagnosis and control of operations. Already a number of advantages have so far become apparent, primarily, those of savings in time and of drastic reductions of x-ray radiation hazards. The first one is due to the fact that the usual waiting time for the developing of photographic plates has been eliminated which may reduce operating-theatre time and the length of anaesthesis. The second one is obtained because the radiation level can be reduced to that for fluoroscopy, but instead of x-ray radiation being required for the whole viewing period it is only needed for the interval of 0·25 seconds or less when image signals are recorded. Photographic records of the x-ray images may be readily obtained by either still photographs or filming of the displayed pictures. This recording arrangement can take the form of a permanent set-up anywhere outside the area of medical activity, since a monitor reserved for this purpose may be supplied with signals from the storage unit as a matter of routine.

The development of electronic and magnetic storage devices for television signals, x-ray sources, image intensifiers and pick-up devices is so much in flux at the present time that it is difficult to predict what type of device and system configuration will ultimately provide the best solution. However, the system described in this paper already meets many of the medical requirements and is serving as a useful tool so far for extensive experimentation and thus the gathering of experience in clinical practice. When fully developed† and industrially reproduced it should find its place in routine usage for medical diagnosis, control of surgery and other applications as yet to be investigated.

8. Acknowledgment

The author is indebted to the Director-General of the Postmaster General's Department, Australia, for permission to carry out this project. Thanks are due to Prof. M. Ewing of the Department of Surgery of the University of Melbourne for his continued interest and encouragement and to Dr. G. Berci, Senior Lecturer in Experimental Surgery, for presenting the basic problem to the author, thus being responsible for the initiation of the project. The helpful advice and assistance with x-ray equipment given by Dr. H. A. Luke, Director, X-ray Department of the Alfred Hospital, Melbourne, is gratefully acknowledged. Messrs. J. Ayres and T. Andrews of Associated Automation Pty. Ltd., Melbourne, constructed the experimental equipment prototype. The whole project was sponsored by the Anti-Cancer Council of Victoria, Melbourne.

9. References

1. H. G. Lubszynski, "A survey of image tubes", *J. Sci. Instrum*, **34**, pp. 81–8, March 1957. Also "Uebersicht ueber Speicherroehren mit Halbtonwiedergabe", *NachrTech. Z.*, **11**, pp. 115–24, March 1958.
2. T. G. Schut and W. J. Oosterkamp, "The application of electronic memories in radiology", *Medicamundi*, **5**, No. 3/4, pp. 85–8, 1959.
3. E. Garthwaite and D. G. Haley, "An x-ray image amplifier using an image orthicon camera tube", *J. Brit.I.R.E.*, **19**, pp. 615–23, October 1959.
4. R. C. Hergenrother, A. S. Luftman and C. F. Sawyer, "Improved storage tube design", *Tele-Tech. & Electronic Ind.*, **15**, pp. 82–3, March 1956.
5. M. Knoll and B. Kazan, "Storage Tubes and their Basic Principles". (Wiley, New York, 1952.) Also "Viewing storage tubes", *Advances in Electronics and Electron Physics*, **8**, pp. 447–501. (Academic Press, New York, 1956.)
6. J. H. Wessels, "A magnetic wheel store for recording television signals", *Philips Tech. Rev.*, **22**, pp. 1–10, November 1960.
7. G. Berci, "Medicine and television", *Med. J. Aust.*, pp. 1005–10, 23rd December 1961.

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† Further development is presently carried out by Mr. J. Davids of Medical TV-Appliances (METVA) Melbourne under contract with the Department of Surgery, University of Melbourne.

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Automatic Inspection—Cybernetic Machines

By

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Presented at the Symposium on "Recent Developments in Industrial Electronics" in London on 2nd–4th April 1962.

Summary: The economic reasons for introducing automatic inspection equipment in process and automatic assembly lines are reviewed and it is concluded that cybernetic or self-steering machines are essential for the multi-point inspection system. Two early examples of automatic inspection equipment are described—a device for locating pin-holes in enamelled copper wire, and a tungsten filament crystal-cleavage tester. The problem of dealing with tolerances on interdependent dimensions is discussed and inspection output logic units are proposed which can carry out automatic limit shifting. An analogue storage device is sometimes useful when a series of successive measurements are made. Stability and machine speed are considered. The cost of automatic inspection equipment is reviewed and the technical and financial considerations involved in adopting the techniques are discussed in general terms.

1. Introduction

1.1. *Economic Reasons for Automatic Inspection Equipment*

In many production processes the degree of automation achieved to date is such that a great deal of tiresome labour has been reduced to a minimum. Hence, from a given team of human workers plus their production machines, it is now commonplace to obtain a much greater production output. In such cases the labour content of any one unit produced, so far as cost is concerned, is now much lower than it was before the automation equipment was introduced. However, the cost of investment on special production equipment has risen appreciably. Nonetheless, in most çases the cost of both items per unit is less in absolute terms than in the older methods of production which prevailed in an earlier period of industrial development.

1.2. *Reduction of Scrap*

On the other hand, the material content per unit is not appreciably different whether we use automation equipment or manual methods, and hence the cost of scrap and the reject produced is still an appreciable item. A further point which arises due to the increasingly exacting demand of the customers is that the products of automation require exacting inspection and this usually involves a growing number of people in the inspection teams in factories using automation. This ensures a product quality of much greater perfection than would have been tolerated in the past where many small imperfections got by. From this, of course, follows the fact that the automated production line technology attempts to squeeze the product between narrow limits and thus the uniformity and quality is improved as is demanded to-day by increasing competition. These remarks apply to all sorts of products which can be purchased to-day at very economic prices.

† Automation Consultants & Associates Ltd., Chertsey, Surrey.

1.3. *Increasing Output*

The increasing output of a given team of workers using automated equipment mostly involves the deployment of additional human inspectors to deal with the increasing quantities of the product so produced. Some of the liberated production personnel can be retrained for this task, but this is not always possible. Thus, in a search for further economies, management is turning more and more to the possibilities of automatic inspection machinery and their development is greatly encouraged to-day. These machines usually consist of combined mechanical and electronic systems.

1.4. *Automatic Assembly*

There is another point which calls for the development of automatic inspection devices, and that is the gradual introduction of automatic assembly machinery and the technical fact, that unlike human assemblers, who can intelligently select good components to assemble, an automatic hopper fed assembly machine can only work properly and continuously if it handles good components. By good components one means those items whose relevant dimensions are within tolerance, though of course many other less important factors might be outside normal tolerances. This is quite obvious if we realize that automatic assembly machines can only work accurately if they have jigs and fixtures which themselves are accurate and thus it is obvious that they would jam if components entered which themselves were inaccurate. In fact, one can be quite definite and state clearly, that automatic assembly does not pay with inaccurate component parts.

1.5. *Automatic Inspection Machines*

The above considerations have led increasingly to the evolution of machines either specifically intended for use in the inspection departments of manufacturing firms, or as auxiliaries (very necessary) to automatic assembly machines. The reasons for this are:

(a) We have to speed up the inspection process itself so that the large quantities produced by the automatic production equipment can be dealt with without having to enlarge the human content of the inspection department.

(b) With the more complex types of products now designed, and which are produced on automatic equipment, we have in fact to deal with a large number of factors and dimensions, all of which have to be checked on every component so as to ensure a consistency of the product.

(c) The older methods of quality control, which involved sampling by human inspectors are no longer sufficient to ensure the consistency which is required, for instance, by automatic assembly machines. More and more factors have to be measured with greater accuracy.

The human sampler also uses his intelligent faculties of deduction and statistical analysis and it is obvious that this cannot be 100%. Human inspection is therefore unsatisfactory when it precedes an automatic assembly machine, where all components (100%) must be correct if there is not to be a jam-up.

We are thus inevitably compelled to evolve new automatic inspection machines. These can either be, (i) directly intended for automatic high-speed inspection of large quantities of parts automatically fed to these inspection machines from hoppers or such like automatic means, or (ii) interposed as automatic inspection devices between the production stages of a transfer line so as to stop the transfer line in the event of a broken tool for instance or other cause of imperfect production, or (iii) placed at the entry end of automatic assembly machines to check (pass or reject) components before attempting to assemble them automatically.[1]

We can introduce an automatic inter-stage inspection device on a transfer line which can stop or re-adjust the machine when the process has drifted outside the tolerance limit. This is frequently done on grinding machines, for instance centreless grinders, where the grind-stones are redressed with special diamond tipped tools when the first object has exceeded the grinding limits and the machine has been automatically stopped. This is quite irrespective of whether we are dealing with a large in-line transfer machine or a smaller circular production machine or a machine of another type.

In the past the author has frequently referred to such machines as conscious machines, i.e. machines endowed with a certain limited intelligence. However, a preferable term is "cybernetic machines", i.e. self-steering machines. In the simplest case the conscious device merely stops the production process if the product's accuracy is insufficient and thus stops further production of scrap, but in more sophisticated types of combined production-inspection equipment the conscious device can be coupled to actuators so as to modify slightly the adjustments of the machine thus keeping the dimensions of the resulting product within tolerance.

1.6. *Historical Background*

It is interesting to reflect that already as early as the beginning of the nineteenth century the collaborators of James Watt introduced the steam engine pressure-versus-piston-displacement "indicator" with which it was possible to indicate the engine performance (indicated horsepower) on a self-produced paper chart. There are other examples also which could be quoted from the nineteenth century.

Jumping to the beginning of the twentieth century, we can mention another example of automatic inspection. An automatic inspecting device which searches for pin holes in enamelled copper wire was introduced by the Post Office Laboratories and is now a well-accepted practical device in all enamelled wire factories. Briefly, it consists of a means of unrolling a spool of enamelled copper wire which may or may not have pin hole defects and passing this through a mercury bath which is connected to a megohmeter system in such a manner that a pin hole will close a circuit to the test instrument. Every time an incipient fault passes through the mercury bath a counter records this fault. The reels of wire are then labelled according to the number of fault counts and when making coils of electro-magnetic devices, they are used selectively, those with the smallest number of faults being used for long coils whereas those with a larger number of faults can be used for short coils; those with an excessive number of faults are rejected. Thus we avoid the appearance of incipient shorted turns in solenoids, transformers and other types of equipment using enamelled copper wire.

Another even more sophisticated device, involving some electronics and a great deal of the kind of technology we see to-day in automatic inspection devices is the tungsten filament crystal-cleavage tester. This was introduced into some valve manufacturing firms around 1932/33 so as to ensure long lives of the then recently introduced long filament series-heated universal a.c./d.c. valves. With the long filament valve, it is obvious that the chances of incipient failures are

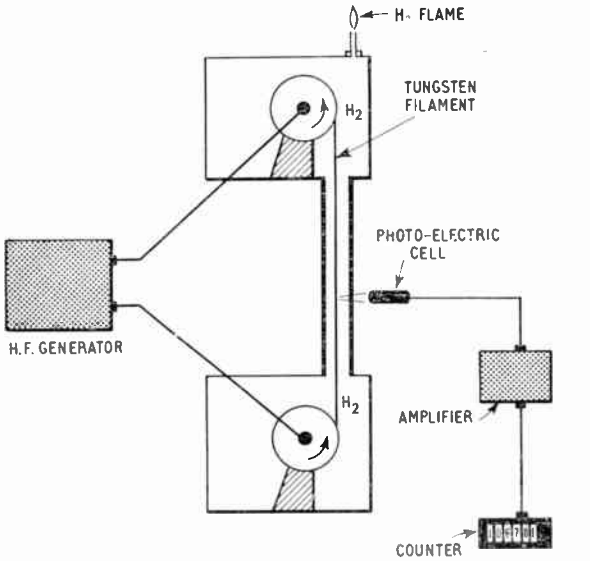
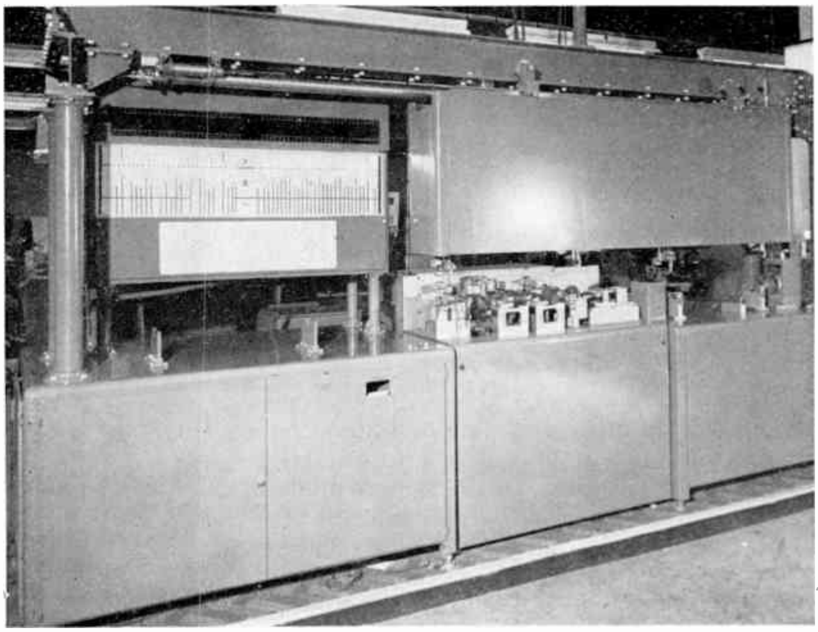


Fig. 1. Automatic test equipment for tungsten filaments employing an invisible crystal-cleavage searching technique.

greater with a long filament than with a short one such as is usual in a.c. valves. To reduce life-failures, tungsten filaments have been drawn out of large single crystals, so called mono-crystals, and attempts are made to keep the longitudinal axis of the mono-crystal all along the filament. This equipment is shown diagrammatically in Fig. 1. Tungsten filament is unwound from the bottom spool which itself acts as an electrical contact for the output of a powerful high frequency oscillator; the top spool acts as the other contact of the high frequency oscillator. The two spools (or intermediate contact saddles) are arranged to represent a half wave of the oscillator frequency. The enclosing glass cavity is filled with hydrogen which provides a reducing atmosphere and prevents the filament from becoming damaged from oxygen in the air. Under normal circumstances at the "current-node" point there is a slight glow as the standing wave is produced along the wire. If an incipient crystal cleavage in the wire passes through this point the local high resistance represented by this cleavage produces a slightly increased brightness in the glow and this can be observed by a photo-electric cell connected through an amplifier to a threshold trigger circuit and pulse counter. Every time an incipient crystal cleavage passes through the cell a count is recorded. Thus, a ready means of sorting out the various spools of tungsten wire according to the number of incipient faults is again provided, whereby those spools with the least number of faults can be used for long filament valves and the others with more faults for short filament valves. By this means the average life expectation on valves is brought into harmony irrespective of whether they have long filaments or short ones. In an inspection department there may be many of these spool unwinding automatic testers and only one person is required to operate a large number of such machines, thus ensuring a greatly improved quality of the mass produced valves or lamps and improved customer satisfaction.

This apparatus has been described in some detail because it shows the type of philosophy that has to

Fig. 2. Three-stage transfer multi-dimension crankshaft inspection machine.



[*Courtesy of Sigma Instruments Ltd.*

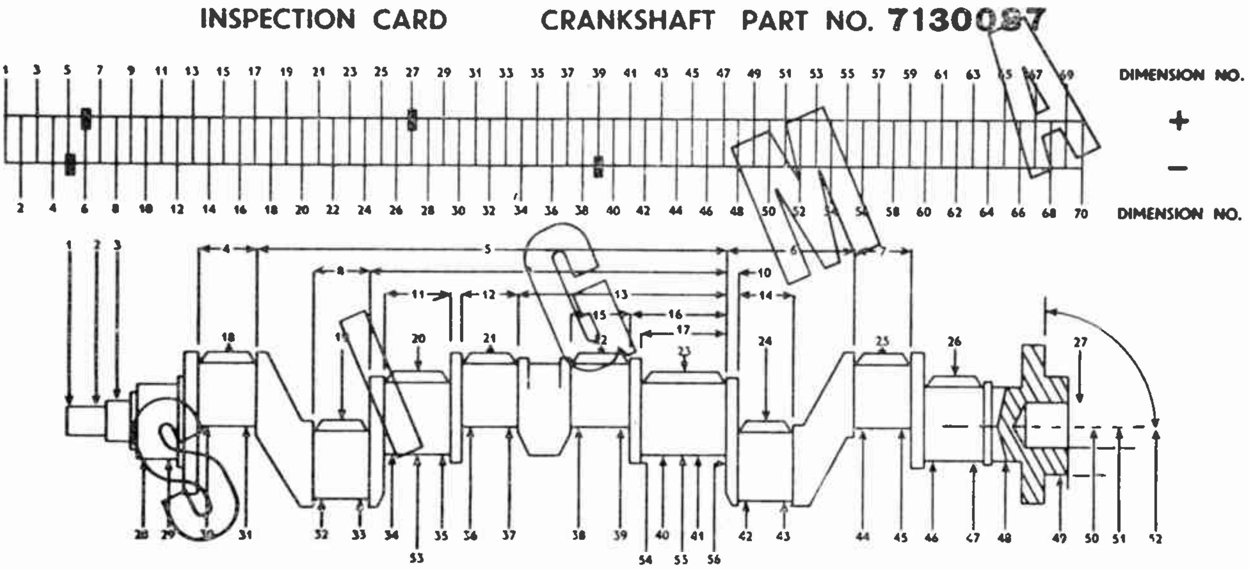


Fig. 3. Punched-card certificate (one per each crankshaft) showing deviations from designed limits, produced automatically by the machine system shown in Fig. 2.

be employed in the evolution of automatic inspection devices and also because it is essentially a radio engineer's product.

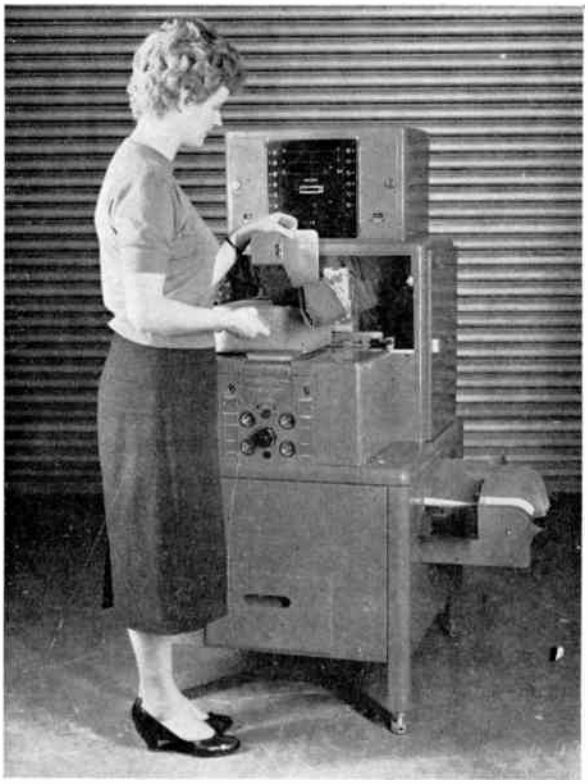
During the 1939–45 war several examples of mechanical-electronic automatic inspection machines were introduced, particularly into the cartridge production lines of ammunition factories. The very large production quantities involved justified these somewhat complicated machines and they also ensured consistent quality of the product.

1.7. *Modern Examples*

There are now a great number of really excellent fault-detecting techniques available and these can be combined with high-speed feeding devices in such a manner that we can design a testing machine to handle quantities of the product quite rapidly. The testing device output can be combined with certain limit devices which can be pre-programmed to give error-signals within tolerance; when they fall outside the tolerance logic circuits are operated which in turn can operate "pass" and "reject" gating machinery These are typical of the simple type of single unit inspection.[2]

2. Multi-point Inspector

There are modern examples of inspecting machines, which measure up to fifty or more dimensions on a component such as a crankshaft or a turbine blade, etc. These modern machines are even able to produce, if required, an automatically punched card or other form of typewritten certificate which is numbered with the component number previously inspected. An example is shown in Fig. 2 and Fig. 3. However, in most cases such multi-point inspection machines have automatic sorting logic which grades and makes decisions on the quality of the product and whether it should be accepted or returned to the production department for further correction. The operator



[*Courtesy of Sigma Instruments Ltd.*

Fig. 4. Fully automatic multi-dimension inspecting machine for dental cartridges. Accurate to within 0·00005 in. (2400 per hour).

correlates the findings of the inspection machine and production machine instructions. By this method improvement in product consistency is obtained (Fig. 4).

2.1. *"Cybernetic" or Inter-dependent Inspection*

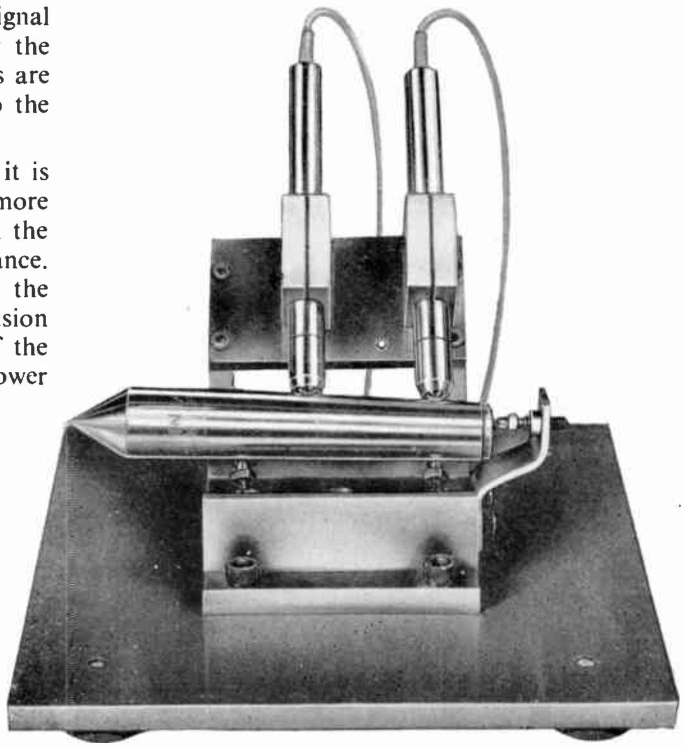
Where in the past a human fitter or matcher or sorter carried out an intelligent assessment of the measured results to determine whether a component produced was acceptable or not, a more advanced type of automatic inspection machine than has been described is required if it is to possess this intelligent faculty of comparison. This applies quite often where two or more dimensions are "interdependent", for instance, where the shape of a component has a rather more complicated contour, say a taper or a nozzle, or where it is designed to obey some rather involved mathematical or geometrical form. In these cases the exact dimensions of two or more points are not so important as the slope of the various surfaces and the general shape. It is possible to design a multi-point inspection machine where the various dimensions are automatically measured by means of inspection heads and their associated equipment to give error output signals for each point. To this is added a special logic system to enable the intelligent assessment to be made automatically. One can design an electronic unit which is adaptable to be programmed to take cognizance of the inter-dependence of these various dimensions and compare them logically. In Fig. 5 is such a device for measuring the angle of taper. If the transducer on the left measures one diameter it produces a reference signal for the measurement of the small diameter by the transducer on the right, and the electronic limits are set up to grade the tapered object according to the difference of the two measurements.

To ascertain the contour or shape of a form it is necessary to consider the relationship of two or more dimensions and it is not sufficient to verify that the individual dimensions should be within tolerance. Thus, in a nozzle for instance, whatever be the dimension a in Fig. 6, the value of the dimension $(b-a)$ should be preserved, within the limits of the permitted error. If the dimension a is at the lower limit of its tolerance then dimensions b and c should be correspondingly lower.

By using inter-dependent inspection logic in automatic machines we obtain an intelligent assessment of quality. In many cases this philosophy enables one actually to widen the limits at the individual measurement points and thereby make manufacture more easy to carry out and therefore more economical, and yet produce more consistent functional results. Such inspection output logic units are usually referred to as "pre-programmed decision devices"; they can be pre-programmed to carry out comparisons also within special tolerance limits of the comparison. Whilst the results are more sophisticated, the actual devices are not unduly complicated and can be either in the form of relay logic or solid-state or valve logic circuits depending upon the type of equipment generally concerned in the design of the whole machine. A further decision logic is usually involved in operating "pass/reject gates" or "grading gates" which are operated one way or another to sort out the components which have passed through the inspection transducers.

2.2. *Examples*

This type of inter-dependent inspection is very useful in the matching of, for instance, roller bearings or ball-bearings to their races and so on. It is also useful in inspecting the exact taper on taper rollers or similar objects which are themselves ground on



[*Courtesy of Parnum Gauges Ltd.*

Fig. 5. Interdependent inspection example: differential gauge measuring two points on a taper roller simultaneously with interdependent logic giving taper-angle directly on scale of instrument (not shown).

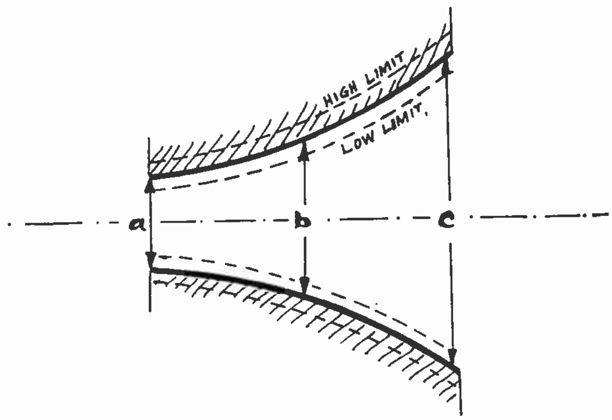


Fig. 6. Interdependent inspection example: measurements on a nozzle curvature.

centreless grinders and where, due to the different periphery of the wide end compared with the narrow end of the taper roller, the wear on the grind-stones is different and in due course the manufacturing tolerances at one end drift with production time at a different rate to the other end. Yet it is obvious that it is the true taper angle which is of importance, not the exact dimension at either end. Machines can be designed to grade the balls and match them to the inner race and the outer race of a bearing so that the final assembled product can be more exact and leave less rattle tolerance than if one adopts the more orthodox method. (The whole assembled bearing is further tested for rattle by acoustic methods.)

2.3. *Automatic Limit Shifting*

It is not intended in this paper to go into minute design details, but in such a brief report one can still convey the main philosophy of how one carries out the design concept. Taking the example in Fig. 6 of a complex shaped part, it is easy to see that if we are to correlate measurement at point *b* and *c* with that taking place at point *a* it is necessary to shift the measurement limit at point *b* and *c* dependent on the first measurement which had taken place at point *a* on each and every object tested. Electronically one can do these things simultaneously, but in some measurement problems it is almost impossible to carry out all measurements mechanically at once (see Section 4). Electronically we can take the actual measurement at point *a*, pass it through a grading circuit which itself can shift the limits at point *b* and point *c* which are measured later in other measuring stations. One can grade points *b* and *c* into several categories moving the upper and lower limits together up and down as the case may be. A far more accurate and final shape on the product can thus be maintained by these inspecting and grading techniques. It is re-emphasized that when measuring a curved object the angle of curvature is more important than the exact dimensions at one, two or three places. In the case of a more complex shape like that of the aerofoil surface of a turbine blade where a large number of points have to be measured and compared before a decision is taken, for instance a small ridge, however shallow, can cause a turbulence in the gas stream when the component is used, and yet orthodox measurements might pass this. Yet if the whole surface is slightly above tolerance but smooth in general shape it can still make a satisfactory turbine blade. In the more complicated cases when very many points have to be correlated, one uses a simple type of analogue computer followed by a not too elaborate "acceptance" or "rejection" or "grading" logic. Although admittedly a digital computer could also be used in such a case, it seems an unnecessarily complicated way of doing this, and it is generally found that the decision logic based on an analogue concept is less expensive and is adequate to carry out such decisions.

3. Logic Blocks

It is frequently necessary specially to design the action and computing circuits as part of the inspection device or machine. In such cases in order that one should not have to design all the special equipment for every object one has to inspect, it seems right to use standard logic blocks in as many places as possible and thereby make the equipment itself more flexible and less costly in the long run.

There is a great need for standardization of at least some of the factors relating to logic blocks at present on the market. The situation is rapidly approaching the chaos that prevailed just before the war in regard to valve types. There are all sorts of types of logic blocks, some which functionally resemble each other; with others the bases plug-in but their connections are absolutely unstandardized and uncorrelated. This makes the work of the intending user quite unnecessarily difficult. The Brit.I.R.E. might co-operate with the British Standards Institution to attempt the standardization of logic blocks.

4. Analogue Storage

In some technical problems it is very often not practicable to carry out all the measurements at the same time due to mechanical difficulties of inserting the measuring probes or transducers or through some other difficulties of shape of the object, or when measuring weight or another abstract factor.[3] In such cases, it is necessary to move the object from stage to stage in a sort of "measuring-transfer-line". The measurement values at each station on any particular object must first be stored up and the information must be later handed out at the moment when the object emerges from the last stage of measurement and is approaching the "sorting gates" to be passed or rejected or graded.

The measurement values in electrical terms are either in analogue or digital form. If in analogue form one has to store up this information in an analogue manner (or convert it from analogue to digital form). In either case we are involved in cost and carefully evaluated studies have to be made before one finally decides on the correct approach. A lot of development work has resulted in an analogue storage device of sufficient accuracy to be used in a number of complex inspection machines. However, there is still a small inherent inaccuracy which might be loosely referred to as noise level in such devices and therefore very carefully assessed decisions have to be taken when including them in a design of a machine which has to work in a factory. At all costs one must avoid unnecessary complexity.

5. Stability

This falls into two groups, inherent basic stability of the mechanical system and the electronic system, and the temperature dependence of both. In all automatic inspection equipment one has to aim at a stability of the highest order, at least five to ten times higher than the accuracy at which the objects are to be measured. This has been achieved in many cases and an accuracy of the order of 0·01% error are not uncommon and in fact, if it were necessary this could be exceeded, with the knowledge and experience now available.

6. Machine Speed

Automatic inspection machines have been built which are capable of inspecting objects at the rate of several per second. However, speed does depend to a large extent on the weight and shape and size of the object and thus no generalization should be made. Perhaps the only generalization is that speed limitations are usually mechanical and not electrical.

7. Cost of Automatic Inspection Equipment

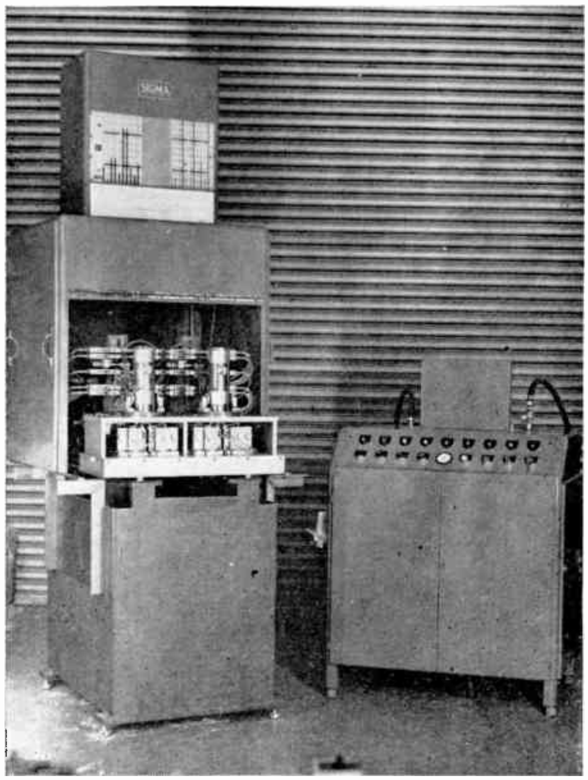
It is wrong to generalize and say that automatic inspection equipment is expensive: cost depends entirely on the complexity of the inspection task involved. The cost of automatic inspection equipment thus ranges from a few shillings to tens of thousands of pounds per device. For instance, a simple "thread-break-monitor" such as is used on knitting or weaving machines to stop the machine if a thread breaks costs definitely less than one pound. It is thus possible for the designer of modern knitting and weaving machines to use thousands of these small monitors on one equipment and thus ensure that the knitted or woven object is free from defect. This is, incidentally, a very good example of an inspection philosophy where monitors are built straight on to the production machine and thereby render it almost impossible to produce a faulty product.

Taking the other extreme case of cost, a good example is the electronic metallurgical specimen analyser. Such devices can give a complete certificate of the metallurgical analysis on a typewriter within a matter of minutes and have the greatest possible importance in metallurgical development of complex alloys. In all cases the cost of the equipment is recovered in the very considerable savings elsewhere in the production process.

Complicated shaped objects can be dimensionally inspected automatically by special purpose machines or general purpose machines adapted with a number of jigs and fixtures etc., to a particular special purpose. One can usually design such equipment to be adjustable within a reasonable range and cover a number of various dimensions of generally similar shaped objects. Equipment used in conjunction with automobile component production, e.g. cylinder liner inspecting machine, can be adapted to small pistons as well as large ones, equally so for poppet valves for small engines and large engines etc. (Fig. 7).

8. The Application of Automatic Inspection Methods

In the author's experience the main difficulties in the creation of automatic inspecting machines lie in the economic considerations which face management



[*Courtesy of Sigma Instruments Ltd.*

Fig. 7. Inspection station for a transfer-line producing cylinder liners, interlocked with production line (not shown). Gauging time 10 seconds.

before they can see their way clear to embarking on a particular project. The Board of directors who have to decide on a large investment, i.e. have to find the money well in advance of the machine earning its keep, must take a calculated gamble. Provided the money is available, the technological advances can be made by the engineers, and the research and machine building can proceed.

The Board has to bear in mind the development time, the growth in sales, the production rate that is likely to occur in the coming years and in the meantime to find the finance for the research and development of these new devices. They must obviously have enough confidence in the likelihood of success before they sanction such development. For this reason we always carry out a sufficiently extensive study for our clients for them to be able to assess the worthwhileness of the proposals. The proposals may come partly from the client, partly emerge from our experience but are usually a combination of both.

8.1. *Preliminary Technical Study*

We must make an intelligent estimate as to the degree of certainty of success. This means limiting the new inventive development to certainly less than half of the whole project. Usually we try to utilize as many known techniques as possible, leaving the unknown part to less than 20%. This latter part has to be conceived, experimentally verified and developed on sound lines. We must envisage the whole equipment which is a reasonably difficult job, but in the light of accumulated experience becomes progressively less risky.

8.2. *Development Costs*

We must make an intelligent assessment and estimate of the likely cost of an inspection machine after the preliminary development has been carried out.

An intelligent estimate must be made of the research and development cost needed to overcome all the snags in the laboratory before the machine is offered up to the production factory. Whilst there are usually some "teething" troubles with all new equipment, we must try to keep them to a minimum.

8.3. *Cost Accountancy Considerations*

We must also try, together with the production personnel and management, to arrive at the economic feasibility of the proposals. This involves working out the various factors which affect the product quality, how important is accuracy, what is the degree of reject percentage at present and what would be the reduction in cost of a reduced "reject-percentage". Here one must carefully bear in mind that every time a production machine is stopped or an assembly machine is stopped due to a faulty tool or faulty part, far more money is lost in production cost than in the cost of the small tool or small part rejected.

The objective facts discovered in the preliminary survey or investigation must be assessed against their economic implications so far as the entire firm is concerned. To this end one must have the collaboration of the accountants and they must have sufficient imagination to be helpful.

At this point it is vital to management to have forward costings based on different rates of growth in production. This can be carried out usually by the cost accountants once they have certain basic assumptions available from the R. and D. team and/or the consultants to give some pivotal point to work to. They must also have sufficiently accurate works costs on the existing methods of production.

8.4. *Long Term Considerations*

Having obtained sufficient facts, management must have sufficient courage to act quickly and adopt a short as well as a long-term development plan, and also follow out logically a re-equipment policy in the works generally. For what is the use of a most elaborate and clever inspection equipment if other parts of the factory are equipped with obsolete equipment? One must be conscious that facts of to-day are not necessarily true of the remote to-morrow and thus the choice of the correct development approach by the technologists is of the greatest importance to long-term growth of the company. It is equally important that the new plant to be developed should be very flexible.

It is usually valuable to have an operational research team who continue to observe the improvements as they occur and correlate these with results of market research, faults statistics and complaints department.

It is just as important to train an absolutely first-class maintenance engineer or engineers.

9. References and Bibliography

1. J. A. Sargrove, Automatic testing in a transfer-line. British Patent No. 635,756 (1946).
2. J. A. Sargrove and P. Huggins, "Automatic inspection—the anatomy of conscious machines," *J. Instn Prod. Engrs*, **34**, p. 563, September 1955.
3. J. A. Sargrove and D. L. Johnston, "Automatic inspection as the key element in automation," *J. Brit.I.R.E.*, **17**, pp. 529–35, October 1957.
4. J. A. Sargrove, "Automation in component testing." *Proceedings of International Symposium on Electronic Components*, R.R.E. Malvern, September 1957. Paper 22, pp. 127–36.
5. J. Loxham, "Control of quality in automatic production," *J. Instn Prod. Engrs*, **36**, pp. 676–98, November 1957.
6. J. Loxham, " Mechanised inspection:—automatic gauging," *Mass Production*, **33**, pp. 73–8, July 1957.

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POINTS FROM THE DISCUSSION

Mr. P. J. Dadswell: It would appear that the use of a cybernetic machine as a technique of inspection of mass produced items may soon develop to the stage where its use ceases to be merely a question of economics, but becomes essential to the very possibility of being able to mass produce successfully that item by automatic systems which demand 100% inspections.

A multiplicity of such machines and the need for their accurate calibration and maintenance by humans may present a serious problem in the future. Could the author indicate the trend and degree to which automatic calibration to built-in sub-standards will be utilized by such machines and comment upon the development which may be expected to remove the need for human interference.

Mr. J. A. Sargrove (*in reply*): I believe that Mr. Dadswell has indicated a very real fact in modern industrial development. Already we are in a position, where certain items of precision parts cannot be made at all without some form of automatic control and measurement, such as miniature ball races, balance wheels for accurate but cheap watches, fine instrument and watch springs, etc.: in each case 100% of the production must be inspected by some means. But this is where the economics comes in as the use of cybernetic self-steering automatic inspection machines do the job at an economic rate for the job even if one has to depreciate the special machines and their development within the cost of say five years' production. I think that we will see more and more self-testing and self-adjusting measuring systems, as has been the trend in automatic self-balancing recording potentiometers, etc. But there is a lot of work still to be done before we can feel that dimensional measuring fast machines have reached quite the stage of the self-adjusting potentiometer. This is due to the greater complexity of these new machines, not I feel due to something fundamental in difficulties.

Mr. D. Robb: Claims are made of measurements taken with an accuracy of 1/20th part of 0·001 in. As these dimensions are taken on the shop floor which may have a temperature variation of $\pm$ 5 deg C, this claim seems to be hardly feasible. A nominal figure for the coefficient of linear expansion with temperature would be 11×10^{-6} in/in/deg C for metals; this would give a change of $1{\cdot}1 \times 10^{-4}$ for a 10 deg C change as compared with measured accuracy of $0{\cdot}5 \times 10^{-4}$.

Even if the instrument is manufactured with metals having a low coefficient of linear expansion what is done to cancel errors which may be due to work pieces coming off the production line, not with machining?

Mr. Sargrove (*in reply*): I feel that Mr. Robb views the achieved accuracy as unachievable. It is the actual stability of the whole system, mostly electronic, which I referred to and, of course, relates to the measurement of slip gauges and standard rods also made of Invar, not the product made from ordinary steels with an expansion coefficient, as he says, of the order of 11×10^{-6} in/in/deg C. After all, one must work to a constant sized test piece if one is going to know anything. I feel that in special cases, say in the making of ball races of a particular steel over years, it might be feasible to make the gauging heads and the supports also of the same steel and thus extend the range of temperatures in which the equipment tells the truth. In our prototype high-speed machines, it is the speed of sequential tests that is high speed, and the time interval between the process and the measurement may be quite long, certainly enough to lose the machining or grinding temperature rise. Thus I contend that it is a matter of what we mean by dimensional accuracy. I was not stating that one could measure a hot piece part and then when it cooled out that it would not be smaller. I was saying that the measuring machine had a high system stability and used Invar parts where these were essential.

Mr. F. E. Sanville: While referring to the stability of inspection equipment, Mr. Sargrove mentioned that the materials used should have the lowest possible coefficient of expansion. Surely this is not a general rule.

Mr. Sargrove (*in reply*): I know it is not a general rule, but wouldn't it be better than using high coefficient of thermal expansion steels and having to warm them and the measured part to a standard temperature, as is the case at present, where many inspectors keep their pet micrometer inside their clothes near the body, to be able to rely on the micrometer telling them something *meaningful?* Incidentally, I have seen some micrometer platforms made of a low-coefficient ceramic material, and also some special transducers also of such material. Surely the trend will have to be in this direction for measuring machines in the better than 1/10th thou' accuracy range.

APPLICANTS FOR ELECTION AND TRANSFER

The Membership Committee at its meeting on 30th August 1962 recommended to the Council the election and transfer of 21 candidates to Corporate Membership of the Institution and the election and transfer of 59 candidates to Graduateship and Associateship. In accordance with Bye-Law 21, the Council has directed that the names of the following candidates shall be published under the grade of membership to which election or transfer is proposed by the Council. Any communications from Corporate Members concerning these proposed elections must be addressed by letter to the Secretary within twenty-eight days after the publication of these details.

CORPORATE MEMBERS

Transfer from Associate Member to Member

BOLTON, Ronald. *Nairobi, Kenya.*

Direct Election to Associate Member

ATKINSON, James. *North Shields, County Durham.*
BENNETT, Ronald William. *Borough Green, Kent.*
BENNING, Norman Henry. *Billericay, Essex.*
BYNAND, Dorrell Sydney John. *London, N.W.2.*
COVILL, Dennis Henry, B.Sc. *Hackett Cove, Nova Scotia, Canada.*
CRUIKSHANKS, Harry Kerr. *Salisbury, Southern Rhodesia.*
EAST, Derek. *Betchworth, Surrey.*
EDMONTON, Brian. *Norwich, Norfolk.*
McDONALD, Aubrey John Cowpe. *Thundersley, Essex.*
POWER, Major Richard Frederick, Browning, R.Sigs. *Winchester, Hampshire.*
WOOTTON, William Edward Alfred. *Ilford, Essex.*

Transfer from Associate to Associate Member

GORE, William George. *Basingstoke, Hants.*
JOHNSTONE, William Thomas. *Stafford.*
McCREADIE, Major Anthony Robert, R.Sigs. *Catterick Camp, Yorkshire*
PERRY, Thomas Leslie. *Birstall, Leicestershire.*

Transfer from Graduate to Associate Member

FLOYD, John Thomas. *Hemel Hempstead, Herts.*
REDFERN, Peter David. *Horsham, Sussex.*
WEISSBERG, Ernst Michael. *Ramat Gan, Israel.*

Transfer from Student to Associate Member

HAMMOND, Edward. *Slough, Buckinghamshire.*
PARKIN, Oswald Theodore. *Bedhampton, Hampshire.*

NON-CORPORATE MEMBERS

Direct Election to Associate

COLLINGWOOD, Cuthbert John. *Whitley Bay, Northumberland.*
DATAR, Vinayak Laxman, B.Sc. *Aurangabad, India.*
PERRY, Kenneth Warwick Henry. *Klemsig, South Australia.*

Transfer from Student to Associate

PAGE, James William. *London, W.6.*

Direct Election to Graduate

AKEROYD, Arthur Henry. *Hounslow, Middlesex.*
BAKER, Malcolm Field. *Bromley, Kent.*
BIRD, Kenneth Henry George. *South Ruislip, Middlesex.*
BORLEY, Richard. *Enfield, Middlesex.*
COULON, John Richard. *London, N.18.*
FIELD, Denis Michael. *Malvern Link, Worcestershire.*
FITZGIBBONS, James Daniel. *Enfield, Middlesex.*
GATES, Geoffrey Philip. *Southborough, Kent.*
GHARTEY, Damilda Emanuel Beola. *London, S.W.12.*
GRIFFITHS, Raymond Frederick. *Bristol.*
HARTLEY, Robert Henry Edward. *London, N.9.*
HICKMAN, Capt. Gordon Arthur William, R.Sigs. *B.F.P.O. 69.*
HONEBON, Colin David. *Weymouth, Dorset.*
JOHNSTONE, William Pybus. *Wantage, Berkshire.*
McCALL, Ian. *London, N.8.*
*MALHOTRA, Bahri Jagmohanlal. *Pilani, Rajasthan, India.*
MARSDEN, Norman John. *Manchester.*
OVERY, Edward David. *Enfield, Middlesex.*
QURESHI, Rashid Ahmad, B.Sc.(Eng). *Liverpool.*
ROBB, John. *Glenfield, Leicestershire.*
SAIGAL, Manohar Lal., B.A. *Osterley, Middlesex.*
SHORT, Alan Donald. *Waltham Abbey, Essex.*
WHITEHEAD, Bertram. *Sidcup, Kent.*

Transfer from Student to Graduate

ARMSTRONG, John Patrick. *Basingstoke, Hampshire.*
AUDUS, Michael Francis, B.Sc. *Abingdon, Berkshire.*
BARNARD, Eric Edward. *Hornchurch, Essex.*
BERRY, John Alfred Lester. *Farnborough, Hampshire.*
BINENSTOK, Joseph. *Rehovoth, Israel.*
BIRCHAM, John. *Bristol.*
BRIGGS, Terence. *Ramsey, Huntingdonshire.*
CHAPMAN, Christopher John. *London, S.E.22.*
CHILDS, John Baird. *London, S.W.19.*
COULTER, John Patrick. *Stanmore, Middlesex.*
COXAN, David John. *Malvern Link, Worcestershire.*
DARE, Roderick Michael. *Bristol.*
FENLON, Dennis Sydney. *Bromley, Kent.*
GREENBERG, Maurice Bernard. *Edgware, Middlesex.*
GUPTA, Jitender Kumar, B.A. *Delhi, India.*
HAKHVERDIAN, Armik A. *Tehran, Iran.*
HASAN, Ghulam. *Karachi.*
INKPIN, Jack Dennis. *Portsmouth, Hampshire.*
KENWARD, Michael. *Wallington, Surrey.*
KUMAR, Flt. Lt. Jagdish. *Delhi.*
LAWRENCE, Brian Richard. *Ilford, Essex.*
MALHOTRA, Madan Mohan. *New Delhi.*
MARSHALLECK, Morris Milton. *Cambridge.*
MILLS, Ivan Rickard. *Chelmsford, Essex.*
MUKERJEE, Sudhendu Kumar. *Jodhpur, India.*
NAGESH, Jai Ram. *Rohtak, India.*
PERRIN, Roy Laming. *Manchester.*
PREEDY, Anthony Reginald. *Wellington, Salop.*
TAYLOR, John Chisholm. *South Shields, County Durham.*
THAKRAI, H. B. Rai. *Kew, Surrey.*
THORNHILL, Denzil Robert. *Birmingham.*
TIGWELL, Peter John. *New Malden, Surrey.*

STUDENTSHIP REGISTRATIONS

The following students were registered on the 30th August.

ADEIFE, Johnson Olusegun. *Lagos. Nigeria.*
ANANTHARAM, Belavadi, B.Sc. *Bangalore, India.*
ARMOUR, John Sinclair. *Arborfield, Berkshire.*
AUSTIN, John Edward. *Coventry, Warwickshire.*
BAIRSTOW, Alan. *Harrow, Middlesex.*
BANODKAR, Manamohan Krishna, B.Sc. *Bombay, India.*
BARNES, Alan George. *Hounslow, Middlesex.*
BARRABALL, Erskine Thomas. *Johannesburg, South Africa.*
BEG, Mirza Usman Ali, B.Sc. *London, W.12.*
BENBOW, Kenneth Edward. *B.F.P.O. 69.*
CASSAR, Carmel Laurence. *Sliema, Malta, G.C.*
CHARMER, Francis William. *Cheadle, Cheshire.*
CRAIG, John. *Germiston, South Africa.*
DAYARATNA, Lokuge Don. *London, W.2.*
DIEPERINK, Johanne Kerr. *Johannesburg, South Africa.*
DUTTA, Swapan. *London, N.19.*
ELLIOTT, David Garth, B.Sc. *Woomera, South Australia.*
EVERETT, John. *Malvern, Worcestershire.*
EZAR-MOHAMMED. *Champion Reefs, India.*
EZEOKE, Lawrence Azubuikd. *London, N.4.*
FORD, George. *Liverpool.*
FORDYCE, John Gill. *Edinburgh.*
GRAVES, George. *Locking, Somerset.*
HENERY, Albert Briggs. *Sutton, Surrey.*
HUGHES, Alwyn. *London, W.2.*
JAJBHAV, Abdool Vahed. *B.F.P.O. 53.*
JAYARAM, Thali Kottiath. *Singapore.*
KANAGARAJAH, Kandiah. *Evesham, Worcestershire.*
MANKTELOW, James Terence. *Bushey Heath, Hertfordshire.*
MARRINAN, Patrick Paschal. *Belmullet, Eire.*
MOORE, Walter Derek O'Neil. *Edinburgh.*
NAGARAJA. *Bangalore.*
OTTLEY, Thomas Winchester. *Huddersfield, Yorkshire.*
PATEL, Haribhai Chandubhai, B.Sc. *Kilembe, Uganda.*
PING, Lung Chien. *Singapore.*
PLUMMER, James William. *Sidcup Kent.*
POINTER, Joseph John. *Dartford, Kent.*
POOLMAN, Adrian Albertus. *Kitwe, Northern Rhodesia.*
QADIR, Captain Mohammad Saleem, Pakistan Sigs. *Rawalpindi, West Pakistan.*
RAMAKRISHNAN, Chathapuram Hariharen, B.Sc. *Madras.*
RAMANKUTTY, Pozhath Menon. *Kuwait.*
SANKARANARAYANAN, Palghat Krishnier, B.E. *Karlsruhe-Bulach, Germany.*
WAITT, Capt. Frederick Cyril, R.E.M.E. *Blandford Camp, Dorset.*
SMITH, Joseph. *Macclesfield, Cheshire.*
SPRAGGS, Malcolm Jon. *St. George's, Bermuda.*
THAM WENG LOY. *Taiping, Malaya.*
TIGHE, Francis Vincent. *Wells, Somerset.*
TREBLE, William Elwyn. *Crosskeys, Monmouthshire.*
VAN DER SCHYF, Arnoldus Johannes, B.Sc. *Beroni, South Africa.*
VERMA, Roshan Lal, B.Sc. *Gharaunda, India.*
WILSON, Lawrence. *Enfield Lock, Middlesex.*

*Reinstatements.

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Precision Temperature Measuring Equipment

By

J. J. HUNTER †

Presented at the Symposium on "Recent Developments in Industrial Electronics" in London on 2nd–4th April 1962.

Summary: The paper describes the development of a resistance thermometer of high accuracy together with its associated bridge circuit. The thermometer is of the dual-element type in which two coils of metals having different temperature coefficients of resistance are incorporated in the sensing head. The change in the resistance ratio of the two coils gives a unique indication of temperature.

The bridge circuit developed for use with the thermometer employs the transformer ratio arm method which allows highly accurate and stable ratios to be produced. A modified potentiometer recorder automatically balances the bridge and provides direct read-out. A further refinement is the addition of a shaft digitizer which gives a record of the temperature in a form suitable for automatic data logging. The whole apparatus is stable and robust and can be used in industrial applications.

List of Symbols

D	Dividing ratio per winding.
D_0, D_2, and D_5	Difference in bridge ratio, or ratio interval, across T_2 (unloaded), R_1 and the output of R_2 respectively.
D_1, D_3, and D_4	Dividing factors, or ratios.
N	Total number of windings.
n	Number of windings in output circuit.
R_1	Fine range resistor.
R_2	Slide-wire.
R_c	Resistance of thermometer copper element.
R_M	Resistance of thermometer Minalpha element.
T_1	Coarse ratio transformer.
T_2	Fine ratio transformer.
T_3	Zero shifting transformer.
Z	Series impedance per winding.
Z_0, R_0	Transformer equivalent series impedance.
Z_p	Transformer primary series impedance.
Z_s	Transformer secondary series impedance.

1. Introduction

There is a demand for simple, accurate and highly stable measuring systems, which can be met by circuits based on the Blumlein transformer ratio arm bridge.[1] This paper describes the development and application of the impedance form of this bridge to precision temperature measurement. The bridge described is also well suited, with the appropriate transducers, to measure other physical quantities, such as strain and displacement.

By using a bridge method, accurate measurement of voltage and current is not required, only accurate comparison of the two impedances is necessary, and this can be done with great precision. The comparison may either be between the two elements of a push-pull, or half-bridge, transducer, which is the case that will be considered in this paper; or between a single element transducer and a stable reference impedance or between two separate single element transducers. Methods of dealing with these latter cases are given by Leslie, Hunter and Robb.[2]

1.1. *The Transformer Ratio Arm*

The most accurate ratio standard is that obtained with mutually coupled inductive ratio arms, often called transformer ratio arms due to their similarity with auto-transformers.

With such ratio arms the voltage ratio is determined by the turns ratio of coils on a common magnetic core. By using closely coupled windings, and toroidal cores of high permeability magnetic material, it is relatively simple to make ratio arms accurate to a few parts in a million and with even higher order of stability. The accuracy and stability that can be obtained in this way are, for all practical purposes, almost unobtainable by resistive ratio arms.

An additional advantage, due to the mutual coupling of the windings, is that a large ratio of parallel to series, and output, impedance can be achieved and this can be used in minimizing the effects of both stray shunt loading impedance and the series impedance of the bridge connecting leads.

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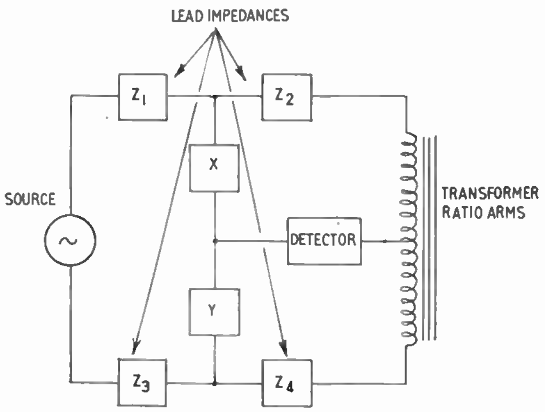

Fig. 1. Mutual impedance bridge.

1.2. *The Mutual Impedance Bridge*

A study of circuit problems encountered with remotely located transducers has shown that the impedance form of the transformer ratio arm bridge, although not favoured in earlier developments, is more suitable for this application.

The mutual impedance bridge described by Clark and Vanderlyn[1] is shown in Fig. 1. The ratio to be measured is that of impedance X to impedance Y. In order to make negligible the effects of the series impedances of the bridge outer connecting leads, represented by Z_1, Z_2, Z_3 and Z_4.

(a) the bridge supply leads are connected first to the impedances to be measured so that series impedances Z_1 and Z_3 are made part of the source impedance;

(b) the shunt impedance of the ratio arms is made high enough so that the series impedances, Z_2 and Z_4, of the connecting leads are negligible in comparison.

No provision is made to correct for the impedance of the bridge inner connecting lead joining X and Y. However, with the type of transducer being considered this can be made physically short and thus of negligible impedance, which is a decided advantage as this is the most difficult lead impedance to eliminate.

The effect of the detector lead impedance is merely to reduce the detector sensitivity if one side of the bridge is earthed so that the balance point is at earth potential.

1.2.1. Reducing the shunt capacitance of the ratio arm leads

The ratio of the bridge is relatively unaffected by shunt capacitive loading on the bridge outer leads due to the low output impedance of the ratio arms; this is exactly the same as good regulation on a well-made transformer. However, with long leads to the transducer, the shunt loading of the lead capacitance could cause a voltage drop in the lead series impedance. In this situation the effective cable capacitance can be greatly reduced by using the outer screen of a coaxial cable to carry the bridge supply while the core acts as the ratio arm return lead (Fig. 2). Any increase in the capacitive load on the bridge supply is of no consequence while, if a multi-core cable is used, the cost and size are not increased since what is now required are three screened leads with the screens separately insulated instead of a five core cable with at least three cores separately screened.

1.3. *The Dual Element Thermometer*

The standard technique in resistance thermometry consists of comparing a temperature-sensitive resistor with a stable reference resistor. Apart from the difficulty of compensating for the long bridge inner lead, for accurate measurement the reference resistor has to be maintained at a stable temperature.

These difficulties can be avoided by placing both resistors at the measurement point.[2] As long as the resistors have different temperature coefficients their ratio is unique for any given temperature.

Robust dual element thermometers, with strain free mounting of resistance elements, have been constructed which maintain accuracies better than 0·01 deg C over long periods.

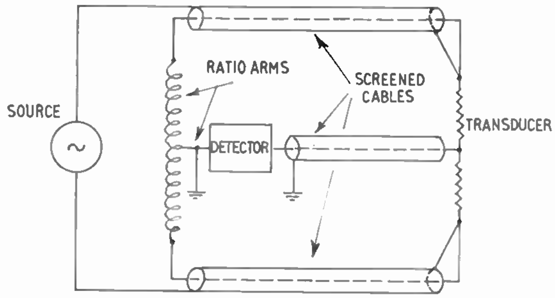

Fig. 2. Circuit to reduce ratio arm lead capacitance.

The dual element thermometer can be used on both d.c. or a.c. bridges, but, as pointed out in this paper, due to the advantages inherent in the use of the transformer ratio arm the a.c. bridge is to be preferred.

2. The Measuring Equipment

The best use of the transformer ratio arm bridge is to have a number of tappings, sufficient for the accuracy required, and alter the ratio by switching the tapping point until the bridge is balanced. This can be done automatically and, in fact, equipment is available with automatic balancing of both real and imaginary components. This is still, however, expensive equipment and it is possible to obtain most of the advantages of the transformer ratio arm

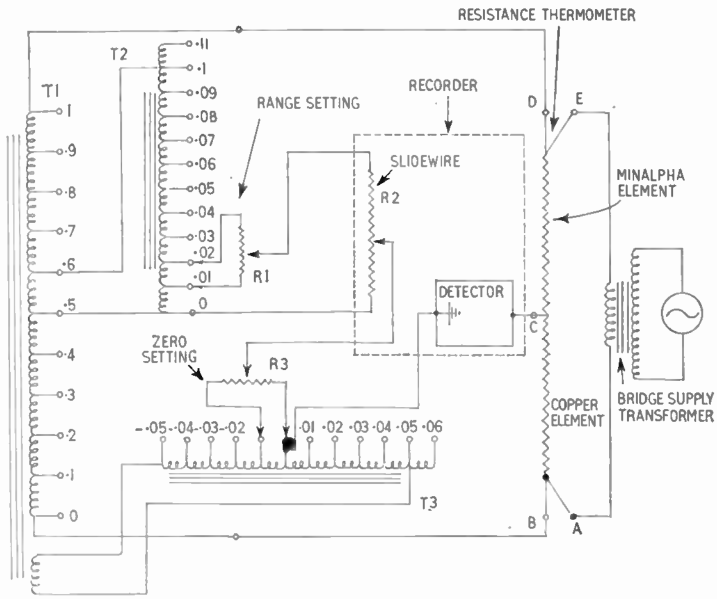

Fig. 3. Resistance thermometer bridge circuit.

bridge at a reasonable cost by making use of an automatic slide-wire recorder. In many cases this type of recorder will be part of equipment already in use and conversion is not difficult.

2.1. *The Resistance Thermometer Bridge Circuit*

The resistance thermometer bridge circuit (Fig. 3) comprises a dual element thermometer as one arm of the bridge, and the other arm is made up of transformers T_1 and T_2, a potential divider resistor R_1 and the recorder slide-wire R_2. The transformer T_3 and associated potential divider R_3 enables a zero shifting potential to be introduced in series with the bridge output. The detector is the amplifier of the slide-wire recorder and drives a servo-motor which restores the slide-wire variable tap to balance when any change in ratio occurs. Since the thermometer elements are non-inductively wound and the bridge operates about unity ratio it has not proved necessary to provide any quadrature balance.

2.1.1. Setting the scale

For the desired temperature range of 15° to 25° C, the thermometer ratio changes from

$$\text{ratio} = \frac{R_c}{R_c + R_M}$$

or

$$\frac{98}{198} = 0{\cdot}495 \text{ at } 15^\circ\, C$$

$$\frac{105}{202} = 0{\cdot}505 \text{ at } 25^\circ\, C$$

where the resistance of the copper element R_c = resistance of the Minalpha element R_M = 100 ohms at 20° C. The temperature coefficient of the copper resistance is approximately 0·4 per cent per deg C, while that of Minalpha is very much smaller and may be neglected for initial setting up, which may be done by substituting range resistors for the thermometer.

The ends of the slide-wire are set so that the desired change in ratio can be obtained over the travel of the slide-wire wiper. As there is some resistance at each end of the slide-wire which the wiper cannot traverse, and as there can be a potential drop in the fine range setting resistor, the ratios set are greater than initially calculated. The correction for the slide-wire residual resistance can be found by using a ratio box in place of the thermometer, with the fine range resistor set at one end. The correction for the range resistor can be calculated, for a resistive variable divider,

$$\text{output resistance} = RF(1-F) \qquad \ldots\ldots(1)$$

where R is the total resistance and F is the fractional setting of the divider.

To reduce the number of contacts in series with the slide-wire, fine range setting has been provided at one end only. To set up the desired ratio, or temperature range, the scale is first set for the correct change in ratio and the zero setting then altered to make the absolute setting correct. This can be easily done since the zero setting controls are independent of the range setting. The zero setting transformer T_3 is supplied from a winding on the coarse ratio transformer T_1, similar to the windings used for the decade division, but not electrically connected to them. With the connections shown (Fig. 3) the zero setting can be adjusted so that a voltage, accurately equal to that provided by a similar setting on the fine range controls, can be added or subtracted from that set on the slide-wire. Thus the slide-wire wiper is offset by an equal amount over all of its travel.

2.1.2. Thermometer self-heating effect

The thermometer energizing current is set at 4 milliamps, which is low enough to ensure that variations in energizing current do not cause significant variations in temperature. The self-heating effect with the thermometers in water with 20 mA energizing current was 0·25 deg C. With 4 mA the rise in temperature due to the energizing current is 0·01 deg C and any variations in this are insignificant.

2.1.3. Thermometer time constant

The thermometer rate of response to temperature change was measured and the time constant found to be 48 seconds.

2.1.4. Detector sensitivity

The detector sensitivity should be high enough to operate the servo-motor for changes of 0·1 per cent of full scale, in this case 0·01 deg C. The change in thermometer resistance for 0·01 deg C is 4 milliohms producing a signal of 8 μV. Since the recorder was originally a 1 millivolt full scale potentiometer recorder the full amplifier gain was not required. The amplifier, at full gain, will operate on a signal of 1 μV.

The amplifier input impedance, mainly due to its input transformer, is about 4000 ohms.

3. Accuracy

The accuracy of the recorder depends upon the stability of the ratio arms and the resistance thermometer, the effect of variations in connecting leads and plugs and the sensitivity of the detector.

3.1. *Thermometer Stability*

The stability of the thermometers over some months of testing at ice point has been found to be better than 0·01 deg C.

3.2. *Ratio Arms Stability*

The ratio transformers[3] have been wound in a manner that gives absolute accuracies of the order of a few parts in a million and experience with other transformer ratio arms has shown, as would be expected, that the stability of the ratio is even greater than this.

The output voltage of T_2 when loaded by the resistor R_1 and the slide-wire, is slightly lower than that indicated by the product of the input voltage and the dividing ratio. This difference between the true and effective ratio, which is due to the transformer output impedance, when known can be allowed for. However, it is of interest to estimate the effect of variations in either the transformer output impedance, the resistor R_1 or the slide-wire.

3.2.1. The transformer ratio arm equivalent circuit

A transformer winding impedance can be represented by

(1) a series impedance, comprising copper resistance and leakage inductive reactance. With the transformers used, at 50 c/s only the copper resistance is significant, this was 2·3 ohms with all eleven windings in series, that is 0·21 ohms per winding,

(2) a parallel impedance due to the magnetizing current required to magnetize the cores. The magnetizing current varies with excitation, so at the bridge voltage of 0·8 volts the parallel impedance is about 4000 ohms, mainly inductive reactance as the core losses are very small.

The series impedance is divided equally among the transformer windings. As the magnetizing current is common to all the windings it will not affect the voltage division between the windings as long as the series impedance of each winding is equal. Thus a simple equivalent circuit can be drawn, disregarding the parallel impedance, and consisting of a series of ideal transformer windings each with associated series impedance (Fig. 4(*a*)). The ideal transformer is assumed to have the following properties:

(1) its series impedance is zero,

(2) its parallel impedance is infinite, and

(3) the following relations hold between its input and output currents and voltages,

$$nD = \frac{n}{N} = \frac{e_2}{e_1} = \frac{i_1}{i_2}$$

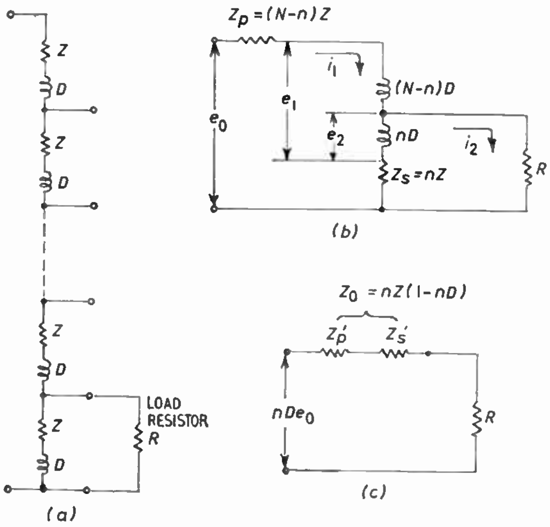

Fig. 4. Equivalent circuits for the ratio transformer.

where nD = dividing ratio

N = total number of windings

n = number of windings in output circuit.

For any tapping point the series impedances in the primary windings can be lumped together and also the windings of the ideal transformer since the same current flows in them. Similarly the series impedances and windings of the secondary can be lumped together. Thus the equivalent circuit for any ratio nD is as shown in Fig. 4(b), and the loop equations for this circuit are

$$e_0 = i_1(Z_p+Z_s)-i_2 Z_s+e_1 \qquad \ldots\ldots(2)$$

and

$$0 = -i_1 Z_s+i_2(Z_s+R)-e_2 \qquad \ldots\ldots(3)$$

From (3)

$$\begin{aligned} e_2 &= -nDi_2 Z_s+i_2 Z_s+i_2 R \\ &= i_2 Z_s(1-nD)+i_2 R \qquad \ldots\ldots(4) \end{aligned}$$

and from (2)

$$e_0 = nDi_2(Z_p+Z_s) - i_2 Z_s + \frac{e_2}{nD}$$

Multiplying by nD and substituting (4) for e_2,

$$\begin{aligned} nDe_0 &= n^2D^2i_2(Z_p+Z_s)-nDi_2 Z_s+ \\ &\qquad +i_2 Z_s(1-nD)+i_2 R \\ &= n^2D^2i_2(Z_p+Z_s)+i_2 Z_s-2nDi_2 Z_s+i_2 R \\ &= i_2(n^2D^2Z_p+Z_s-2nDZ_s+n^2D^2Z_s)+i_2 R \\ &= i_2[n^2D^2Z_p+(1-nD)^2Z_s]+i_2 R \qquad \ldots\ldots(5) \end{aligned}$$

Thus the equivalent circuit can be reduced to that of Fig. 4(c) which has

source voltage nDe_0 = open circuit output voltage

source impedance Z_0 = equivalent primary impedance Z'_p + equivalent secondary impedance Z'_s

Now

$$\begin{aligned} Z'_p &= n^2D^2Z_p \\ &= n^2D^2(N-n)Z \qquad \ldots\ldots(6) \\ Z'_s &= (1-nD)^2Z_s \\ &= (1-nD)^2nZ \qquad \ldots\ldots(7) \end{aligned}$$

and

$$\begin{aligned} Z_0 &= Z'_p+Z'_s \\ &= n^2D^2(N-n)Z+(1-nD)^2nZ \\ &= nZ(nD^2N-2nD+1) \\ &= nZ[1+nD(ND-2)] \text{ and } ND = 1 \\ &= nZ(1-nD) \qquad \ldots\ldots(8) \end{aligned}$$

It can easily be shown that this is identical to the output impedance of a dividing network formed by the series impedances alone.

To calculate the effective ratios it is useful to be able to separate the effects of primary and secondary series impedances.

3.2.2. Impedance and ratio values

For the transformers used, the number of windings $N = 10$, thus the dividing ratio per winding $D = 0{\cdot}1$. The series impedance per winding $Z = 0{\cdot}21$ ohms resistive impedance, thus for $n = 1$,

$$\begin{aligned} Z_0 = R_0 &= Z'_p+Z'_s \\ &= 0{\cdot}0189+0{\cdot}1701 \\ &= 0{\cdot}189 \text{ ohm} \qquad \ldots\ldots(9) \end{aligned}$$

and for $n = 2$,

$$\begin{aligned} R_0 &= 0{\cdot}0672+0{\cdot}2688 \\ &= 0{\cdot}336 \text{ ohm} \qquad \ldots\ldots(10) \end{aligned}$$

3.2.3. Fine range resistor

The effective ratio interval D_2 across the fine range resistor differs from the product of the turns ratio (D) and the input ratio interval ($= 0{\cdot}1$) due to the loading effect of R_1. Thus $D_0 = 0{\cdot}1\ D$,

$$\begin{aligned} D_2 &= D_0 \frac{R_1}{R_0+R_1+R_x} \\ &= D_0 \frac{R_1}{R_1+R'_0} \end{aligned}$$

where $R_0 = R_0-R_x$ and R_x = contact resistances of the range switch and a relay which is in the circuit, although not shown in Fig. 3. To illustrate the effect of variation of resistance the convenient value of $R_x = 0{\cdot}111$ ohm will be taken so that $R'_0 = R_0-R_x = 0{\cdot}3$ ohm. So if

$$\begin{aligned} D_1 &= \frac{R_1}{R_1+R'_0} \\ dD_1 &= \frac{\partial D_1}{\partial R_1}.dR_1 + \frac{\partial D_1}{\partial R'_0}.dR'_0 \\ &= \frac{R'_0}{(R_1+R'_0)^2}.dR_1 - \frac{R_1}{(R_1+R'_0)^2}.dR'_0 \ldots(11) \end{aligned}$$

In this case $R' \ll R_1$, so that

$$\begin{aligned} dD_1 &= \frac{R'_0}{R_1^2}.dR_1 - \frac{dR'_0}{R_1} \qquad \ldots\ldots(12) \\ &= \frac{0{\cdot}3}{625}dR_1 - \frac{1}{25}dR'_0 \\ &= 0{\cdot}000\,48\,dR_1-0{\cdot}04\,dR'_0 \end{aligned}$$

and $dD_2 = dD_1\, D_0$ as D_0 is constant

$$= 0{\cdot}01\,dD_1 = 0{\cdot}000\,004\,8\,dR_1-0{\cdot}0004\,dR'_0$$

For a change in temperature of 0·01 deg C the change in the dual-element thermometer ratio is approximately

$$\begin{aligned} dD_T &= \frac{R_M}{(R_c+R_M)^2}dR_c - \frac{R_c}{(R_c+R_M)^2}dR_M \\ &= \frac{1}{400} \times 0{\cdot}004-0 \text{ since } dR_M \text{ is negligible} \\ &= 0{\cdot}000\,01 \end{aligned}$$

Thus to cause an equivalent change in the ratio arm, that is, to make $dD_2 = 0{\cdot}000\,01$, R_1 alone would have to vary by almost 2 ohms, which is unlikely with a good quality wire-wound resistor, or R'_0 alone would have to vary by 25 mΩ. A change of this amount in the transformer output impedance R_0 would require a change in temperature of the transformer windings of about 35 deg C and this can also be discounted, at least in our application. In general, to ensure that the variation of contact resistance does not cause an error, instrument quality switches and relays must be used with contacts giving low resistance at low voltages and currents. Both relay and switch used in this work have gold-plated contacts, with resistances specified as being below 50 mΩ per contact. Although the actual contact resistances were not measured, it was found that operation of the switch and relay did not affect the calibration. For fixed applications, of course, there is no need to have a range switch, nor relays either with only one thermometer. In this application the relay is required to switch the equipment between two similar thermometers.

3.2.4. Slide-wire

It has been assumed in the previous section that any change in R_1 was uniform so that the ratio was only affected by changes in R_1 or R'_0 relative to each other. A similar assumption will be made for the slide-wire as this, like resistor R_1, is homogeneous and temperature affected changes in resistance, for example, will affect the whole component similarly. Internal changes will of course affect the stability of both the resistor R_1 and slide-wire. In the case of R_1 this has been assumed negligible since the resistor is only used during setting up and calibration. In the case of the slide-wire, the type of recorder in which it is used is commonly specified by manufacturers as being accurate to 0·25 per cent of full scale. This factor includes both the linearity and stability of the slide-wire, and also other components which have been removed in the conversion. It is likely that the slide-wire is accurate to one turn in the 750 of which it is composed, otherwise little margin of error would have been left for the rest of the original circuit of the potentiometer recorder.

The equivalent circuit of the resistor R_1 and the slide-wire is shown in Fig. 4. By using eqn. (12) it can be shown that, with the slide-wire at the 0·01 and 0·02 taps, any change in the slide-wire resistance is likely to be negligible while the contact resistance plus series impedance could vary by about 50 mΩ at the 0·01, and 25 mΩ at the 0·02 tap, if the slide-wire alone is considered, without causing errors greater than 0·01 deg C. However, the effect of R_1 causes a greater allowable variation at the 0·01 tap; since the current at that tap is the difference of the currents in the slide-wire and resistor R_1, at the 0·02 tap the currents add, so that the allowable variation in resistance is halved.

For the slide-wire, at any fractional setting D_4 of R_1, it can be assumed without much error that the ratio interval D_5 across the slide-wire is

$$D_5 = D_2 D_3 D_4 + 0{\cdot}01$$

where
$$D_3 = \frac{R_2}{R_2 + R'_1}$$

and R'_1 is the output resistance of R_1 which can be easily shown to be $R_1 D_4(1-D_4)$. Thus assuming D_2 and D_4 constant at any setting of D_4,

$$dD_5 = D_2 D_4\, dD_3 \qquad \text{......(13)}$$

and
$$dD_3 = \frac{R'_1}{(R_2+R'_1)^2}\,dR_2 - \frac{R_2}{(R_2+R'_1)^2}\,dR'_1$$

As the value of R'_1 depends also on D_4 the worst case for dD_5 with regard to dR_2, is given by

$$\frac{d(D_4 R'_1)}{dD_4} = 0$$

Thus
$$2D_4 - 3D_4^2 = 0$$

and
$$D_4 = 2/3 \qquad \text{......(14)}$$

and at this value

$$dD_5 = 0{\cdot}01 \times 0{\cdot}66 \left(\frac{5{\cdot}5}{2525}\,dR_2 - \frac{25}{2525}\,dR'_1\right)$$

$$= 0{\cdot}000\,014\,65\,dR_2 - 0{\cdot}000\,065\,5\,dR'_0$$

that is, R_2 alone can vary by 0·68 ohms, or approximately 1·5 per cent, to cause a change equivalent to 0·01 deg C.

The worst case for dD_5, with regard to dR_1, is given by

$$\frac{dR'_1}{dR_1} = \frac{d(R_1 D_4 - R_1 D_4^2)}{dR_1} = 0$$

i.e. when
$$D_4 = 0{\cdot}5 \qquad \text{......(15)}$$

giving
$$dD_5 = 0{\cdot}000\,01\,dR_2 - 0{\cdot}0001\,dR'_1$$

that is, R'_1 alone can vary by 0·1 ohms or again approximately 1·5 per cent.

Changes in either R_1 or R_2 as large as 1·5 per cent are unlikely, but attention must be paid to connections and a wire-wound resistor with low wiper resistance should be used for R_1.

Since only 80 per cent of the slide-wire is used the output ratio interval is $0{\cdot}8D_5$ and the errors are also diminished by this factor.

The loading effect of the amplifier on the slide-wire is negligible since the amplifier input impedance is 4000 ohms and, at balance, the residual signal is not more than 10 μV.

3.2.5. Discrimination of slide-wire and encoder

The slide-wire has 750 turns and is assumed accurate (see 3.2.4) to 1 turn. The encoder has a range of 880 digits and is specified as being accurate to one digit. The worst case would be if the slide-wire turns had a random position variation of 1/2 turn and the encoder of 1/2 digit. In this case the combined

$$\text{accuracy} = \sqrt{\left[\left(\frac{1}{750}\right)^2 + \left(\frac{1}{880}\right)^2\right]} = 0{\cdot}175 \text{ per cent,}$$

equivalent to 0·0175 deg C.

The accuracy might be better than this depending on the spacing of the slide-wire turns and the encoder track divisions. In addition, this overall accuracy indicates the standard error from a linear characteristic, including linearity and stability, so that the stability alone should be better than 0·175 per cent.

3.2.6. Discussion

In the preceding sections a simple equivalent circuit of the transformer ratio arm has been derived and an estimate made of the likely sources of error in the ratio arm circuit. It should be noted that the assumptions made regarding the value of contact resistances do not affect to any significant extent the amount of permissible variation in them as this is dependent on the value of the main circuit resistor. This change in contact resistance appears to be the only likely source of error; with care, and the use of good quality components these should remain below 0·01 deg C.

The assumptions made in the analysis of the loading effect of the resistive divider on T_2 are not strictly accurate, but they allow the effects of the various circuit elements to be treated separately and give results, as far as the critical components are concerned, that are reasonably accurate. If the absolute ratios at the taps were to be calculated this could be done by transforming the star circuit formed by the resistive elements into the equivalent mesh.

The loading effect of T_2 on T_1 has not been considered as, with the tappings used, the maximum load is 4000 ohms shunt impedance of T_2 in parallel with the 800 ohms reflected impedance of resistor R_1, and the slide-wire, and in this case although the ratio interval is ten times greater than at T_2, there are no contact resistances in the circuit. If necessary the methods already used can be applied to T_1.

An estimate of the overall accuracy of the equipment is now possible since the individual errors of the various components have been found; these are

(a) for the dual element thermometer—less than 0·01 deg C from tests,

(b) for the ratio arm and leads—less than 0·01 deg C (see Sect. 3.2),

(c) for slide-wire and encoder—less than 0·0175 deg C (see Sect. 3.2.5),

$$\text{overall accuracy} = \sqrt{[(0{\cdot}01)^2+(0{\cdot}01)^2+(0{\cdot}0175)^2]}$$
$$= 0{\cdot}0226 \text{ deg C}$$

This figure does not include an allowance for the non-linearity of the temperature coefficient of the dual element and in addition for changing temperatures a correction may have to be made for the rate of change of temperature.

4. Calibration

The calibration was carried out with a dual element thermometer immersed in a water bath. As a reference standard two mercury-in-glass thermometers were used marked in increments of 0·02 deg C and accurate, after correction from their calibration curve, to 0·01 deg C.

After an initial run to set the scale the water bath temperature was slowly raised from 15° C to 25° C and readings of temperature, time, recorder scale and encoder output were taken. This procedure was then reversed and readings taken from 25° C to 15° C. The calibration took about one week to carry out, and some 166 readings were taken and evaluated.

The readings were corrected for rate of change of temperature where necessary. The time constant of the thermometer was found to be 48 seconds and, from the recorder output for a step change in temperature, the thermometer is equivalent to a simple lag circuit. For linearly changing temperatures (i.e., a ramp temperature function) the correction $\varepsilon = kT$ can be applied, where k is the rate of change of temperature and T is the thermometer time constant. Thus the steady rate of change of temperature should not be greater than 0·01 deg C in 48 seconds if the temperature lag is not to exceed 0·01 deg C. For

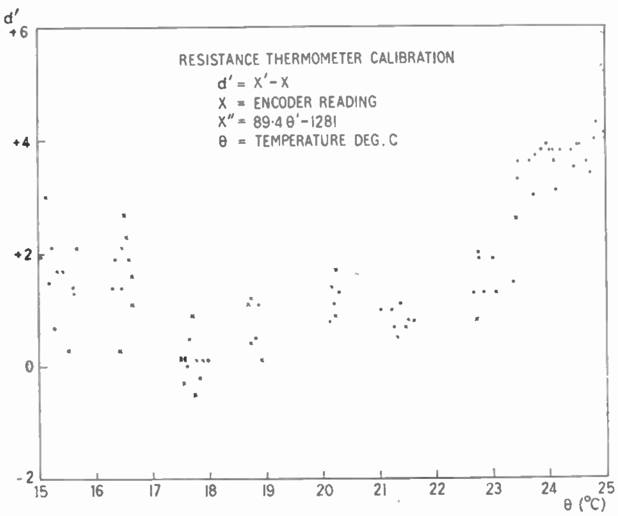

Fig. 5. Resistance thermometer calibration—deviation from linear law.

descending temperatures, the correction was difficult, as the rate of change of temperature was not monotonic with time, when the bath temperature was decreased below the room ambient temperature of 22° C. This was thought to be the cause of some extra scatter on the descending temperature scale. The calibration showed that most of the readings lie within ±2 digits, equivalent to 0·0226 deg C (Fig. 5) if a linear law is assumed and within 1 digit, equivalent to ±0·0113 deg C, with correction for a square term (Fig. 6).

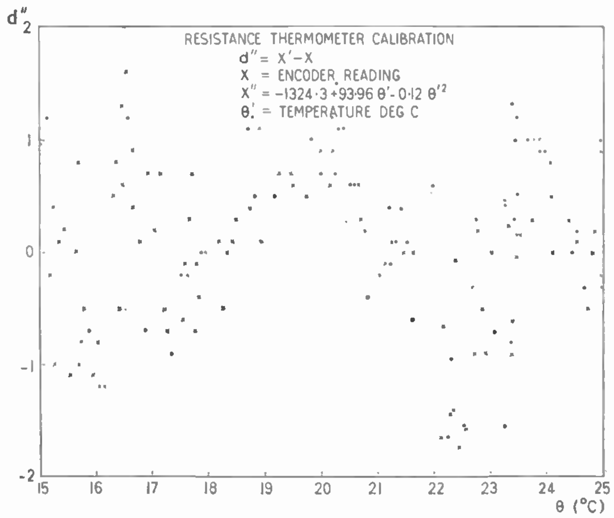

Fig. 6. Resistance thermometer calibration—deviation from linear plus square law.

This result of ±0·0113 deg C, or 0·0226 deg C, is in agreement with the estimate made in Section 3. However, this indicates that the measuring equipment is better than this since the calibrating equipment was accurate only to 0·01 deg C, in addition some of the worst points were obtained when a correction for temperature lag was difficult to obtain and some of the error must be assigned to these two factors.

By substituting range resistors, after the test, the linear temperature co-efficient of the dual element thermometer was found to be 0·003 955 per deg C.

5. Conclusion

This paper has described an application of a measuring technique that is outstanding for its accuracy and stability. The equipment is intended for use on a large flowmeter calibration line where temperature change is slow and where a robust measuring element is preferred; for other applications a different design of measuring element with a faster response might be desirable.

The accuracy of this equipment is comparable with that of the best mercury-in-glass thermometers; its other advantages are that it provides remote indication, records, has a digital read-out and can be used in environments where a mercury-in-glass thermometer would not survive. It is believed that the performance of the equipment is better, or at least as good as, that of similar resistance thermometer or thermocouple equipments and that the circuit techniques used will ensure that this performance is retained over long periods.

6. Acknowledgments

The ratio transformers were constructed to the design of Dr. T. R. Foord (University of Glasgow). The assistance of Mr. A. J. Binnie, Mr. R. Clark, Mr. J. P. Rata and Mr. J. Langlands in the construction of the equipment and in the experimental work is gratefully acknowledged.

Some of the features described are the subject of a patent application.

The work described was carried out in the National Engineering Laboratory of the Department of Scientific and Industrial Research, and this paper is published by permission of the Director.

7. References

1. H. A. M. Clark and P. B. Vanderlyn, "Double-ratio a.c. bridges with inductively-coupled ratio arms", *Proc. Instn Elect. Engrs*, 96, Part III, No. 41, pp. 189–210, 1949. (I.E.E. Paper No. 742)
2. W. H. P. Leslie, J. J. Hunter and D. Robb, "Precision temperature measurement outside the laboratory", *Research*, 13, pp. 250–6, July 1960.
3. T. R. Foord and R. C. Langlands, "Measuring toroidal transformer ratios", *Electronic Technology*, 39, pp. 59–66, February 1962.

Manuscript received by the Institution on 27th February, 1962 (Paper No. 756).

POINTS FROM THE DISCUSSION

Mr. J. R. Arrowsmith: I was interested to see that Mr. Hunter uses resistive potentiometers for the latter stages of interpolation. I would like to ask if he has had quadrature troubles due to this. When I was concerned with a similar type of transformer bridge used for displacement measurement we found it impossible to use resistive interpolation due to the quadrature effect and we eventually dropped it. I would therefore be surprised if this bridge can be used as an effective displacement transducer as Mr. Hunter suggested.

Mr. P. M. Fitch (Graduate): What would be the problems involved in adapting the system of temperature measurement described, to temperatures in the range 400–500 °C?

Mr. L. Nelson-Jones (Associate Member): Could the author tell us something of the ice point apparatus used to verify the stability of the recorder described?

Mr. J. J. Hunter (*in reply*): The two-phase servo motors employed in self-balancing slide-wire recorders have a phase-sensitive characteristic and some quadrature signal can be tolerated without causing error. The main problem is that if the residual quadrature signal is large enough it can saturate the servo-amplifier. In such a situation a quadrature balancing component, usually a capacitor, is necessary. If, however, one setting of quadrature balance is not adequate over the full working range a second feed-back circuit can be employed to reduce the quadrature signal. This need not be elaborate and at least one manufacturer in this country supplies such equipment.

The use of resistors for fine range and zero setting has not involved any quadrature compensation in our case. This might be required at higher frequencies or with a poor transformer that had a large leakage inductance component to its output impedance.

In general, large quadrature signals would not be expected with a resistive displacement transducer and with an inductive displacement transducer, where they are likely to occur, their effect can be made negligible by using a quadrature suppressor circuit.

In reply to Mr. Fitch, the only problem involved in measuring temperatures in the range 400–500° C would be that another type of wire would be required for the resistance thermometer winding as, in this case, pure Chilean copper wire with an ordinary enamel coating has been used and this is not suitable for temperatures much above 100° C.

With regard to the ice point apparatus, this was made in accordance with N.P.L. advice and consisted of an insulated metal container, full of ice, placed inside another insulated container full of ice. The inner container is then filled with distilled water which is almost at the freezing point. To check that the inner container is full of the ice-water mixture, some water is run off through a drain cock and the resultant drop in water level observed. The ice must be made from distilled water. The thermometers are immersed in the inner container, the plug and beginning of the lead being covered with ice, and an insulated cover fitted to the box. Using this apparatus it was found that the dual-element thermometers gave similar readings within a few milli-degrees over periods of weeks. It is not known whether this amount of inaccuracy was due to the thermometers or the ice-point apparatus since no more accurate method, such as the use of a triple point cell, was available. Some trouble was experienced in ensuring that uncontaminated ice was being obtained and a check was made on the conductivity of the melted ice.

Radio Engineering Overseas . . .

The following abstracts are taken from Commonwealth, European and Asian journals received by the Institution's Library. Abstracts of papers published in American journals are not included because they are available in many other publications. Members who wish to consult any of the papers quoted should apply to the Librarian, giving full bibliographical details, i.e. title, author, journal and date, of the paper required. All papers are in the language of the country of origin of the journal unless otherwise stated. Translations cannot be supplied. Information on translating services will be found in the Institution publication "Library Services and Technical Information".

ELECTRONIC MEDICAL RECORDERS

Time-variable physiological phenomena may in some cases be observed directly, either aurally or visually but it is usually more convenient to record the signals. This allows extraction of a greater quantity of information from the phenomenon under study, and reduces the time-factor considerations for the observer. In a French paper two such recorders are described for medical use. The first is to be used for measurement of physiological pressure, while the second is designed to record foetal heart rhythms.

"Electronic medical recorders", F. Juster. *Electronique medicale*, **14**, No. 13, pp. 11–16, September–October 1961.

MICROWAVE MEASURING EQUIPMENT

The development of multi-channel microwave transmission system creates the necessity for accurate measurement of the amplitude characteristics of the repeaters. A recent Japanese paper describes the development of equipment for this purpose which has an accuracy of 0·1 dB over a $\pm$ 15 Mc/s band. To obtain high accuracy, the authors utilized an automatic power control system using a barretter detector as a reference for the sweeper. Maximum loop gain of 70 dB was obtained for the a.c. components of the sweeper output. Equipments for the 4000 Mc/s and 6000 Mc/s bands have been designed.

"Microwave amplitude characteristics measuring equipment", M. Ota and I. Sugiura. *Review of the Electrical Communication Laboratory, NTT*, **3**, No. 9–10, pp. 606–11, September–October 1961.

LONG DISTANCE COLOUR TELEVISION TRANSMISSION

The colour-television transmission tests carried out during the last two years between Darmstadt, Berne and Rome have shown that in principle it is possible to transmit N.T.S.C. colour-television signals over international radio links of modern design covering distances in the order of those given for the reference circuit. This can be achieved without appreciable loss of picture quality even in the case of very complicated international networks with several points with demodulation to video frequencies. The international link used for this purpose has not been prepared specifically for these colour-television transmission tests. The operational conditions were similar to those for ordinary Eurovision transmissions.

"Colour-television transmission tests on an international long-distance television link between Darmstadt, Berne and Rome", K. Bernath, F. Cappuccini, and J. Müller. *Nachrichtentechnische Zeitschrift*, **15**, No. 4, pp. 161–6, April 1962.

MODULATION OF A VOLTAGE REGULATOR

In principle, an electrical voltage regulator has the form of a servo system and possesses the three basic elements of such a system, namely the output element, the control element and the reference element. The fact that in this case these three elements may be of the same nature and that each of them may be a voltage makes it possible to consider a voltage regulator either as a servo system or as a negative feedback amplifier which is required only to reduce the defects of its own power supply. After having examined this double point of view, two French engineers go on to deduce the possibility of using a voltage regulating device as a true amplifier providing a regulated and modulated voltage. There follows a description of an original application in which the carcinotron tube is associated in a very simple circuit with a power supply which simultaneously performs several functions. The entire equipment forms a generator or a transmitter capable of providing by electronic control all the functions usually required from a stable f.m. oscillator.

"Modulation of a voltage regulator and its application to the carcinotron tube", V. Biggi and A. Courty. *Onde Electrique*, **42**, pp. 37–47, January 1962.

ANALOGUE COMPUTER FOR COLOUR SOURCES

Determining the "colour point" of a light source calls for a series of simple but laborious computations. The computer described in a Dutch paper performs this work rapidly and automatically; the C.I.E. distribution coefficients, which define the spectral sensitivity of the eye of a "standard observer", are built into the machine. The colour point of the source is determined from the relative spectral energy distribution $S(\lambda)$, measured at a series of wavelengths rising in steps of 10 nm. These values are multiplied by corresponding C.I.E. distribution coefficients $\bar{x}(\lambda)$, $\bar{y}(\lambda)$ and $\bar{z}(\lambda)$. The products $S(\lambda)\bar{x}(\lambda)$, $S(\lambda)\bar{y}(\lambda)$ and $S(\lambda)\bar{z}(\lambda)$ are all added to find the values of X, Y and Z which define the chromaticity of the light. For every wavelength at which $S(\lambda)$ is measured the computer contains three resistors whose values are proportional to $1/\bar{x}(\lambda)$, $1/\bar{y}(\lambda)$ and $1/\bar{z}(\lambda)$. A voltage proportional to the measured value of $S(\lambda)$ is applied to these resistors. The currents then flowing through them are proportional to the products mentioned, and are added in the computer. Other operations which can be carried out with the aid of the computer include normalizing of a relative spectral energy distribution.

"A simple analogue computer for determining the colour point of a light source", B. van der Waal. *Philips Technical Review*, **23**, No. 4, pp. 118–21, 1961–62. (In English.)