The Journal of

THE BRITISH INSTITUTION OF RADIO ENGINEERS

FOUNDED 1925 INCORPORATED 1932

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

VOLUME 20 SEPTEMBER 1960 NUMBER 9

THE YEAR AHEAD

THE autumn season provides new opportunity for fresh thought and interests. Particularly does this apply to members of the Institution who have renewed opportunity for meeting each other through the medium of local section activities.

In Great Britain alone the Institution programme for the 1960-61 session already provides for over one hundred meetings. Over thirty of these meetings will be held in London, and at least sixty-five in the local Sections in the United Kingdom. Particular interest has already been shown in the two-day symposium on "New Components" to be held in London in October and which will comprise some twenty papers. In February 1961 a meeting on the "Tunnel Diode" is being arranged jointly with the Institute of Physics, and in March another symposium will be held in London on "Instrumentation for Nuclear Power Stations." The South Western Section is also sponsoring a one-and-a-half day Convention on "Aviation Electronics and its Industrial Applications," to be held in Bristol on 7th-8th October.

Details of these and other meetings are being circulated in the programme booklet covering the first half of the new session. Additional meetings are also being organized by the Committees of the specialized Groups of the Institution. Thus, the year ahead promises to be one of great activity for the Brit.I.R.E.

The Commonwealth Sections have also been most active. During the summer, representatives of the Sections in Canada, India, New Zealand, Pakistan and South Africa have visited Great Britain and discussed with officers of the Institution plans for meetings in their particular Sections during the forthcoming months.

Additional to these programmes will be the arrangements for the 1961 International Convention on "Communications and Space Research" to be held in Oxford in July. This summer meeting is sure to attract an attendance of members from all over the world and especially from the Commonwealth.

Thus, the new session shortly to commence should provide once again an opportunity for every member to benefit from the work which has been done by the standing and local Committees in the past months. The pattern of papers, symposiums, and Conventions will indicate the ever widening scope of the professional interests of members and provide yet further opportunity for extending those interests and for association with engineers in similar fields. Indeed, the scope of professional interests shown in the forthcoming programme presents an interesting comparison with the activities planned by the founders of the Institution in the autumn of 1926.

It cannot be expected that all members will attend every meeting in their immediate vicinity, nor is it possible for more than a cross-section of members to attend the national symposiums or the international Convention. It is certain, however, that the programme for the coming session will afford a few meetings of particular personal interest to each member. To provide such opportunity for the discussion of research and development is the duty of the Institution: its reward lies in the attendance and support which is given to these functions, especially by the members.

G. D. C.

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INSTITUTION NOTICES

The Institution's Petition for a Charter

The following Notice from the Privy Council Office appeared in *The London Gazette* for 5th August, 1960:

Notice is hereby given that a Petition of the Earl Mountbatten of Burma and others, praying for the grant of a Charter of Incorporation to the British Institution of Radio Engineers, has been presented to Her Majesty in Council; and, Her Majesty having referred the said Petition to a Committee of the Lords of the Council, Notice is further given that all Petitions for or against such grant should be delivered at the Privy Council Office, on or before the 5th day of September next.

Membership Records

Although only used for confidential and internal information, it would be appreciated if members would advise the Institution of a change in employment. Only brief information is required, such as the name of the company or organization, and the type of appointment.

Changes of address, unless of a temporary nature, should be notified to the Institution without delay to avoid the *Journal* and other correspondence going astray.

Examiners Required

The Radio Trades Examination Board regularly requires local examiners and invigilators for the Radio and Television Servicing Practical Tests. The examiners and assistant examiners are responsible to the Examinations Committee of the Board for running the examination at a particular centre, faulting the receivers in accordance with instructions, and assessing the candidates' work.

The examinations are normally held on a Saturday afternoon and preparation for the examination can be arranged in the evenings. An honorarium and expenses are paid.

Any member of the Institution who is interested in helping in this work is invited to submit his name, and an indication of the area within which he would be prepared to assist, to the Secretary of the R.T.E.B. at 9 Bedford Square, London, W.C.1.

Institution Premiums and Awards

The Council of the Institution announces that the following awards are to be made for outstanding papers published in the *Journal* during 1959:

THE ASSOCIATED REDIFFUSION PREMIUM:
To be awarded jointly to the authors of the following papers: "A Gating Circuit for Single-gun Colour Television Tubes" by K. G. Freeman, B.Sc. (Graduate) (*published in November 1959*); and "The Testing and Operation of 4½ inch Image Orthicon Tubes" by D. C. Brothers, B.Sc.(Eng.) (*December*).

THE HEINRICH HERTZ PREMIUM:
"Transistors in Video Equipment" by P. B. Helsdon (Associate Member). (*December.*)

A. F. BULGIN PREMIUM:
"A Rocket Borne Magnetometer" by K. Burrows, M.Sc. (Associate Member). (*December.*)

THE BRABAZON PREMIUM:
"A Low-drain Distress Beacon for a Crash Position Indicator" by D. M. Makow, Dipl.Ing., H. R. Smyth, M.B.E., S. K. Keays and R. R. Real, M.Eng. (*March.*)

LESLIE MCMICHAEL PREMIUM:
"A 6-channel High Frequency Telemetry System" by T. C. R. S. Fowler, B.Sc. (*August.*)

THE CHARLES BABBAGE AWARD:
To be awarded jointly to the authors of the following papers: "Switching Circuits using Bi-directional Non-linear Impedances" by T. B. Tomlinson, Ph.D. (Associate Member) (*September*); and "Ferro-electrics and Computer Storage" by M. Prutton, Ph.D. (*February.*)

THE MARCONI AWARD:
"A Vidicon Camera for Industrial Colour Television" by I. J. P. James, B.Sc. (*March.*)

These Premiums and Awards will be presented by the President at the Annual General Meeting in London.

Correction

In the paper "A Simple Analogue to Digital Converter with Non-Linearity Compensation," published in the July issue of the *Journal*, the following corrections should be made:

Page 521, Fig. 5—The base and collector connections of the transistors VT1 to VT9 inclusive should be interchanged.

The Education and Training of the Professional Radio and Electronic Engineer †

A report prepared for Council by the Education Committee

Summary: The report considers the size of the radio and electronics industry and the wide application of radio and electronic engineering in scientific research and in all branches of industry, commerce and the defence services. It is concluded that radio and electronic engineering needs a special and distinctive training at all levels—in universities, colleges of advanced technology and technical colleges. There should, however, be flexibility in curricula and in practical training schemes. The report reviews present academic and practical training facilities and makes recommendations for their development.

An appendix analyses the radio and electronics content of courses available in universities and colleges. It has been thought worthwhile to add a further appendix dealing with the training of the electronic technician.

Contents

1. Introduction

The supply of trained engineers now and in the future continues to be a matter of great concern in all industrial countries. This applies particularly to engineers trained in the fields of radio and electronics. As recently as last year the Committee on Scientific Manpower[1] of the Advisory Council on Scientific Policy, in referring to the estimated demand by industry for scientists and engineers during the next three years, quoted electronics as the industry in which employers expect the greatest increase (47 per cent.).

This means a large increase in numbers, since out of a total of some 300,000 people employed by the radio and electronics industry, well over 6,000 are qualified scientists and engineers. It is difficult to quote exact figures showing the size of the industry, since surveys of the Ministry of Labour have only recently included

† Approved for publication by the Council on 13th February, 1960. (Report No. 20.)
U.D.C. No. 378:621.37/9

radio and electronics as a separate classification. Previously these were included under the general heading of Electrical Engineering thus obscuring the size and importance of the industry.

The industry is represented jointly by the Radio Industry Council and the Electronic Engineering Association, and has stated that the total number of employees, including engineers, is 300,000. The annual value of production of the principal companies connected with the Radio Industry Council and Electronic Engineering Association is £470,000,000, of which not less than £60,000,000 of equipment is exported.

These figures do not include the Government, public corporations and the defence Services. It may be concluded that the total employment exceeds 500,000, and the employment of professional engineers and scientists is probably in excess of 10,000.

However, this is only part of the whole field of radio and electronics. A feature of its development over the past twenty years has been the penetration of electronics into most branches of science and technology, industry and commerce, and its wide use in the Services. Many non-electrical industries employ an electronic development group. This employment of electronic engineers to advise on the wider application of electronics illustrates the diversification as well as intense development of the associated engineering science.

2. The Problem

In many respects the problem of education and training is as great as that which existed at the end of the second world war. In 1944 the Institution's Post-War Report[2] advocated a new approach to the training of radio and electronic engineers, and many of its recommendations have now become common practice. But the continued expansion of industry and the demands of Government departments and the Services, together with the widespread adoption of electronics in other fields of manufacturing activity, raise further problems on the scope of both academic and practical training, not only for the engineer but also for supporting staff, i.e., the technician, craftsman and operative.

The field of radio and electronics unquestionably requires specialized training. On the other hand, in order to ensure the proper use of electronics in industry generally, there must be flexible training to cover the wide variety of applications. It is therefore most important to ensure that the study of the fundamental theory of radio and electronics is properly established. There is much to be said for a common *basic* training for all engineers whatever their eventual employment, but after this a different emphasis is required according to the particular branch of technology concerned. The emphasis must not be deferred until the last stages of training.

The Council of the Institution has promoted this report as a contribution toward securing the quantity and quality of engineers required for the further development of the profession and industry.

3. Definitions

In recent years there has been much confusion of thought on the definition of an engineer and the differentiation between the engineer and other technical staff. The White Paper on Technical Education[3] defined the technologist, technician and craftsman and the Crowther Report[4] expanded these definitions and added one of the operative (these definitions are given in Appendix 1). Throughout this report the radio and electronic engineer is considered to be a typical technologist. Following these proposals the Institution has adopted this definition of the radio and electronic engineer:—

> "The professional radio and electronic engineer is competent by virtue of his education and training to apply scientific method to the analysis and solution of technological problems in his own field. He is capable of following progress in radio and electronic engineering by consulting and assimilating newly published information and by applying it independently. He should thus be able to make contributions on his own account to the advancement of technology. His work involves personal responsibility based on the exercise of original thought and trained judgment; he may be responsible for the supervision of technical and administrative work of others in the field of research, development, design and production or in the

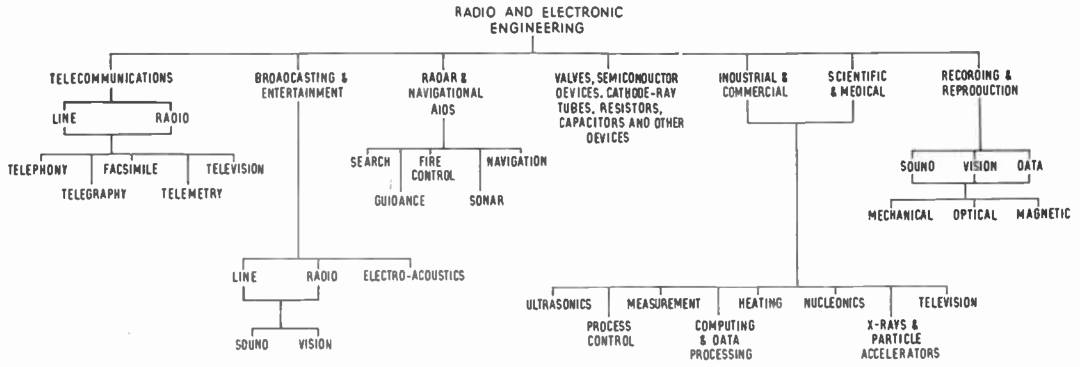

Fig. 1. The scope of radio and electronic engineering.

control of technicians engaged in the maintenance and operation of technical equipment."

It is not an easy task to define the field of radio and electronics in which this engineer will be employed, but the following has been used for the purpose of this report:—

> The development and application of devices which exploit the properties of electrons and other charged particles in communication, control, measurement, computing and related fields.

The scope of radio and electronic engineering is illustrated in Fig. 1.

4. The Graduateship Examination of the Institution

The Institution has based its examination on the need for a specialist approach to radio and electronics since it first set examinations in this subject in 1929. As radio and electronic engineering has increased in importance, the Graduateship Examination has attracted larger numbers of candidates—17 in 1939 and 778 in 1959†. This growth indicates the demand for such a distinctive approach.

The recommendations of the Institution, as laid out in its Post-War Report, are considered to have had a marked effect on other courses of training as they were expanded after the war. The influence of the Institution is shown, for example, by the change in the emphasis of the Higher National Certificate and endorsement subjects, many of which have been designed specifically to meet the Institution's requirements.

† In 1956 the Examination attracted a record number of 1,340 entries.

The present Graduateship Examination syllabus is shown in Table 1.

Table 1

SECTION A.

	Subject	*Approximate London University equivalent*
1.	Physics I and II	G.C.E. "A" level.
2.	Principles of Radio and Electronics	B.Sc.(Eng.) Part II.
3(i)	Mathematics I	Slightly above G.C.E. "A" level.

SECTION B.

3(ii)	Mathematics II	B.Sc.(Eng.) Part II.
4.	Advanced Radio and Electronic Engineering	B.Sc.(Eng.) Part III.
5.	Specialist subject chosen from one of the following:	

Audio Frequency Engineering Applied Electronics Electronic Measurements Radar Engineering and Microwave Techniques Radio Reception Radio Transmission Television Valve Technology and Manufacture	Applied techniques which are dealt with in these specialist subjects do not normally appear in university curricula but the level of treatment corresponds to Part III B.Sc. (Eng.).

Improvements which will inevitably be demanded in the examination's structure arise partly from the widening scope of radio and electronic science engineering and partly from the need for a more thorough grounding in pure science. The future structure of the Graduateship Examination is given in Appendix 3.

5. External Training Facilities

Apart from its own Graduateship Examination the Institution is naturally much concerned with other courses of training, particularly those which purport to prepare students for the radio and electronics profession. These courses are not always suited to the requirements of the profession and industry and are open to improvement in this respect.

Courses of training for the professional radio and electronic engineer are currently provided in universities, colleges of advanced technology, technical colleges and by the Services (see Appendix 2). Each type of course is designed to provide the form of training best suited to the qualifications and background of the students concerned.

5.1. *University First Degrees*

5.1.1. Electrical engineering degree

The majority of university graduates entering the field of radio and electronics have an engineering degree with appropriate specialization. The radio and electronics content of university degrees is, however, extremely variable. In some cases over 80 per cent. of the time in the final year is devoted to radio and electronic subjects; in others it is as little as 20 per cent.

There as always been resistance on the part of university authorities to the introduction of what is regarded as unnecessary specialization, or the teaching of specialized technologies. Universities regard their function as the inculcation of a fundamental approach and the provision of an analytical discipline. A degree course designed specifically for radio and electronic engineering can, however, satisfy this requirement. Certainly no more specialization need be involved than in other engineering courses.

A large majority of students in university departments of electrical engineering decide to specialize in radio and electronics and choose appropriate subjects where suitable options are provided. The Institution supports the idea of integrated engineering education in the early years, and accepts the fact that radio and electronics must often be taught in electrical engineering departments—although it naturally welcomes the establishment of chairs in electronic engineering. Yet it must emphasize the desirability of courses being related to the needs of radio and electronic engineering science instead of the practice of allowing radio and electronics to be treated as an appendage to technological courses in heavy electrical engineering.

In universities where no electrical engineering department exists, and in new universities, it would be logical to develop courses in electronic engineering (or applied electronics) from within physics departments.

When and if honours degree schemes in radio and electronics grow out of such courses, it would be more appropriate for the supporting subsidiary subjects of study to be physics and mathematics rather than related technologies.

5.1.2. Physics degree

Electronics can be equally associated with physics as with electrical engineering, and some, if not most, physics degree courses include electronics as part of the curriculum. The physicist, after suitable practical training and experience, is often employed as an electronic design engineer, and industry will continue to recruit a large number of its technologists from this field. This is shown by the report on Scientific and Engineering Manpower in Great Britain, 1959[1], which states that out of 4,541 qualified staff employed in the electronics industry considered in the report, 1,079 are physicists.

Equally important is the fact that in industries where no electronic engineers are employed, the physicist is often the first to understand and advocate the potentialities and applications of electronics.

The Institution considers it desirable that all scientists and engineers are taught basic electronics. This will remove the "black box" complex which is so common among engineers not trained in electronics. It will also enable these technologists to play their part in the introduction of electronic methods of measurement and control.

5.2. *The Diploma in Technology*

As far as the profession of radio and electronic engineering is concerned, two types of Diploma in Technology will be of interest; the Applied Physics and the Electrical Engineering Diplomas. Since the Diploma in Technology is intended to cater for the new technologies and industrial requirements, the Institution hopes to see the development and introduction of a Diploma in Technology in Electronic Engineering. Such a course would embody the Institution's main recommendations for university degrees—a common first year for all branches of engineering after which subjects with the appropriate emphasis and treatment are introduced.

There is a wide variety of courses outside the universities which include radio and electronic subjects. In examining these courses in relation to its own entrance requirements, the Institution has found it essential to investigate the syllabus content in some detail, to ensure that radio and electronics are adequately treated.

The integrated practical and academic training which is inherent in a Diploma in Technology course, on account of the usual sandwich form, is to be commended, as is the direction of practical training by the colleges whilst the student is serving in industry. The Institution hopes that there will be a rapid extension of these courses, although it appreciates that the difficulty at the moment is finding more widespread industrial support to extend the courses at the pace required. The majority of Diploma in Technology courses in this field are "works based," i.e., the students are recruited and paid by industry. In spite of magnificent work by some of the larger organizations, it would appear that the greater part of industry is not making its full contribution. Co-operative schemes whereby small firms combine to provide suitable training may provide a partial solution.

However, the Crowther Report[4] suggested that industrial support for these courses is reaching its maximum. To extend them at anything like the pace required for the development of industry, it will be necessary to ensure that more college-based courses are available. "College-based" courses are those where the students are recruited by the college. The students receive a local education authority grant whilst attending full-time at college but not during the industrial training period. To make college-based courses attractive, grants should also be made available for the industrial training period.

Provided that places for practical training are available in industry, the Institution favours college-based courses as a means of ensuring a rapid extension of the number of students under training.

5.3. *Associateships and Diplomas of Technical Colleges*

The standards of these qualifications vary a great deal and it is necessary to investigate each case on its merits to ensure that it is a suitable exempting qualification for the Institution's examination. Recently many college associateships have been offered which are intended as forerunners for Diplomas in Technology. The Institution hopes that it will not be long before such courses will be embraced in the Dip. Tech. scheme to avoid a multiplicity of qualifications.

5.4. *Higher National Diplomas*

The Higher National Diploma is generally arranged as a three-year "sandwich" course with an optional fourth year for the award of a College Diploma. The entrance level is a good O.N.C. or G.C.E. Advanced Level in two appropriate subjects (or one advanced level pass and an equivalent course of study).

The final standard of achievement makes the Higher National Diploma an acceptable qualification for the professional radio and electronic engineer, provided the radio and electronics content is adequate. Here again the problem is one of adjusting the syllabus to suit the needs of the profession rather than of treating radio and electronics as additional subjects subsidiary to heavy electrical engineering.

5.5. *Higher National Certificate with Professional Endorsements*

The Crowther Report has confirmed that one of the most widely used ways of qualifying for membership of professional Institutions is the Higher National Certificate with credits and endorsements. It is also the ladder up which the technician climbs, even though he may not reach the highest level and become a technologist or professional engineer.

The Higher National Certificate scheme involves a five-year part-time course, either part-time day (one whole day and one evening) or three evenings per week. The length of the course to secure professional qualification—often six years, and in many cases a great deal longer—is a serious disadvantage. Nevertheless the Institution would not wish this avenue to be closed.

Experience has shown that the type of student most likely to reach professional level via the Higher National Certificate is able to secure exemption from the first year (S.1) by virtue of appropriate G.C.E., "O" level passes. This type of student is becoming rare since the trend is for such a candidate to stay at school to obtain Advanced level passes. As a result the number of engineers recruited by this path is likely to decrease.

Until alternative courses (e.g. Dip. Tech., H.N.D.) are universally adopted, every effort should be made to ensure that adequate release is available for students to study for the Higher National Certificate and, if capable, to proceed to the professional endorsement level.

Whilst for many years the Higher National Certificate will continue to occupy an important place in the part-time training structure, it is hoped that during the next ten years there will be an increase in the number of sandwich courses and block release courses†. Much more than government exhortation may be necessary for this to happen. Industrial support for training schemes has been considerable, but still occupies a low place in the order of priorities in the smaller manufacturing organizations, and is one of the first items to suffer in the event of any recession. Training must be regarded by industry as an essential service.

6. Post-Graduate Education and Training

6.1. *Academic Post-Graduate Courses in Universities and Colleges of Technology.*

Courses for a higher degree or diploma in the field of radio and electronic engineering are naturally more specialized and in general they provide further training for the scientist or engineer who is already academically qualified for professional work. These post-graduate courses also have another purpose in the reorientation of technologists. Persons accepted for post-graduate courses in radio and electronics may, or may not, already be qualified in the radio and electronic engineering field. Particularly useful engineers can be produced by fundamental training in physics or the mechanical engineering field, for example, with subsequent post-graduate training in a radio and electronics subject.

The future requirements of the Institution in terms of the Higher National Certificate are given in Appendix 4.

6.2. *Post-Graduate Training in Research*

If the United Kingdom is to maintain and improve its position as a leading nation in radio and electronics more effort will have to be devoted to fundamental research. For this purpose many more university graduates will be required with some university research experience. Training in research provides character training, through the development of resourcefulness and initiative. It is an important feature of this training that the student is left to develop ideas and methods with the minimum of guidance from the tutor.

There are two higher degrees which may be awarded as the result of research training and the submission of a thesis: M.Sc. and Ph.D. These two higher degree schemes continue to be of very great importance, especially since British universities have now agreed that the Diploma in Technology is an additional route to these degrees. It is possible that the best way to expand post-graduate research training is to encourage more students to aim at an M.Sc. degree even though they may not proceed to the level of a Ph.D.

In both forms of post-graduate training—academic courses and training in research, it is not essential for the training to follow immediately after graduation. In fact industrial experience often equips a person to make better use of this training. To encourage graduates to return for post-graduate training the D.S.I.R. is prepared to increase the value of its studentships by up to £200 a year[7].

† Block release: A system whereby the equivalent number of days of study under day release are taken together. This results in several weeks full-time study followed by an unbroken period four times as long in industry.

6.3. *Membership of the College of Technologists (M.C.T.).*

The proposals by the National Council for Technological Awards on the award of a qualification beyond the level of the Diploma in Technology have only recently been published.[5]

Until the standard of the research work involved and the type of work accepted is more clearly evident the Institution does not feel able to comment on its eventual place in the field of post-graduate training. The additional co-operation between industry and colleges which can be expected to ensue from these proposals is welcome.

It appears from the information published so far that a candidate for M.C.T. cannot generally be accepted if he is "college based." It is felt that there is a case for reconsidering this decision.

7. Research and Teaching

As far as the universities and colleges are concerned, healthy research schools are of prime importance if teaching is to be of a high level. for by this means the best scientists and technologists are attracted into these institutions. The attitude that research is an activity to be pursued only if there is time, is now giving way to the realization that teachers have not only to transmit knowledge but to create new knowledge as well. Teaching is more likely to be effective when done by those who are also engaged on research, and first-hand experience of a particular field gives authority to a lecture which might otherwise be lacking. In this way the teaching syllabus is always being enriched and unnecessary older material being discarded for more pertinent new topics. The latest report of the University Grants Committee supports this view.[6]

The Institution would like to see more research coupled with teaching carried out in both universities and colleges, since this is the best way of getting the increased numbers of good teachers which will be needed in the future.

8. Training in the Armed Forces

All three Services have a lengthy experience of training both officers and tradesmen in electronics and electrical engineering, often in very large numbers.

At the professional level the Services send officers to the universities to study for first degrees in engineering. This may include electrical and electronic engineering when such specializations are provided for at the particular university. Both the Royal Navy and the Army have set up their own internal schemes for training to the standard of the London University (External) B.Sc., in Engineering, whereas the Royal Air Force has directed its training scheme for technical cadets so that they sit for the Higher National Diploma.

As part of their training, selected officers in all three Services are given post-graduate training in electronics or related fields. This may be arranged by nominating officers to attend appropriate courses at the universities or colleges. Various courses of post-graduate status are run directly by the Services, and are normally directed to technologies of peculiar interest to the armed forces, such as guided weapons.

All three Services conduct many specialist courses for their officers in signals, radar, guided weapons, etc., at levels appropriate to the technologist and the higher-grade technician.

The bulk of the *technician* training, however, is provided for those not holding commissioned status. An important contribution is made by youth training schemes which correspond to industrial apprenticeships and are for three years or more. These have been developed over some forty years in the Royal Navy, the Army and the Royal Air Force and provide for various forms of specialization in electronics. Adults are also trained to approximately the same level of competence in electronics in a period of about a year, although usually with less attention to a broad training in mathematics and science than in the youth schemes. The latter achieve various measures of external recognition, such as Ordinary National Certificate. The City and Guilds of London Institute's Technician Certificates are likely to provide a useful yardstick for such training courses. Supervisory grades in all three Services receive additional training of about a year's duration to fit them for more difficult technical tasks or increased responsibilities in the control of junior tradesmen.

9. Practical Training

The Institution has never insisted upon nor proposed a *formal* practical training scheme as an essential requirement for membership although, of course, appropriate practical experience and responsibility is essential. This policy is based on the belief that the type of excessively repetitive mechanical work which the formal course sometimes entails is certainly not appropriate for the professional radio and electronic engineer, although some manual skill is valuable. The Institution has instead recognized the need for flexible training, both practical and academic, to cover the wide variety of applications. This view is true both at the student and post-graduate level, and the Institution recommends that there should be a proper organization of apprenticeship schemes to ensure that the time spent under training is reduced to the minimum required for the trainee to obtain the experience and skills appropriate to his field of employment.

An important requirement is for a careful correlation between academic training and its practical application, as for example the place of academic theory in the design of commercial products. Post-graduate apprentices should have contact with engineers at a high level rather than be left to do the best they can by watching more junior employees at work.

Many firms and public organizations appreciate this and have developed well-organized practical training schemes, but unfortunately they are in a minority.

In the case of the full-time student, vacation training is particularly valuable to provide the first contact with industry. Overseas training is also arranged by a student exchange scheme and should be developed.

9.1. *The Post-Graduate Apprenticeship.*

There is no doubt of the need for practical experience under the supervision of a competent engineer, but there are no rigid rules which one can apply to the training of a university graduate. Most graduates will have had some basic mechanical training in the form of a vacation training scheme and so the emphasis must be on the transition from full-time education to full-time employment.

There is a definite need for formal training schemes in large organizations primarily concerned with radio and electronics. The two-year post-graduate apprenticeship has been used generally in the engineering industry for many years, and will probably continue, although there is a feeling that it ought to be considered very carefully to determine whether the time is being spent economically and whether each individual item of training really requires the time that has been allotted to it. Certainly in this vital industry the post-graduate apprentices must not become bored, as they often do. It is acknowledged that some organizations do a good job and spare no effort to ensure a well-organized and effective training but the standard varies.

One solution which is becoming increasingly popular is the division of the practical training into two sessions of one year—one before and one after university training. This is only practicable if facilities exist to maintain the student's academic interest.

As a means of relating the academic and practical work more closely, some companies and organizations have set up their own colleges attached to their works, and this aids the transition from full-time education to full-time employment and from the college laboratory to the development laboratory. Technical colleges and colleges of technology provide corresponding facilities for many of the smaller companies.

Many graduates entering the electronics field, however, will not enter firms with a formal training scheme of this type. The use of electronics in all industries makes it unlikely that there will be a training scheme specifically for electronic engineers. Ideally in such a situation the young graduate should be under the control of the senior engineer, who will guide his work to ensure that he gets the maximum possible opportunity to appreciate the processes employed in his organization and, in particular, the application of electronics to those processes.

In some cases there will be no need for such extensive practical training and the university graduate, especially one who has spent some time on post-graduate research, can be employed directly in research in industry or Government service although a variety of experience in early years is essential. The engineer's practical training must always be related to his subsequent employment and to his academic qualifications.

Opportunities exist, but more will have to be developed, for graduate engineers to secure part of their training or early experience overseas. It is considered that some national advantage may well result from an international exchange of young engineers, who will have an opportunity to widen their experience.

9.2. *Practical Sandwich Training*

The same principles for practical training must apply in sandwich training as in post-graduate training. The practical training must not be regarded as a necessary evil, and it must be arranged so as to cause the minimum inconvenience to the student. It should also be linked positively to his academic training, and should keep him interested and alert and never allow him to stagnate. Consultation by the employer and employee with the college tutor will assist in ensuring that the student obtains the maximum benefit from the practical training. Every task which he is trained to do must have a particular function and logical conclusion.

9.3. *The Five-Year Apprenticeship with Part-Time Day Release*

Linked as it is with a long part-time academic course this method of training cannot be regarded as entirely satisfactory for the professional engineer. However, the practice will inevitably continue to produce engineers emerging from the main stream of technicians who will be trained by this method for many years to come. Thus the professional engineers will receive into their ranks people so trained who eventually reach the academic standards laid down.

This method of training, which is primarily intended for high grade technicians, must be carefully planned to make the best use of the available time. Those apprentices who show potentialities for a professional engineer's qualifications will often transfer to a Diploma in Technology or Higher National Diploma course, but some will remain whose interest must be maintained and progress encouraged. The recommendation of the Crowther report advocating a more rapid introduction of block release and the extension of sandwich training will, if accepted, do much to lessen the difficulties inherent in the part-time method.

10. Industrial Administration

In the Institution's Post-War Report published in October, 1944, a section was devoted to the importance of staff relationships and administration, and the final words of that report were "it is imperative that any training directed towards the preparation of personnel to undertake positions entailing disciplinary or technical control of others should include an approach to industrial administration." That this has not been done to an adequate extent is due to the fact that many professional and educational bodies have not included this subject in their examinations. One noticeable shortage in the engineering industry is the scarcity of good engineering managers. The disadvantages of the employment of managers without engineering training in this technical field have been exposed on many occasions, and as time proceeds there is no doubt it is desirable that more engineers should fill the top management positions. The Institution therefore considers that encouragement should be given to the inclusion of a study of industrial administration as part of the technologist's training.

Apart from all its other advantages, a suitable study of industrial administration might well provide part of a broader education.

11. Liberal Studies and Broader Education

There can be no doubt that the study of cultural subjects is an important part of the education of the professional engineer. The influence of the Institution will always be used to encourage rather than deter the introduction of cultural subjects into curricula as far as practicable.

The Institution will continue to study the development and effects of the broadening education in universities, colleges of advanced technology, and technical colleges.

12. Conclusions

The radio and electronics industry is a very large and important industry. Its evolution is thought to have been impeded by the failure of many universities and colleges to develop courses of study which are separate and distinctive and designed to cater for the special needs of this profession.

Many of the courses at present claiming to cater for the special needs of the radio and electronics industry are far from ideal.

The majority of students taking professional or sub-professional courses in electrical engineering at universities and technical colleges elect to take radio and electronics subjects where a choice is offered.

The shortage of professional engineers and scientists is particularly acute in the radio and electronics field. This will continue to be a problem until adequate and proper training courses are provided.

Despite the support given to training by most of the larger firms in the industry, the total contribution is insufficient to satisfy the demands of industry as a whole.

The shortage of qualified personnel is made more acute by the growing employment of radio and electronic engineers by organizations not primarily concerned with radio and electronics. In addition these non-electronic firms do not contribute to any significant extent to the pool of trained electronic engineers.

Formal training schemes in industry have not always been developed so as to use the time available to the maximum advantage.

13. Recommendations

(i) There should be a considerable expansion of education facilities for radio and electronic engineers, particularly in full-time and sandwich courses. (Section 5.)

(ii) There must be an increased emphasis on radio and electronics in electrical engineering and physics courses and there must be more new courses specifically designed for the radio and electronics profession. (Section 5.)

(iii) The Institution should continue to regard the Higher National Certificate with credits and suitable professional endorsements and appropriate radio and electronics content as a means to professional qualification. (Section 5.5.)

(iv) Practical experience under a qualified engineer is an essential part of the professional engineer's training but formally organized practical training is not the only means of achieving this. (Section 9.)

(v) As far as practicable the training provided by the Services should be related to civilian courses and qualifications. (Section 8.)

(vi) Post-graduate courses in universities and technical colleges should be extended and industry should be encouraged to recognize the additional value of this training. (Section 6 (1).)

(vii) Post-graduate research training in universities or colleges may be particularly valuable for any person who is to occupy an important place in industry. (Section 6(2).)

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16. Appendix 1:

The Training of Technicians and Craftsmen

As a professional Institution of engineers, the Institution and its members must be intimately concerned with the training of supporting staff. These may be classified broadly as technician, craftsmen and operatives. The definitions of these grades have been given in the Crowther Report[4] as follows:

> The *Technician* is one who is qualified by specialist technical education and practical training to apply in a responsible manner proven techniques which are commonly understood by those who are expert in a branch of engineering, or new techniques prescribed by a professional technologist. His work involves the supervision of skilled craftsmen, and his education and training must be such that he can understand the reasons for and the purpose of the operations for which he is responsible. The job may involved:
>
> the design of plant and equipment under the direction of a technologist;
>
> supervising the erection and construction and maintenance of plant;
>
> testing and surveying;
>
> inspection, etc.
>
> A *Craftsman* is a man equipped with the necessary skill to make components under the supervision of a technician or technologist using established techniques; or to follow established practice in erecting, maintaining or servicing engineering machinery. He must be capable of understanding technical descriptions and following an engineering drawing.
>
> The *Operative* is a man who after a period of training which may vary from a few weeks full-time or part-time up to two or three years part-time, is capable of carrying out specific operations involving the use of machinery and plant which do not call for traditional craft skills. As the latter become more highly developed and specialized, there is a greater need for a generalized basic training which will enable the operative to become quickly familiar with changing methods and techniques.

The grading of posts in industry and the vague use of the term technician, have to some extent been responsible for the uncertainty of the type of person required for a particular job. In professional engineering there has been an attempt to define an engineer by his education and training, and yet there are engineers without such qualifications must be included on account of their ability and position. This applies equally to the technician, whose proven ability as well as training must be considered.

It is, however, important that greater attention is paid to the academic training of technicians and the introduction of courses specifically designed to meet this need has been a valuable development in technical education. Despite the attempts to define it the term technician still covers a wide category of workers. The highest grade technician will take the National Certificate course and he may eventually qualify as a professional engineer. If he progresses to the Higher National Certificate his course of study will not normally include endorsement subjects or mathematics at the A2 level: these omissions will have to be rectified if he is to qualify as a professional engineer.

The lower grades will take the City and Guilds of London Institute examinations for Telecommunications Technicians and Electrical Technicians, in each case selecting appropriate optional subjects.

The common first year for both the National Certificate and Technicians courses provides an opportunity for selection which it is hoped will eventually lead to better results in the National Certificate Examinations.

Radio and electronic engineering has long presented particularly onerous demands in quality and quantity for technicians and craftsmen for employment on testing and servicing work. Courses specifically designed to meet these requirements have been initiated by the Radio Trades Examination Board† and lead to the award of the Radio and Television Servicing Certificate. More recently the growing need for technicians skilled in the installation and maintenance of electronic devices used by industry has been catered for by the same body, the relevant course leading to the award of the Electronic Servicing Certificate.

Practical Training for Technicians.—It is a reasonable generalization to say that whereas the radio and electronic engineer in his ultimate employment requires a larger measure of knowledge of constructional techniques and a smaller measure of personal manual skill, the technician requires reversed proportions of these. A logical deduction from this is that practical training, namely workshop training in constructional methods and in the manual skills demanded by these, is of greater importance in the case of the technician. Ideally a technician should first have acquired a reasonable level of manual competence from some appropriate craft experience. In practice the technician employed in the radio and electronics field requires craft skills which vary according to his specialist employment.

The practical training programme must be based on a precise appraisal of the nature and extent of those skills which will be essential to the particular specialization envisaged. Such specialization is fundamentally inherent in all efforts by industry to provide an adequate supply of properly qualified technicians.

17. Appendix 2:

Radio and Electronics Courses in U.K.

This information has been compiled from a postal survey of universities, colleges of technology and technical colleges. The questionnaires were circulated on 10th January, 1960, and the information has been compiled from returns received up to 1st March, 1960.

The two relevant questions asked were:—

(a) what proportion of course time is devoted to electronics, communications and other light current topics?

(b) if a choice of subjects is offered what proportion of students opt to take radio and electronics subjects?

† Constituent organizations of the Radio Trades Examination Board are:

The British Radio Equipment Manufacturers' Association.

The Radio & Television Retailers' Association.

The British Institution of Radio Engineers.

The Scottish Radio Retailers' Association.

UNIVERSITY DEGREES

16 replies received.

In 8 cases there is no option although the radio and electronics content may be considerable.

In the remaining 8 over three-quarter of students chose to take radio and electronics and the content varied from $\frac{1}{4}$ to $\frac{4}{5}$ in the final year.

Total number of students in final year 465 and of these approximately 350 will have taken the maximum number of electronics subjects available.

EXTERNAL LONDON DEGREES (including internal degrees taken at technical colleges)

10 replies received.

A choice of subjects is only available at 3 colleges where three quarters or more students elect to take radio and electronics. The electronics content varies from $\frac{1}{5}$ to $\frac{3}{5}$ in the final year.

Total number of students in final year is 111.

DIPLOMAS IN TECHNOLOGY (ENGINEERING).

9 replies received.

Electronics content varies from $\frac{1}{10}$ to $\frac{1}{2}$ in the final year and the proportion of students taking electronics varies from one third to three-quarters with a choice in 6 cases.

Total number of students in final year is 60.

COLLEGE DIPLOMAS OR ASSOCIATESHIPS

8 replies received.

Electronics content similar to Diploma in Technology with a choice in 3 colleges and proportion of students taking electronics is approximately 60 per cent.

Total number of students in final year is 124.

HIGHER NATIONAL DIPLOMAS

18 replies received.

The proportion of electronics varies from $\frac{1}{10}$ to $\frac{3}{5}$ but is usually about $\frac{1}{3}$ and the proportion of students taking electronics is approximately three-quarters (choice in 9 cases).

Total number of students in final year is 183.

HIGHER NATIONAL CERTIFICATE—ELECTRICAL ENGINEERING

96 replies received (excluding nil returns)

48 offer courses where electronics represents more than $\frac{1}{3}$ of the course time in the final two years.

Where a choice is offered (in 61 cases) more than three-quarters of the students take electronics.

Total number of students in final year is approximately 2,600.

HIGHER NATIONAL CERTIFICATE—APPLIED PHYSICS.

14 replies received.

8 offer courses where electronics represents more than $\frac{1}{3}$ of the course time in the final two years. Generally speaking no choice is offered.

Total number of students in final year is 169.

18. Appendix 3:

The New Structure of the Graduateship Examination

This will operate from May, 1962, in the case of the subjects of Section A, and November, 1963, in the case of the subjects of Section B.

Section A

(Five compulsory three-hour papers)

PHYSICS (I). Heat, Mechanics, Properties of Matter.
PHYSICS (II). Light, Sound and Structure of Matter.
PRINCIPLES OF ELECTRICITY. Electricity and Magnetism, A.C. Theory, Motors and Generators.
PRINCIPLES OF RADIO AND ELECTRONICS.
MATHEMATICS I.

Section B

(Four compulsory three-hour papers)

MATHEMATICS II.
ADVANCED RADIO AND ELECTRONIC ENGINEERING I.
ADVANCED RADIO AND ELECTRONIC ENGINEERING II.
SPECIALIST SUBJECT.

Section C

Essay paper on PRINCIPLES OF MANAGEMENT.

19. Appendix 4:

Acceptance of Higher National Certificates

With the adoption of the new scheme of the Graduateship Examination there will be a change in the requirements in terms of the

Higher National Certificate. With effect from September, 1963, applicants for entire exemption will be required to submit evidence of success in the subjects shown below with credit level throughout. Colleges will be required to submit their schemes for approval and exemption will only be granted when such approval has been given.

Ordinary National Certificates with credits.

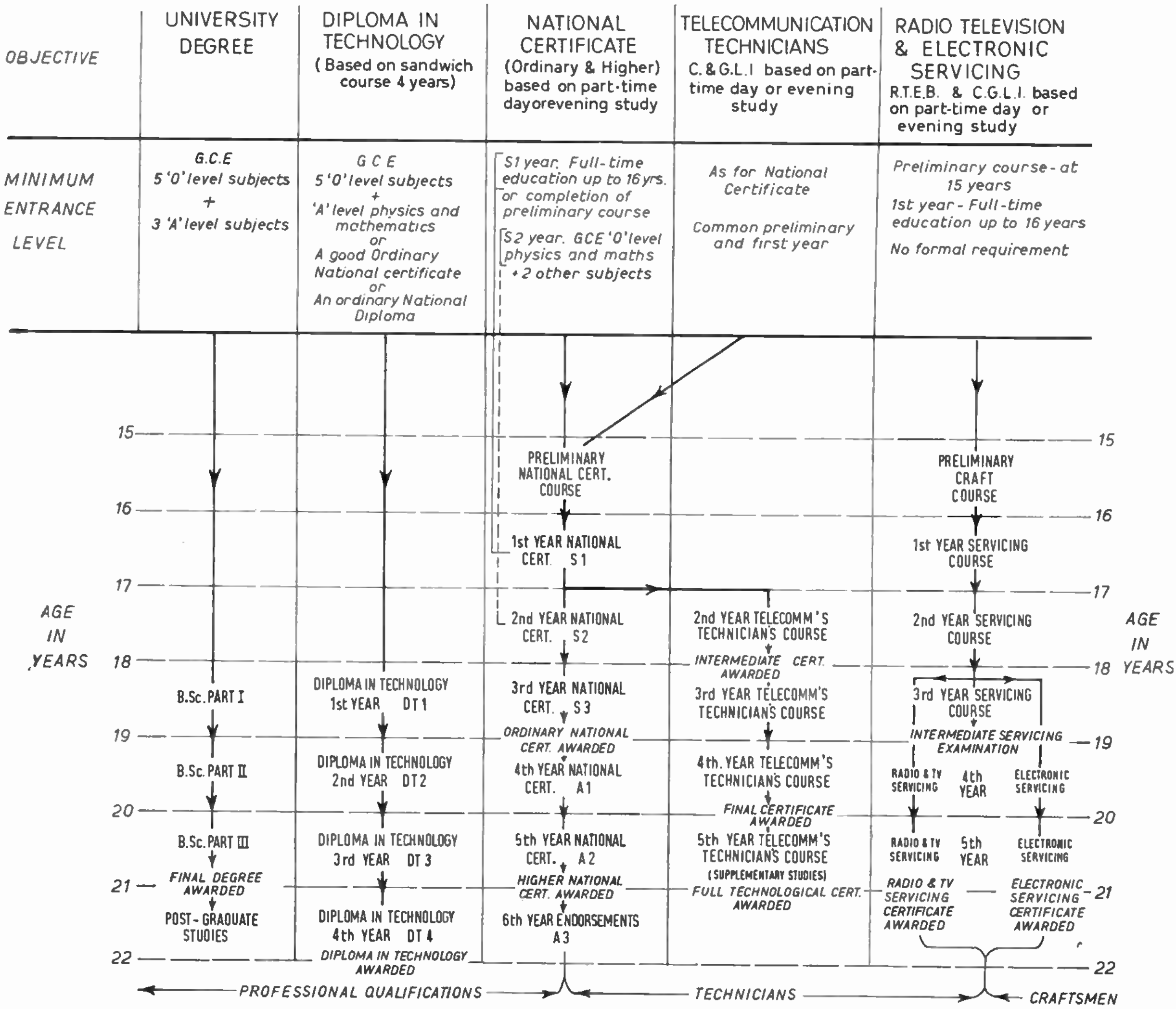
(The Institution hopes that those colleges predominately concerned with the teaching of radio and electronics will provide a course containing the maximum amount of electronics in the S.3 year).

A.1 Year Mathematics.
Electronic Engineering.
Electrical Technology (a fundamental subject).

A.2 Year Mathematics.
Two Radio or Electronic Engineering subjects or one Radio and Electronic Engineering subject and a subject in a closely associated field, e.g., Control Systems, Measurements.

A.3 Year A specialist Radio and Electronic Engineering subject of a type and standard equivalent to the Specialist Subjects of the Graduateship Examination.

20. Appendix 5: Career Routes in Radio and Electronic Engineering



The Transport of Paper Tape in Digital Computation †

by

ANDREW D. BOOTH, D.SC., PH.D., MEMBER ‡

The introductory paper at a Symposium on Input and Output Devices for Computers, held in London on 4th November, 1959.

Summary: Using the principles of elementary dynamics limits are put on the speeds with which a paper transport mechanism which is required to stop at a given character can be expected to work. It is shown that these speeds are nearly four times those so far achieved.

1. Introduction

This short note has been written to give a physical background to the papers on input and output devices with which this symposium is concerned. It appears to be necessary because no published data seem to be available which cover even the most elementary properties of tape, let alone the dynamics of tape handling systems.

Three main topics will receive attention: the physical parameters of paper tape, the dynamics of mechanisms for arresting the motion of a moving tape, and the dynamics of the form of tape moving device which is most frequently used for high-speed systems at the present time.

2. Physical Constants

The following data were obtained by averaging ten measurements from different samples of five-hole teletype tape. In all cases the probable errors are about $\pm 10\%$.

Width of tape	= 0·687″
Thickness of tape	= 0·004″
Linear density	= 0·015g/cm
Tensile strength of unperforated tape	= 6 kg
Tensile strength of fully perforated tape	= 3 kg
Coefficient of friction between tape and finely ground machine surfaces of steel, aluminium and brass	= 0·36

† Manuscript received 18th November, 1959. (Paper No. 577.)

‡ Department of Numerical Automation, Birkbeck College, University of London, London, W.C.1.

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3. Stopping the Tape

In the analyses of tape motion which follow it will be assumed, in line with modern high-speed tape handling practice, that no direct use is made of the sprocket holes for moving the tape. These holes are used merely to supply clock impulses by direct electrical contact or by photo-electric means and the clock impulses actuate an electro-mechanical brake. The dynamics of the electro-mechanism will not be considered here, since there are an infinite number of variants according to whether a direct-acting magnetic solenoid, a piezo-electric or Johnsen-Rahbek effect electro-static, or a vacuum system is used.

All of the systems, however, involve the eventual application to the tape of normal forces of the type shown in Fig. 1.

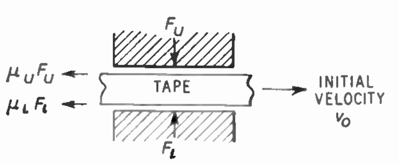

Fig. 1. Basic scheme for a tape braking mechanism.

In the most favoured scheme $\mu_u \cong \mu_l$ and $F_u = F_l$, where μ_u and μ_l are the coefficients of friction between the tape and braking surfaces, and F_u $(=F_l)$ is the normal braking force. Assuming for the moment that the mass of tape which is being stopped is m and that the initial velocity is v_0, the equation of motion is:

$$m\dot{v} = -2\,\mu F \qquad \ldots\ldots\ldots(1)$$

where $\mu = \mu_u \approx \mu_l$ and $F = F_u = F_l$.

D

If $v = v_0$ at $t = 0$, the solution of this differential equation is:

$$v = v_0 - \left(\frac{2\mu F}{m}\right) t \qquad \text{.........(2)}$$

so that the tape comes to rest after a time t_s given by:

$$t_s = \frac{mV_0}{2\mu F} \qquad \text{.........(3)}$$

To find the distance, s, through which the tape moves before coming to rest, let x represent distance measured so that $x = 0$ when $t = 0$. Integrating eqn. (2) and inserting boundary conditions

$$x = v_0 t - \frac{\mu F}{m} t^2$$

whence, from (3)

$$s = \frac{mV_0^2}{4\mu F} \qquad \text{.........(4)}$$

The next point to be considered is the mass of tape which is actually being braked. This will depend upon the details of the tape guiding system, but a plausible length, derived from an inspection of several existing high-speed tape transport systems, is 10 cm which gives a tape weight of 0·15 grammes. On the other hand, it has been pointed out that at high speeds, tape is comparatively rigid so that 100 cm of tape, weighing 1·5 grammes might be more realistic an estimate. The value of F will depend on the details of the electro-mechanical system, but, if a safety factor of 3 on the braking of a fully perforated tape is assumed to be reasonable, it is clear that $2\mu F = 1$ kg is a limiting value.

With this value of the braking force it is necessary for the tape to stop with the sprocket hole detecting mechanism over the hole and this involves a stopping distance of 0·037 in. = 0·0925 cm, if photo-electric detection is used and it is assumed that the detection system reacts at one half of the maximum signal amplitude and falls out at the same value or 0·045 in. = 0·114 cm, if the physical diameter of the hole is assumed to be the allowable stopping distance.

Inserting these values of m, $2\mu F$ and s in (4) we obtain the limiting velocity, v_0; and, from (3) the corresponding stopping times T_s. The results of these calculations are given in Table 1.

It follows that, if suitable pay-out and spooling techniques are used to reduce the length of active tape to the 10-cm level the speeds attainable are about four times those which mark the current maximum. Failing this, however, there is little scope for improvement.

Table 1

m (grammes)	s (cm)	v_0 cm/sec	in./sec	T_s (millisec)
0·15	0·114	1221	= 481	0·19
0·15	0·0925	1100	= 443	0·17
1·5	0·114	386	= 152	0·59
1·5	0·0925	348	= 137	0·57

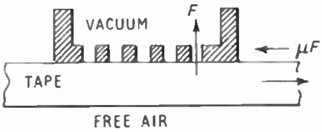

Fig. 2. Vacuum braking system for tape.

It is also worthy of note that vacuum braking systems, involving as they do a one-sided application of braking force to the tape, as shown in Fig. 2, require for the same braking effect the application of twice the force, F, as do two-sided systems such as that shown in Fig. 1.

4. Moving the Tape

Mechanisms for moving paper tape can, like those for braking just mentioned, be divided into two classes, apart from those which use a sprocket wheel and which are not considered here. The first class squeezes the tape between a continuously-rotating capstan and a freely-pivoted pinch roller, whilst in the second both rollers move continuously and squeeze the tape at an appropriate time.

For the free pinch-roller mechanism, shown in Fig. 3, two modes of action are possible. In the first the friction coefficient between the driven capstan and the tape, μ_u, is sufficiently greater than that between tape and pinch roller, μ_l, for the tape to slip on the pinch roller. In this case, with the same notation as before, the equation of motion is :

$$m\dot{v} = (\mu_u - \mu_l)F \qquad \text{.........(5)}$$

In static experiments which used metal or nylon rollers it was found that $(\mu_u - \mu_l)$ never exceeded 0·05 so that, if this mechanism obtains, the time t_a, to reach the limiting velocity v_0 is given by:

$$t_a = \frac{mv_0}{(\mu_u - \mu_l)F}$$

and the corresponding space, s_a, through which the tape moves can be calculated from:

$$s_a = \tfrac{1}{2}v_0 t_a.$$

If the same normal roller force as was assumed for the braking is used, that is,

$$F = \frac{1\text{ kg}}{2\mu} = 1{\cdot}39\text{ kg},$$

the values of t_a and s_a corresponding to the tape masses and speeds of Table 1 are as given in Table 2.

Because the coefficient of dynamic friction is almost always less than that of static friction it is unlikely that the above mechanism is the true one. A high-speed cinematograph film showed that, with steel upper and lower rollers, slipping occurred at the point of contact of capstan roller and tape and that the tape and the free pinch roller remained at rest with respect to each other. In this case the equation of motion becomes :

$$I\ddot{\theta} + mr^2\ddot{\theta} = \mu_u F.r \qquad \text{.........(7)}$$

where θ is the angle through which the lower (free) roller has turned, I is the moment of inertia of the lower roller about its axis, and r is the radius of the lower roller. It is assumed that the tape thickness is small compared with r. Now:

$$I = Mr^2/2,$$

where M is the mass of the roller, whence:

$$\left(\frac{M}{2} + m\right) r\ddot{\theta} = \mu_u F.$$

or, if v is the linear velocity of the tape so that $v = r\dot{\theta}$

$$\left(\frac{M}{2} + m\right)\dot{v} = \mu_u F. \qquad \text{.........(8)}$$

For a typical steel pinch roller $M = 6$ grammes, and, with the values of m, μ_u, F and v_0 used previously, the starting times and distances are easily calculated to be as shown in Table 3.

Because the distance through which the tape travels before it reaches its full speed is, in both of the above modes of operation, considerably greater than the inter-sprocket distance of 0·1 in., it follows that in neither case would start/stop operation be possible at anything like the free tape speeds for which the calculations

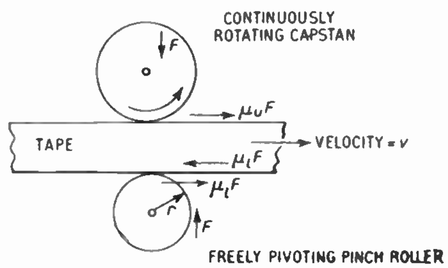

Fig. 3. Free pinch-roller mechanism.

were made. The actual theoretical maximum speed can be derived as follows : eqn. (4) shows that, for tape moving with an initial velocity v_0 a distance s is required to stop. The integration of eqns. (5) and (8) respectively shows that the velocity v_0 will be attained in the following distances :

$$\frac{mv_0^2}{2(\mu_u - \mu_l)F} \quad \text{and} \quad \frac{(M/2 + m)v_0^2}{2\mu_u F}$$

Now the sum of acceleration distance and stopping distance must be equal to the distance between punchings, d say, if the maximum speed is to be attained. Whence:

Table 2

m (grammes)	v_0 (cm/sec)	t_a (millisec)	s_a cm	s_a in.
0·15	1220	2·69	1·64	0·65
0·15	1100	2·42	1·33	0·52
1·5	386	8·49	1·64	0·65
1·5	348	7·66	1·33	0·52

Table 3

m (grammes)	v_0 (cm/sec)	t_a (millisec)	s_a cm	s_a in.
0·15	1220	7·84	4·78	1·88
0·15	1100	7·07	3·89	1·53
1·5	386	3·54	0·68	0·27
1·5	348	3·19	0·56	0·22

$$\frac{mv_0^2}{4\mu F} - \frac{mv_0^2}{2(\mu_u - \mu_l)F} = d \qquad \text{.........(9)}$$

and

$$\frac{mv_0^2}{4\mu F} + \frac{(M/2 + m)v_0^2}{2\mu_u F} = d \qquad \text{.........(10)}$$

in the two cases.

Inserting the numerical values given previously, together with $d = 0{\cdot}1$ in. $= 0{\cdot}254$ cm, we obtain

from (9) $v_0 = 464$ cm/sec
and } $m = 0{\cdot}15$ grammes
from (10) $v_0 = 278$ cm/sec

or:

from (9) $v_0 = 147$ cm/sec
and } $m = 1{\cdot}5$ grammes
from (10) $v_0 = 218$ cm/sec

which lead to total cycle times of

1·09 millisec
1·83 millisec } $m = 0{\cdot}15$ grammes

and

3·46 millisec
2·33 millisec } $m = 1{\cdot}5$ grammes

respectively.

Thus the greatest start/stop rate which can be expected from a system which uses 0·15 grammes of tape, if the idle-roller slips, is 917/sec, whilst, if, as is likely, the roller does not slip, the rate is reduced to 546/sec. On the other hand, with 1·5 grammes of tape, these frequencies become 289/sec and 429/sec respectively.

Neither of these modes of action gives the best possible result; this is achieved when both upper and lower rollers are driven continuously with the same peripheral velocity so that the equation of motion of the tape becomes

$$m\dot{v} = 2\mu F$$

which is the same as the equation for retardation. In this case, if the rollers have the critical surface velocities, the time which the tape requires to attain this speed is the same as that required to stop it, and the acceleration and stopping distances are the same; the intervening space is traversed at the critical velocity and the total start/stop times are as shown in Table 4. The same table also gives the corresponding start/stop frequencies.

Table 4

m (grammes)	v_0 (cm/sec)	Total time between sprocket holes (millisec)	Frequency cycles/sec
0·15	1221	0·40	2500
0·15	1100	0·40	2500
1·5	386	1·25	800
1·5	348	1·26	794

5. Conclusion

The estimates which have been given above are well in advance of present paper tape speeds and they are, in any case, only approximations to the true state of affairs. They are important, however, in showing that there is ample room for improving the performance of paper tape transport devices which, at present, achieve linear tape velocities of only about 100 in./sec compared with 400 in./sec which seems possible in the light of the calculations given in this note. Start/stop frequencies are perhaps less important in view of the high internal speed of modern computers, but even here the present maximum of about 600/sec is only about one-quarter of the theoretical maximum rate.

Some of these discrepancies are accounted for by the limitations of the electro-mechanical actuators themselves, but these may be reduced or removed by better design; a more likely source of difficulty lies, however, in the need to produce physical movement in pinch-rollers and braking blocks. In principle such movement can be reduced to that needed to compensate for irregularities (including joins) in the tapes themselves, say $\pm 0{\cdot}0004$ in., and assuming that forces of the order of 1 kg are available, such movements can be induced in masses of 10 grammes in times of the order of 0·2 millisec, assuming that sufficient driving power is available. It follows that there is good reason to hope that tape handling equipment which has a character rate of 2000/sec may soon be produced and that this will allow on/off operation at frequencies of 1 kc/s.

A High-speed Tape Reader†

by

R. D. LACY, M.A.‡

A paper presented at a Symposium on Input and Output Devices for Computers, held in London on 4th November 1959.

In the Chair: Dr. A. D. Booth (*Member*)

Summary: At speeds of 1,000 characters/sec, photo-electric sensing of the information is essential and the mechanical control of the tape should be as simple and as free from inertial forces as possible. An electro-magnetic brake and clutch are operated from a photo-transistor sensing the position of the sprocket hole to locate the tape in the reading positions. The action of the brake is virtually free from inertia and the tape can be stopped on any character from the maximum speed. The functional elements, the clutch, brake and photo-sensing head have been designed to be completely interchangeable in the production models which are also fitted with adjustable guide rollers for 5, 6, 7 and 8-hole tape. The optical system permits accurate reading of tape on which the holes are incorrectly positioned relative to the edge. Functional tests show that the accuracy and reliability of the reader in service is of a very high order. Over 10^6 characters have been read from standard pattern loops without detecting an error.

1. Introduction

The advent of computing has created a new demand for high-speed reading of punched paper tape. Whereas seven characters per second is still a standard speed in communications, 1,000 characters per second is not extravagantly high for input to a computer. The fact that such speeds can be achieved with relatively cheap and robust instruments is one indication that paper tape is likely to remain a data handling medium for some time to come.

2. Historical Background

The Elliott High-speed Tape Reader is a small compact instrument of simple construction and capable of reading 5, 6, 7 or 8-hole paper tape at any speed up to 1,000 characters per second; it is shown in Fig. 1. Its design is based on the readers which were made by Cambridge University Mathematical Laboratory and which have been in use with the EDSAC 2 for the last three years. During this time, their reliability has been extensively proved and full credit should be paid to Dr. M. V. Wilkes and his colleagues for its design and development.

In spite of the satisfactory operation of the reader with EDSAC 2, it was decided to make a number of changes to improve its appearance, extend its range, and make it easier to produce and maintain. In the first place, the covers were re-styled. A ball-bearing motor of half the power consumption was used instead of the original plain bearing type. The optical system was improved and the lamp run at approximately half voltage to decrease the power dissipation inside the case. The tape release bar was re-sited for easier operation and made more robust and adjustable for varying tape widths. The bases of the photo-transistors were connected through 4·7 kilohm resistors to the emitters to increase the temperature stability and variable load resistors were put in the emitter circuits for adjusting the sensitivity of the transistors. The number of transistors was increased from six to nine so that 8-hole tape

† Manuscript received 27th April, 1960. (Paper No. 578.)
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U.D.C. No. 621.394.332:681.14

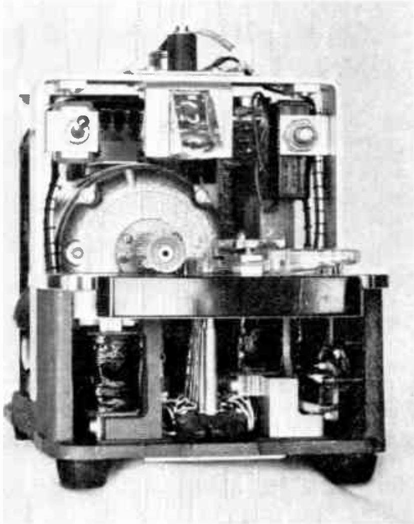


Fig. 1. The high-speed tape reader. (a) External and (b) internal views.

could be read when required. Finally, the detail mechanical design was radically changed so that it could be manufactured as a group of separate sub-assemblies and so that the functional elements would be completely interchangeable, a point particularly important in servicing.

The dangers of interfering with a design which had already been proved in service were known and these changes were not lightly undertaken. However the problems experienced in putting experimental designs into production even after there has been evidence of satisfactory performance in particular applications were also familiar and an attempt was made to steer the middle course. Events have shown that the change from the hand built model to production models has been achieved with an increase in range of operation and serviceability.

3. General Principles of Operation

The use of perforated tape in the computing industry naturally relied at the start on the standard set in telegraphic communications. In that field, the normal operating speed was approximately seven characters/sec and the increase to 1,000 characters/sec was considerable. However this has in fact been achieved by a mechanism which is simpler than its forerunner. There are only four essential components in the instrument, namely the *brake*, the *photo-sensing head*, the *guide rollers* and the *clutch*; even the clutch is not so much an essential as a very desirable device to avoid wear on the paper tape.

In Fig. 2, the paper tape may be seen running through the essential components which are shown diagrammatically. The instrument is usually connected to the computer in such a way that the next character to be read is already illuminated by the beam of light from the lamp. Whilst the reader is waiting for an instruction from the computer to read that character, the electro-magnetic brake is energized and the pinch rollers are pulled out of contact with the tape so that the clutch is inoperative. The photo-cells are connected via amplifiers and

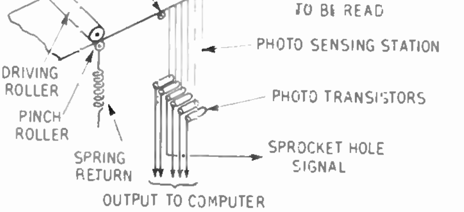


Fig. 2. Photo-electric tape reader.

squarers to the computer and the computer receives its information character by character in 5, 6, 7 or 8-bit form depending on the number of holes in the paper tape. As soon as the computer is ready for the next character, the computer strobe opens the gates and the character illuminated goes into the computer. Then the brake is automatically released and the clutch engaged. The paper tape immediately moves forward and light is cut off from the photo-cells. The first photo-cell to be darkened is the one under the sprocket hole and then the digit photo-cells are all darkened together. Similarly, as the next character moves into the beam of light, the bits of the character are first to be illuminated and then the sprocket hole. As soon as the sprocket hole is illuminated, the signal from the sprocket photo-cell switches off the clutch after amplification and switches on the brake. The tape stops almost immediately and waits for the next read instruction from the computer. Fig. 3 shows the connections to the computer in a schematic form.

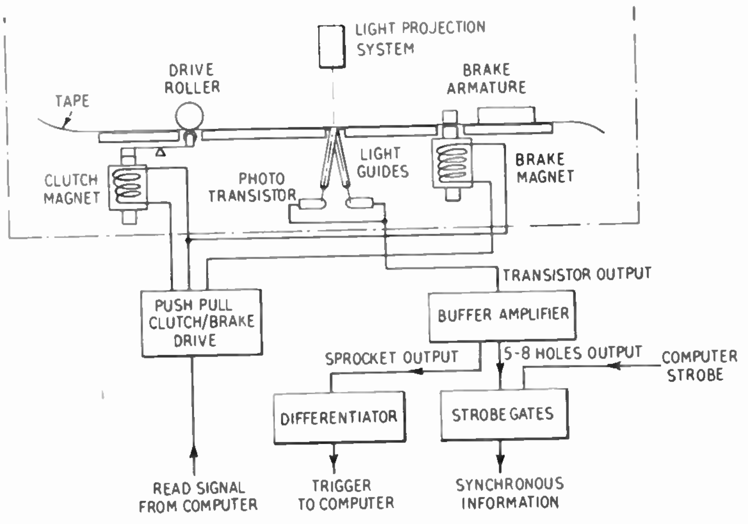


Fig. 3. Block diagram of computer connections.

The principle of operation as just described is very simple and straightforward. The critical feature is the ability of the instrument to stop the tape sufficiently quickly so that the character remains fully illuminated when the tape has stopped. The maximum permissible stopping distance is therefore approximately three-quarters of the diameter of the sprocket hole i.e. 0·033 in. When the tape is running through at full speed, the characters are passing at the rate of 1,000/sec and since there are 10 characters/in., the maximum speed of the tape is 100 in./sec. The total time available from receiving the stop signal to the tape being stopped is therefore 0·00067 sec. In order to achieve this very high speed of operation, there is virtually no mechanical movement of the brake. The braking surfaces below and above the tape are always under light spring pressure and when the braking force is applied it is only necessary to compress the paper microscopically. The braking force is arranged to be at least three times the clutch force and, therefore, it is not essential to have the clutch operating in precisely the correct phase relation to the brake. Indeed, it would be impossible to achieve the same response on the clutch because the clearance between the paper and the pinch rollers must be large enough to allow the free passage of a tape joint. The other major factor to be considered is the inductance of the brake coils. These coils are designed to give the full brake force when 5V d.c. is applied to the coils. However, so that the brake force is applied with as little time delay as possible, the instantaneous voltage applied to the coils is approximately 1,600V. This is achieved by having the clutch and brake coils in the anode circuits of two separate driving valves and connected through a common 10-H inductance to the h.t. line (see Fig. 4). With this arrangement, the brake is quite capable of stopping the tape accurately and reliably on a character from the full speed of 1,000 characters/sec.

Referring to Fig. 4, the computer read signal and its inverse come into the circuit at points (21/PL1) and (9/PL1) respectively. The read and inverse signals normally swing between the limits ± 10V and are connected to the grids of

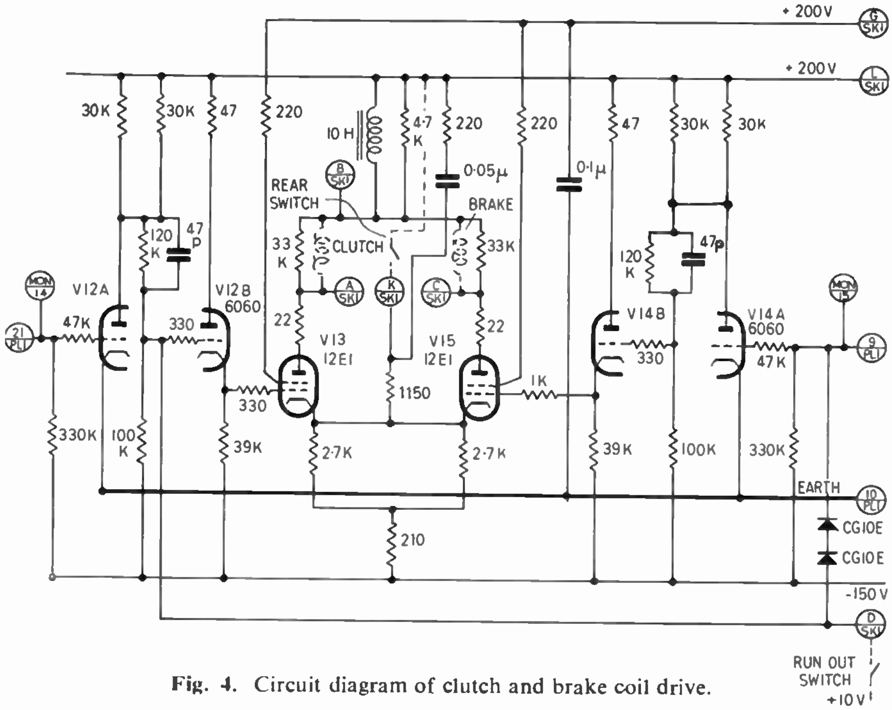


Fig. 4. Circuit diagram of clutch and brake coil drive.

the valves V12A and V14A. These valves are connected as d.c. amplifiers and the outputs are connected to the grids of the cathode followers, V12B and V14B. The outputs from the cathode followers swing between earth and −40V.

When the system is quiescent, the inverse signal line is at −10V and the output from the cathode follower, V14B, is at earth potential. The brake valve, V15, is consequently conducting and the brake coil, which is connected between B/SK1 and C/SK1, is energized. Similarly, since the read signal line is at +10V, the clutch valve V13 is cut-off and the clutch coil, which is connected between the points A/SK1 and B/SK1, is not energized. When the read signal comes through from the computer, the clutch valve V13 is switched on and the brake valve V15 is switched off. When the operating bar is depressed, the rear switch connects points L/SK1 and K/SK1 and the cathodes of the brake and clutch valves rise to 30V and both valves are very effectively cut off. The brake and clutch coils are then de-energized and the tape can be inserted and withdrawn without difficulty. The run-out switch connects point D/SK1 to +10V and causes the clutch to be switched on and the brake to be switched off.

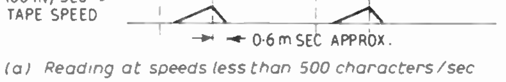
When the reader is operating at speeds up to approximately 500 characters/sec, the tape is stopped on each character and the character can be seen to stop in the centre of the illuminated area. Above 500 characters/sec the tape does not stop on individual characters in a group, although it does stop accurately on the last character. It is important to realize that although the tape is not stopping, it is completely under the control of the computer, and the reading accuracy is not impaired in any way. This point can be readily appreciated by considering the sequence of events in the reading cycle. Figure 5 shows the idealized waveforms. At speeds greater than 500 characters/sec, the reading signal is received before the tape has stopped so that the tape after being slowed down is allowed to accelerate again. At these speeds, the clutch is effectively permanently engaged, i.e. the armature does not have time to drop back to its rest position. The actual reading of the character occurs before the character reaches the central position and, in the extreme case at a speed of 1,000 characters/sec, at the instant when the sprocket hole is detected. The sprocket hole is smaller in diameter than the digit holes so that a tolerance equal to half the difference in the diameters of the holes is avail- for inaccuracies in tape punching.

4. Construction

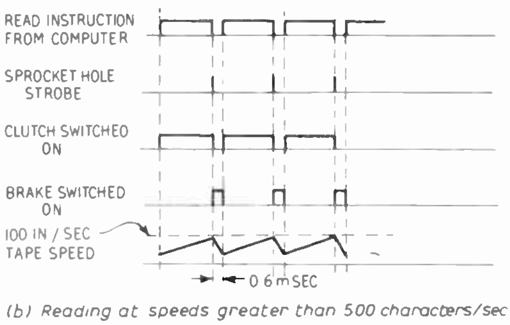
Figure 6 shows an exploded view of the tape reader. There are five assemblies corresponding to the four essential components namely:

(1) Guide rollers
(2) Electro-magnetic pinch rollers
(3) Driving motor spindle
(4) Electro-magnetic brake
(5) Photo-transistor and light guide assembly.

There are four guide rollers; the back two are screwed into the tape table and the front two are adjustable for tape width by moving the operating bar in or out. When the operating bar is depressed, the front rollers fall below the level of the tape table so that the tape can be inserted or withdrawn sideways from the front edge. The readers are wired so that when the operating bar is depressed the brake coils are disconnected and the brake is automatically released. It can also be arranged to move the tape on to the first character to be read when the operating bar is released. The tape table also carries a light slit through which the light can pass through holes in the tape onto the light guides leading to the photo-transistors. For ease of servicing, the tape table can be removed by taking out four screws and the clutch and brake assemblies are then completely revealed.



(a) Reading at speeds less than 500 characters/sec



(b) Reading at speeds greater than 500 characters/sec

Fig. 5. Instantaneous tape speed.

The pinch rollers are spring-loaded off the tape and are carried on a bracket which pivots on a knife edge. At the opposite end of the bracket there is an armature which is pulled down by an electro-magnet when energized, thereby gripping the tape between the pinch rollers and the driving spindle. The driving spindle rotates at 2,900 rev./min and its peripheral speed is 100 in./sec. The spindle runs on grease packed ball bearings. At the opposite end of the motor spindle is a fan which draws air across the lamp and transistor block to keep the assembly, and in particular the photo-transistors, cool. The result is that the temperature rise at the transistors is only 2-3°C and the instrument case is just perceptibly warm although the total dissipation is about 30W.

The optical system is illuminated by a 12V, 36W pre-focus lamp which for long life is under run at $7\frac{1}{2}$V. If the transistors are correctly set at this voltage, the reading accuracy is usually not affected by up to ± 1V swing from normal. The light guides are of perspex and permit considerable lateral movement of the tape without loss of light at the photo-transistor.

The electrical connections are made through plugs mounted at the back of the instrument. All the connections to the photo-transistors go to a 12-way plug and the power connections terminate at a 18-way plug.

In the front of the reader, the switch on the left-hand side turns off the lamp and motor in case the instrument is likely to be left inactive for long periods. The press button on the right-hand side is a tape run-out switch. At the back of the reader there is a bank of flat potentiometers which are adjustable loads for setting the sensitivity of the photo-transistors. Figure 4 shows the circuit diagram of the drive to the clutch and brake coils.

5. Adjustments

Each transistor is adjustable in and out of its socket and by turning it round a certain degree

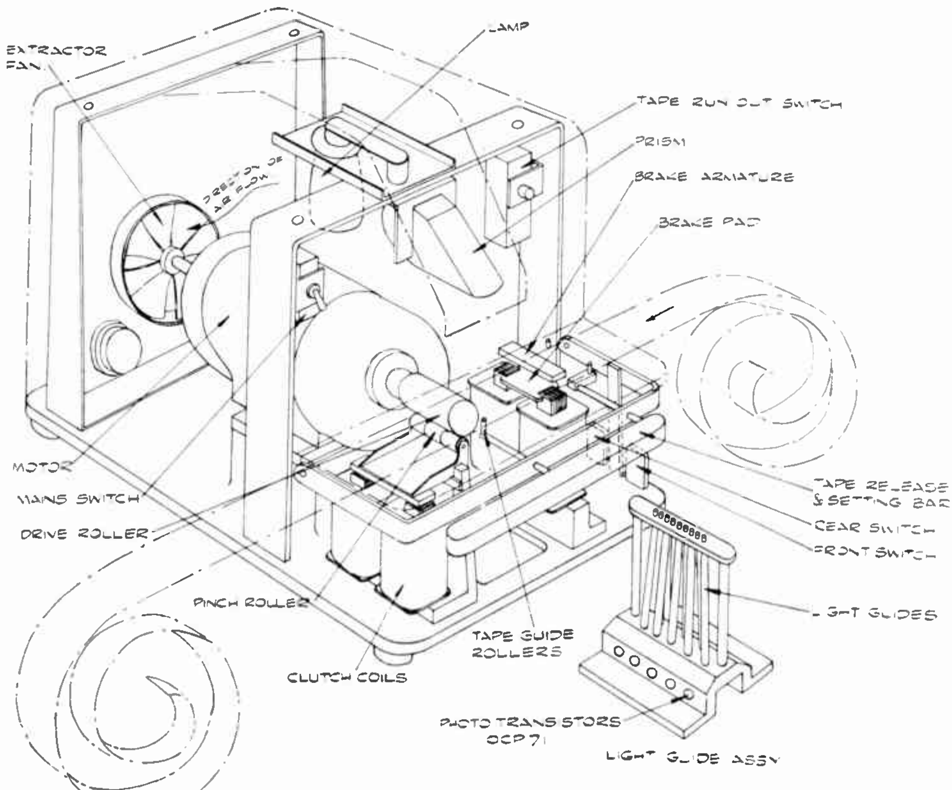


Fig. 6. Diagrammatic view of the high-speed tape reader.

of effective lateral movement can be obtained. When the transistor is correctly positioned, the sensitivity is adjusted by varying the load between the +10V line and the emitter. The adjustment is made so that the output after amplifying and squaring goes up when the hole in the paper tape is 0·015 in over the light slit. This setting is not normally done statically by accurately positioning the tape but by allowing a loop punched with the characters U and J to pass through the reader at full speed and then the output waveforms are adjusted to those shown in Fig. 7. The digit waveform has a mark space ratio of 1:1·4 and the sprocket hole 1·5:1. The leading edge of the sprocket hole waveform lags on the digit hole waveform by 0·115P, i.e. 0·0115 in. since $P = 0{\cdot}1$ in.

The clutch and brake forces are adjusted mechanically by varying the air-gap in the magnetic circuits. In the case of the clutch, the armature can be moved across the pole face for fine adjustment and shimmed for coarse adjustment. Shims under the brake pad can be changed to increase or decrease the brake force. The limits of the clutch and brake forces are quite wide for satisfactory operation and the ratio of the brake force to clutch force is normally 3:1 or greater.

The clearance between the pinch and drive rollers is adjustable by a stop not shown in the diagram and is set to allow the tape plus an adhesive tape joint to pass freely between them.

6. Accuracy and Reliability

Accuracy and reliability are often talked about in the same breath because they are both usually upset by the same fault. It is as well to make a clear distinction and, for the purpose of this discussion, reserve the term reliability as a measure of the operating time between changes of components or adjustments. Similarly, accuracy can be defined as a statistical measure of the number of characters which are correctly read before an error occurs, when the instrument is correctly adjusted. In other words, the reliability is determined by the rate at which the instrument is disturbed from its correct settings, and accuracy is a measure of the ability of its design to overcome imperfections in the material being handled.

The reliability of the instrument is obviously very favourably influenced by its mechanical simplicity. The only components subject to deterioration or change, under normal operation conditions are:

(1) The motor
(2) The lamp
(3) The brake pad
(4) The needle rollers
(5) The clutch bracket pivots
(6) The transistors

From general experience it is expected that the motor will have a life of one or two years and the lamp (because it is being considerably underrun) probably in excess of 1,000 hr.

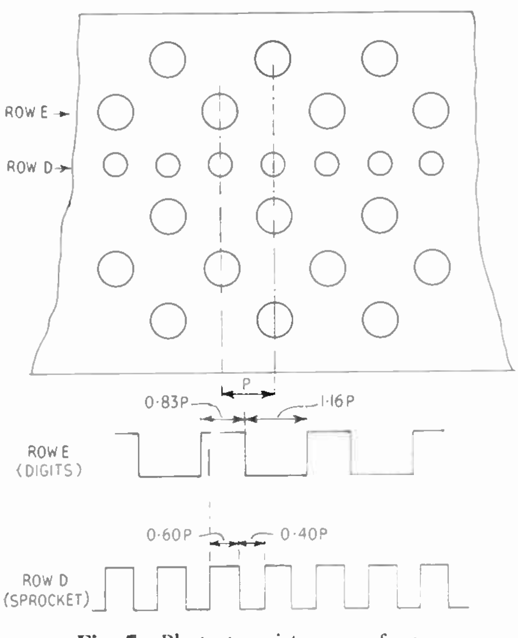


Fig. 7. Photo-transistor waveforms.

The life of the brake pad, needle rollers and the clutch bracket pivots have not yet been determined in general service. However, the original models made in Cambridge have been in service for approximately three years, and it has been reported that the brake pad requires replacement every two months. A new type of brake pad whose life is expected to be considerably longer is now being used.

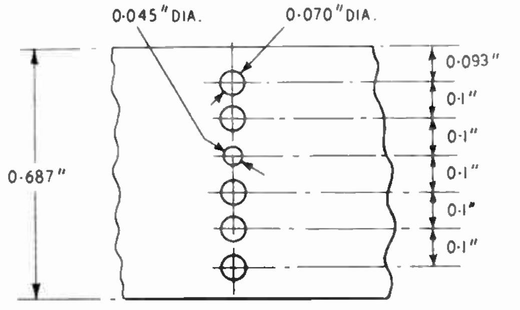


Fig. 8. Tape dimensions.

In considering the accuracy of the instrument, functional tests of production models have shown that providing the adjustments are correct and the tape is precisely punched, the accuracy is 100 per cent. when checked over millions of characters. Inaccurate reading in service however can occur due to:

(1) Tape joints
(2) Incorrect positioning of the punched holes relative to the edge of the tape. (See Fig. 8.)
(3) Characters punched out of line with the sprocket hole.
(4) Grease spots or flaws in the tape transmitting light.

Tapes should be spliced between characters and the two ends closely butted together and held with adhesive cellulose tape. Even when correctly made the joint can still lead to errors if dirt adheres to the adhesive tape to make it opaque. Most carefully made joints can be used time and time again but occasionally, a joint will cause an error.

When the tape is punched, the character holes are carefully located relative to each other and the sprocket hole but not to the edge of the tape. In this reader the lateral position of the tape is controlled by the guide rollers working on the edge of the tape. However, no errors have been caused by inaccurate location of the holes relative to the edge, as far as is known, and particular care has been taken in the design to permit as much tolerance as possible.

It is unlikely that the character holes will be out of line with sprocket holes unless a unipunch has been used or if the tape has come out of its guides in the punch. When reading at speeds up to 500 characters/sec, the characters stop centrally over the light slit. In this case, the character holes could be misaligned by as much as ±0·040 in. without misreading. At full speed, as we have seen earlier, the reading takes place when the sprocket-hole signal is received, or very slightly later, so that the tolerance in that case is only 0·012 in. (character hole lagging the sprocket hole but very much greater in the opposite direction).

Grease spots or flaws in the paper tend to make the paper translucent and can cause misreading. Tests with a number of different grades and colours of paper have shown no reason why the worst quality should not be successfully used. There is a slight variation of thickness between some grades but all the types that have been examined lie between 0·0035 and 0·0045 in. The brake and clutch forces vary a little depending on the texture and thickness but usually they stay within the specified limits and the ratio of 3:1 still holds. (If the paper has a low coefficient of friction then the brake and clutch forces diminish together, tending to maintain the same ratio.)

If the reader works under conditions of large variations of temperature, as for instance, in a process control plant, then temperature drift of the photo-transistors is likely to be the cause of errors. Fortunately, this is not likely in the case of office applications where the temperature has to be controlled within reasonable bounds to maintain the operators' accuracy. Controlled experiments have shown that the reader is satisfactory from 40°F to 95°F.

7. Transistor Drive Circuits

The reader was originally designed in conjunction with valve drive circuits. The brake and clutch coils have been suitably redesigned for low voltage operation, but the top speed is limited by the maximum voltage from the transistors. At the moment, speed is limited to 500 characters/sec but this is unlikely to remain the top speed for very long. At this speed, the maximum voltage across the transistor is only 20 volts and much better transistors than were originally tried are now becoming available.

8. Tape Handling

No attempts have been made to introduce elaborate tape spooling and the practice of the original Cambridge University model has been followed. The simple tape holder shown in Fig. 9 is quite capable of dispensing tape at any speed and under conditions of stop-start from reels up to 5 in. diameter. The accuracy of the reader, as far as can be determined, is not affected by pulling tape from the dispenser.

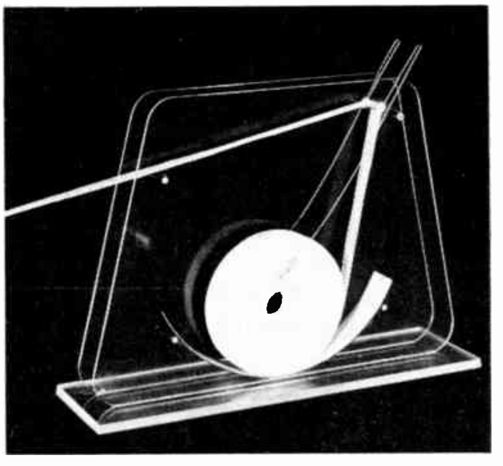


Fig. 9. The tape holder.

Obviously, the operator still has the tedious business of re-winding the tape but this seems to be a small disadvantage compared with the cost of sophisticated spooling equipment which in any case winds up the tape in the wrong direction.

9. Conclusion

The jump from 7 to 1,000 characters/sec has been accomplished without any loss of accuracy and reliability because of the extremely simple tape transport mechanism used in this instrument. The operation is virtually free from the effects of inertia and the moving parts are not subject to violent accelerations.

A New 600 Cards per Minute Card Reader †

by

H. H. G. GROOM‡

A paper presented at a Symposium on Input and Output Devices for Computers, held in London on 4th November, 1959.

In the Chair : Dr. A. D. Booth (*Member*)

Summary : The requirements for the machine, and their fulfilment are discussed. The card transporting mechanism, including the method of feeding individual cards, and the novel stacking unit are discussed. Two systems of card sensing are described, one using photo-transistors, the other silicon photo-voltaic cells. The results of checks of card registration and the resulting card clocking system are given. The need to replace some relay logic with faster elements is discussed and some control functions mentioned.

1. Introduction

With the ever-increasing internal speeds of computers, constant efforts are being made to raise the speed of input and output devices. In the field of punched card equipment, increasing the input rate from cards raises special problems since the specification of the card material cannot be changed to ease feeding and sensing problems without regard to wider considerations. Thus the transporting mechanism must be so designed that high accelerations of the card are achieved without damage to card edges to allow the same card to be processed again on a number of subsequent job runs.

The main problems in such equipment may be grouped as follows:

(1) Card transporting
(2) Sensing
(3) Card tracking or clocking
(4) Control system.

With the exception of the sensing system, the other problems are interrelated, and it is only possible to simplify one at the cost of increased complexity of the others. These four aspects are discussed with reference to the present high-speed reader.

† Manuscript received 14th March 1960. (Paper No. 579.)

‡ International Computers & Tabulators Ltd., Gunnels Wood Road, Stevenage, Hertfordshire.

U.D.C. No. 681.177:621.383

2. Factors in Design

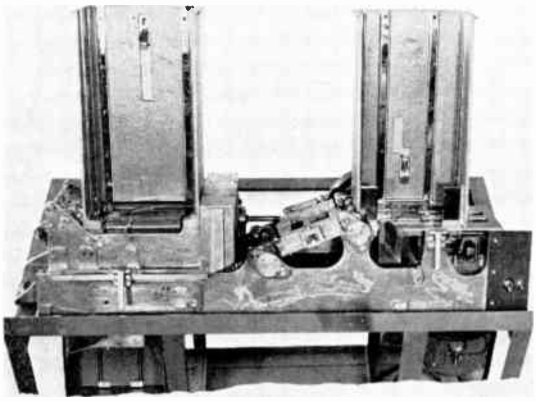
This card reader, which is designed specifically as a computer input, operates in the serial mode, i.e. information is presented to the reading head column by column. The machine is constructed in two main assemblies—the card transport with the reading head, and a stand incorporating the control circuits and the requisite power supplies.

The advantages which are obtained from serial operation are :

(i) Compatibility with the logic of serial computers.

(ii) Ease of encoding since information is presented to the encoder column by column, so that all information punched in any one column is available simultaneously. Thus transformation from the 12-line stream of the card code to, say, the 7-line stream of a computer code, is achieved as a continuous process as the card is scanned.

(iii) Economy, since for an 80-column card, only 12 sensing cells, one per card row, are required instead of the 80 which parallel scanning would necessitate. When, in addition to the primary sensing station, a checking station is included, the economy is even more obvious, i.e. 24 cells as against 160.



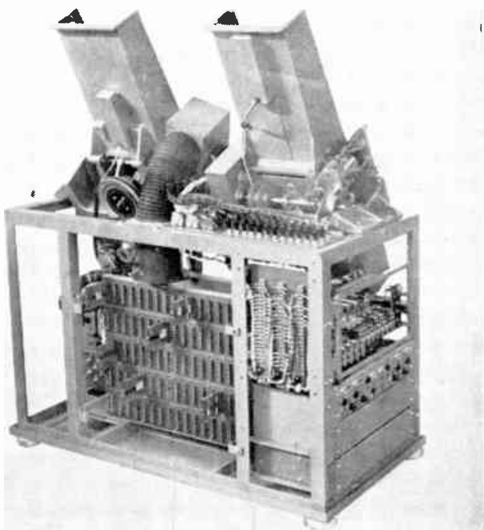


Fig. 1. (above). Front view of card transport.

Fig. 2. (right). Rear view of machine with covers removed. The panel into which are plugged the electronic packages is in the centre of the stand.

(iv) Card skew is easier to control.

The disadvantage of the serial mode is that the card velocity is higher for a given rate of card feeding, but this may be overcome by due attention to the mechanics.

In addition to a basic operating speed of 600 cards per minute, further design aims were as follows :

(1) "Single-shot" operation, i.e. the ability to select cards individually.

(2) Removal of cards from the main stacker without interruption of card feeding; this precluded the use of the normal "gravity" type stackers.

(3) Ample card magazine capacity, an obvious necessity with the high rate of card feeding since an insufficient "buffer" of cards would be an embarrassment to operators. The weight of cards increases the problem of feeding "off the bottom".

(4) Provision of an auxiliary or "reject" stacker to accept cards that are diverted away from the main stacker either because of a reading error, or because it is desired to separate them from the remainder of the cards.

(5) Ease of maintenance, especially essential in all high speed mechanisms.

3. Mechanical Arrangement

Figure 3 shows the essentials of the card transport. Cards are loaded into the magazine at the right and are subsequently stacked (under normal conditions) in the main (upward) stacker on the left. The whole machine slopes backwards at an angle of approximately 25 deg.

The magazine, which is open-fronted to allow easy loading, has a capacity of 2,000 cards and contains lever-operated microswitches to indicate to the operator "magazine low," etc. Beneath the magazine is housed the feed-knife mechanism. This comprises a carriage holding the two feed knives. Each knife is pivoted, independently, at the right-hand end, and both may be held down by latch levers.

With the driving motor started, the whole knife carriage reciprocates on the slides by means of the crank, the crank shaft being belt driven from the motor. The knives are so latched that when no cards are to be fed, they move below the surface of the magazine bed. To the right, and below the knife carriage, are situated the knife latch interposers (one for each knife) and their operating magnets. When the computer demands a card, the magnets are switched in as the carriage moves towards back-dead-centre, thus raising the ends of the interposers to a point where they are struck by the knife-latch levers. The carriage continues to move, thus unlatching the knives and allowing them to rise, under spring tension, as soon as they become clear of the card stack (at the back-dead-centre) to a position 0·005 in. above the magazine bed. In their forward stroke, the bottom card is therefore driven forward to the first feed rolls, and a "throat" just preceding these, gives assurance that only one card is taken at a time.

At the end of their forward stroke, the knives are re-latched by a platform which rocks the knives downwards, thus allowing the latches to re-engage. No further cards will thus be fed unless the knife magnets are again switched in.

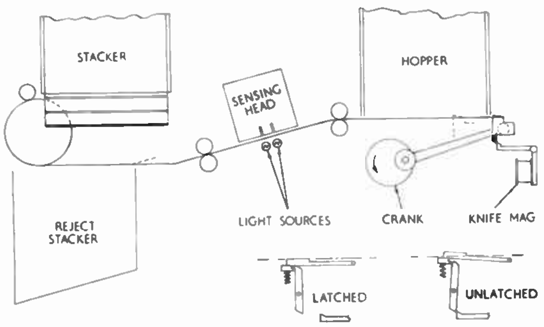
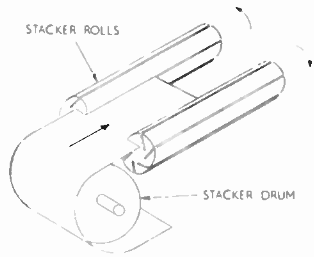


Fig. 3. Card transport layout.

The feed rolls are driven from the crank shaft and rotate at a speed corresponding to the full reading velocity of the card (approximately 125 in./sec). The timing is arranged so that the feed rolls take control of the card as it is presented to them. The card then passes beneath the sensing head to a further set of rolls. Approximately 45 millisec after the last column has passed both the reading and checking station, the card leading edge is positioned in front of a mechanical "gate", comprising a flap which may be raised to divert a card to the reject stacker, or left closed to allow progress to the main upward stacker. The reject stacker is a simple gravity-operated device with a spring loaded platform; it has a capacity of 500 cards.

The main (upward) stacker presents a novel approach to the problem of removal of stacked cards during feeding (Fig. 4). Having passed the reject-pocket flap, the card is guided round a rubber-coated drum to a pair of stacker rolls,

Fig. 4.
The upward stacker —basic principles.



each roll having six longitudinal slots. With the rolls stationary, the card is threaded within a pair of slots and when it is fully home, the rolls are rotated (in opposite directions to one another) by Geneva gearing so that the card is lifted upwards. Other cards in the stacker are meanwhile supported on the periphery of the rolls. The capacity of the main stacker is 2,000.

For ease of maintenance, both the magazine and main stacker are hinged so that they may be laid back to expose the knife mechanism and underside of the stacker.

4. Card Sensing

Two types of sensing head have been designed. The first uses a photo-transistor as the active element and the second a silicon photo-voltaic cell, the latter type having become available since the first design.

The design aim in both cases has been to avoid any form of optical system. This reduces manufacturing problems and costs, and avoids the difficulties of damaged or obscured lenses or light guides during service.

4.1. *Photo-transistor Sensing Head*

In the design of the first sensing head, a comparison was made between the photo-cells currently available, and this reduced the choice to germanium devices. Those compared were a British photo-diode (PG40A), an American photo-diode (Sylvania 1N77A) and a British germanium photo-transistor (Mullard OCP71). The significant factors taken into consideration were the dark currents at the maximum temperatures to be met in the equipment, and the light current at a particular illumination. The criterion of merit was taken as the ratio of light-to-dark current. Calculation of this ratio for the three possibilities showed that the OCP71 photo-transistor was two and a half times better than the American photo-diode,

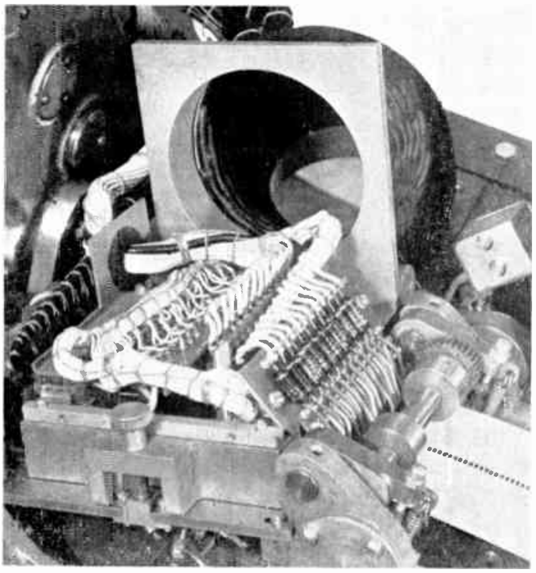


Fig. 5. Photo-transistor sensing head with the cover removed.

and more than fifty times better than the PG40A. The base connection of the transistor also offered possibility of compensation for increase of dark current with temperature.

Accordingly, the first sensing head design consists of two rows of photo-transistors (one row for read, the other for check) straddled across the card bed. The arrangement permits the checking station to be a minimum of three column pitches behind the reading station. The block containing the cells has a masking slot cut for each station which is equal to the width of card between adjacent holes. The cells are thus completely obscured between holes and the maximum change of illumination is achieved.

The cell block is housed in a frame which also contains the photo-transistor base resistors and the ducting arrangements for the cooling air which is blown over the cells (Fig. 5). This forced air also assists in removing card fluff. The whole head is hinged to allow easy access to the card bed.

When considering a suitable light source, it was thought initially that an inadequate distribution of light would be achieved with a small number of large bulbs, and a row of small torch-like bulbs was used for each sensing station. The life of these bulbs was extremely short mainly due to the excessive vibration of the first experimental reader. A source was then evolved which comprises a spiral of nichrome wire wound on a Vitreosil former, the whole encased in a Vitreosil tube of approximately $\frac{1}{4}$ in. diameter. One such source for each station is mounted directly beneath the card bed, the radiated energy reaching the cells via holes drilled in this bed. The physical dimensions involved permit close spacing between the light sources and cells. Each source is run (dull orange) at 70 watts.

With this arrangement, a minimum current change of 0·5 milliamps is achieved in the photo-transistor. Figure 6 shows the associated amplifier. The amplifying transistor (an OC76) is normally held conducting by about 15 milliamps. When a punched hole allows light to fall on the photo-transistors, the collector current increases rapidly and diverts current away from the base of the OC76, thus causing the latter to cut off. The change of 15 milliamps through the primary of the transformer provides the output. After amplification, the d.c. component of the cell current is fed back to the photo-transistor base to stabilize the operating point of cell and amplifier against effects of temperature variation. Safe operation up to 60°C is achieved.

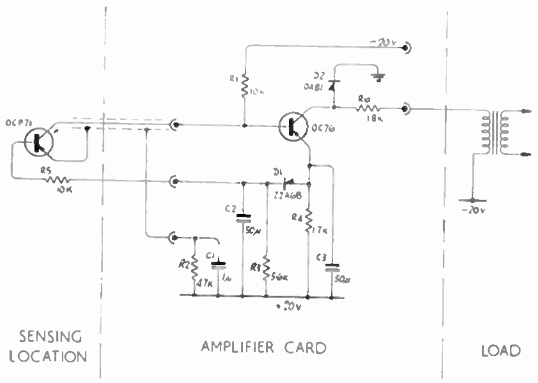


Fig. 6. Photo-transistor amplifier.

4.2. *Silicon Photo-voltaic Sensing Head*

With these cells a new approach is possible in view of their negligible dark current—an overriding consideration before. A directly-coupled system is possible, thus avoiding the pulse stretching system that follows the output transformer of the earlier design. The only problems remaining arise from the possible variation of "obscuration" level, due to variations in transparency of different cards, and the leakage current of the first amplifying transistor.

The size of the silicon cells allows them to be mounted directly beneath the card bed with a glass insert, flush with the bed, providing protection. The cells are soldered into a printed circuit board, and connections taken away via a plug and socket to the amplifiers in the main body of the machine. The basic cell and amplifier circuit is shown in Fig. 7. As the cell is unmasked by a punched hole, the current provided by the cell causes the transistor to switch on, thus providing an output at the collector terminal.

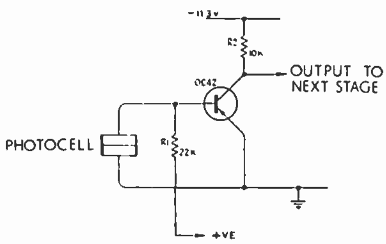


Fig. 7. Silicon photo-voltaic cell amplifier.

The design takes into account the worst case for both

(a) current from a cell due to card material with maximum transparency;
(b) leakage current in the first transistor.

To reduce effects due to (b), a low leakage transistor (a Mullard OC42) was chosen which also improves the design because of its high current gain.

Since it was possible to invert the sensing system by accommodating the cells beneath the card bed, the restriction on light source size was largely removed. Three car headlight bulbs are therefore used, these bulbs being reasonably shock-resistant, particularly when under-run. The bulbs, nominally 36 W each at 6 V, are run at 4 V, giving adequate light distribution.

The final output from the amplifier is such that, for worst conditions, which include "transparency" current, leakage current and resistor tolerances, etc., a minimum pulse length of 65% of a column pitch is obtained.

5. Card Clocking System

To define the columnar position of punchings when being sensed, it is necessary to provide some form of clock track, since combining the output of all rows in some form of OR gate does not cater for the case of blank columns. With a machine in which a card is delivered to the sensing station at a time not directly related to shaft positions, some form of self-clocking system, derived from the card itself, is essential. Similarly, if the card registration is insufficiently accurate in a machine where it is intended to deliver a card in sychronism with the machine cycle, self-clocking is again necessary.

Tests were therefore conducted to establish the accuracy of registration in the reader, using a photo-sensed slotted disc mounted on the crankshaft to provide clocking pulses. The results were as follows:

(*a*) *Initial card delivery*
Under dynamic conditions, the uncertainty in the arrival of the first column at the reading station at no time exceeded ¼ column pitch. Comparing this with performance at very slow speeds, this uncertainty represented delay in delivery.

(*b*) *Variations during reading*
During subsequent passage of the card under the sensing head, there was a systematic change of registration up to a maximum of ¼ column pitch at the last column. This corresponded to the feed roll diameter being oversize by 0·003 in. Examination of the feed roll confirmed this manufacturing error which was corrected.

Thus, production spreads permitting, the tolerance on nominal position makes a self-clocking system unnecessary.

The clock pulse generator adopted was therefore an engineered version of the slotted disc and photo-transistor sensing arrangement. A second sensing cell, operated from certain of the slots which are elongated, provides additional "marker" pulses required for control purposes. The relation of clock pulses to information pulses is readily set under dynamic conditions by a thumb-screw adjustment.

The measured variation in card position implies that the minimum pulse length required for safe strobing (by an infinitely narrow clock pulse) is 25% of column pitch. The problem of the short pulses available from the amplifier outputs in the photo-transistor design is overcome by using one ferrite core per row for both the read and check stations. Information from the rows set their appropriate cores. The cores are then cleared by a pulse derived from the clock generator, and the resultant output is passed to the subsequent encoder system.

The silicon cell arrangement, with its amplifier output of 65% of column pitch, avoids the necessity for pulse stretching.

6. Control

There are two major control points—the feed-knife magnets and the reject stacker-gate magnet. It is obvious, however, that other essential controls necessitated by operator facilities, indicators for "magazine empty", etc., and fault protection, require a somewhat more sophisticated system.

Some of these controls are readily provided by standard relay techniques, but comparative slowness of relays would, however, create difficulties in other cases. For example, the time between checking the last column of one card, and the time at which the knife magnets must be pulsed, if a second card is required to follow immediately, is three millisec. Other considerations of control necessitate conditioning the magnet pulsing, so that interposed relay operate times are not permissible. Accordingly a range of transistorized logical elements are used to control such critical functions. These elements include triggers, amplifiers, delays, etc.

In conjunction with these transistor elements, photo-electric cams are provided to give the necessary sychronizing pulses for gates preceding the triggers which control the feed knife magnet amplifiers, etc. Figure 8 shows the arrangement of such photo-electric cams. Each has two slotted discs, independently adjustable on a common hub, so that one such assembly serves two photo-sensing heads, and provides two independently variable timings.

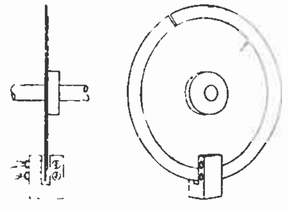


Fig. 8. Photo-electric cam layout.

The control system includes protection against foreseeable faults. To assist in this, two other photo-sensing points are fitted. One is an extra cell in the line of check sensing cells, the "back-edge detector", which permits a failure to feed a card to be detected. A second, mounted on the stacker drum, detects failure of a card to enter the stacker correctly, and thus protects the cards following from being damaged. Fault conditions will cause further card feeding to be prevented, the drive motor to be switched off, and an indicator light lit at both the reader and the computer console.

Since the card reader is normally computer-controlled, the operator controls available on the reader itself are limited. One such control permits the operator to select either a "read" condition, whereby the reader diverts rejected cards to the reject stacker and automatically feeds the next card, or alternatively, a "stop" condition, whereby further feeding is inhibited following a card rejection.

7. Conclusion

A high-speed card reader has been described in which a simple reciprocating mechanism has been used as the basis for serial presentation of data to a computer. By due attention to the mechanism, a reliable card registration has been achieved thus enabling a simple and economic system of card tracking to be employed. The novel stacking arrangement avoids interruption of the card flow. As a result of the requirements of control, the transistorized circuit elements have provided a system which is readily adjusted to suit varying needs. The resultant machine represents a valuable advance in card handling speeds whilst remaining economically attractive.

8. Acknowledgments

In conclusion, the author wishes to acknowledge the work of Mr. R. Grimes and Mr. M. L. N. Forrest in the design and development of the mechanics and electronics respectively.

The author also wishes to express his thanks to International Computers and Tabulators Ltd., for permission to publish this paper.

High-Speed Printers†

by

W. A. J. DAVIE‡

A paper presented at a Symposium on Input and Output Devices for Computers, held in London on 4th November, 1959.

In the Chair: Dr. A. D. Booth (*Member*)

Summary: The distinction between serial and parallel printers and between stoppable and continuous running printers is drawn, and some of the features found in high-speed printers are discussed firstly as regards the document to be produced, and secondly as regards the inclusion of the printer in a data processing system. A comparison of on-line and off-line methods of connection follows. In the brief survey of printing principles used in high-speed printers, both mechanical and non-mechanical types are treated. A short section on checking is followed by comments on future trends in high-speed printers, including the possibility of re-entry.

1. Introduction

In an electronic data processing system some device is required which is capable of translating the output into legible form at high speed, firstly in order that large amounts of data may be produced from the system in explicit form, and secondly so that the overall performance of the system is not unduly impaired. These remarks are especially true of systems used for business applications, and occasionally of those used in scientific applications.

Only printers capable of printing at speeds in excess of 100 lines per minute will be considered in this paper and though this excludes some very useful devices, the field is still very large. The slower printers, of course, still find many applications in even the most up-to-date machines.

Both serial and parallel types of printer are capable of high speed. A serial printer is one in which a single head capable of writing any character in the machine's repertoire is moved across the paper, writing the line of print as it goes; a parallel printer is one in which there is a separate head for each character position in the line of printing and the line of print is treated as an entity. Parallel printers are often known as line printers, and it would appear that they must of necessity be faster than serial printers. This is in fact so, in so far as mechanical printers are concerned, but when non-mechanical printers are considered, in which the writing head may be a beam of electrons in a cathode-ray tube, it will be seen that the time of traverse can be very fast indeed, and consequently serial printers of this type are capable of high speeds.

There are two methods of connection of a high-speed printer in an electronic data processing system. When used on-line, the printer is virtually connected to the computer main store, and in consequence receives information almost as soon as it is available within the computer. When used off-line, the information is written from the computer on to some intermediate storage medium, usually magnetic tape, which is then transferred to a reading device coupled to the printer. This means that the printer part of the system functions independently of the computer.

There is one further point which has considerable bearing on the remarks which follow. This is the ability of a printer to stop after printing a given line and resume at some unspecified

† Manuscript received 19th March, 1960. (Paper No. 580.)

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U.D.C. No. 621.394.33:681.14

time later when called upon to do so. Not all printers, especially some of the very high-speed non-mechanical types, are able to do this. In fact, one of the non-mechanical types using thermal fixing of its print requires the paper to move continuously to function correctly and so is unable to stop on demand. This, however, does mean that paper may be shifted faster, since at high speed it is easier to move paper continuously than to move it in discrete jumps, as is the case with most mechanical devices. Some of the stoppable printers also use this fact and move paper continuously over groups of lines which do not require to be printed on, with a considerable gain in the overall speed of producing a document. High-speed printers may, then, be classified as stoppable printers, and continuous running printers. This is one of the more basic forms of classification, especially in system considerations, and it should always be borne in mind when the speed of a printer is quoted.

2. Features of a High-speed Printer

The two basic requirements of a high-speed printer are to print characters and to move paper. Besides these essentials several other factors influence the suitability of a given machine in a given application. Consideration of the documents to be produced may show that a variation in print quality is tolerable, depending for instance on whether the documents are for distribution to customers or for use in a stores department within a company. The documents also determine the number of character positions required in a line of print; in general about seventy characters are printed in a line, but spaces are also required, and the general range of the number of character positions in printers in use at present is from ninety to one hundred and forty. When moving paper, registration of the print on given lines is very important especially with pre-printed stationery, and this applies equally to single-line shifting and "throwing." ("Throwing" is the term used to describe the action of moving paper continuously through a number of lines until a given registration point is reached.) Also important when considering the documents produced is the subject of copies: the quality and number of copies which may be produced and also the printing of the information in alternative or selective form, such as a summary, will be of interest.

The features which are of interest when a printer is used in an electronic data processing system are less easily defined, but probably the first in importance is reliability. Reliability in this case means not only that the device must be free from break-down, but also that it must not be error-prone, that is, of such a type that it may give random errors which could be interpreted by a reader of a document as valid. The speed of a printer in a data processing system is not particularly critical so long as a speed match can be attained between the rate of production of the information by the computer and the subsequent rate of printing. This is most usually determined by the application in which the system is used. The economics of the printer in a system must also be considered but this is a large subject and will not be further discussed here. Finally there is the ease of use of a printer, which possibly does not receive the attention which is its due. All routine jobs such as ribbon changing, paper loading, and the setting up of pre-printed forms should be simple and easy to accomplish. It is even worthwhile to have some simple special devices to aid these jobs, such as magnets to hold up paper bails whilst loading paper, since operators tend to think more highly of a piece of equipment when it has been designed with them in mind, and this leads to efficient operation.

Several other features have been designed into high-speed printers which ease their use or benefit their performance. The use of tabulation points both horizontal and vertical is widespread. A vertical tabulation point is a point to which the form is shifted before printing a given line (say a totals line) and may be specified as being so many lines from the previous line, or it may be a registration point which can in fact be coded in some cases. Horizontal tabulation is done in different ways in serial and parallel printers. In a serial printer, the principle is similar to that for vertical tabulation whilst in a parallel printer horizontal tabulation is achieved by means of electrical connection units which are patch-panels enabling a programmer to wire from any character output line to any print column. Tabulation points can save a lot of storage space for information, and also avoid the necessity for redundant zeros. Twin webs of paper either overlaid or side by side, moving at different speeds can also be very useful for producing some types of commercial document, especially those requiring a summary. One at least of the non-mechanical printers is capable of printing its own forms which is a very attractive feature, and one of the mechanical printers is capable of controlled penetration of printing on certain characters, so that these are emphasised if required. Finally certain printers can have their character repertoire changed very easily and cheaply, and though this is probably more desirable from a maker's point of view than from a customer's, it does in fact give the customer absolute choice of repertoire.

3. A Comparison of On-line and Off-line Connection

In this comparison an attempt is made to show the arguments which may be reckoned for and against the two types of connection, but the choice is usually determined by the application, though in fact, no really reliable printer suitable for on-line connection has been available in this country until recently. For general use. the on-line connection is probably most useful, but in specific applications the off-line connection may be vastly superior.

When using on-line connection, less equipment is generally required since function sharing can be done with other parts of the computer, and of course less storage of information is required altogether, there being no need for a permanent storage medium. Also advantageous is the rapidity with which the explicit results of a programme are available and this can save considerable waste of time and effort due to either machine or programme faults. Information theory also would suggest that the on-line connection is less error-prone since fewer processes are involved. Against the above, however, must be set the costliness of the very fast printer which is required, and in fact this must in general be of the stoppable variety, which is unfortunate since the highest speed printers currently available are continuous running. Further, should any part of the system be unserviceable it is possible that one may neither print nor compute; this means that maintenance times on the equipment must be low and reliability very high.

When the off-line connection is used the speed match between the printer and the rest of the system is much less critical and a very fast or very slow printer can be used. However, a battery of slow printers is not usually a satisfactory solution due to the complex organization of the information flow which is required. Possibly the most cogent argument for the off-line connection is that, with a stoppable printer, editing of information is possible. For instance, a selective search may be done, or a variety of documents produced using the same information or different parts of the same information by re-running with different controls, thus considerably reducing the load on the computer.

A new type of connection known as on-off line has been evolved by some manufacturers in an effort to gain the advantages of both systems. In this, the printer is fed from a small section of the central processor devoted exclusively to it, and capable of connection either to the central processor or to a selected magnetic tape store.

4. Brief Survey of Printing Principles

When classified by the method of printing which is used, high-speed printers fall into two major groups, electro-mechanical and non-mechanical. The electro-mechanical group may be sub-divided into those with permanent type and those which use styli to form the letters, whilst the most important non-mechanical printers to date use Xerography.

4.1. *Electro-mechanical Printers*

4.1.1. Permanent type printers

With these printers, one can almost trace a genealogy which starts with printers using a type-bar. As an example of this, consider the I.B.M. type bar, shown in Fig. 1. In this all the bars, one for each position in the line of print, are pushed down against springs and allowed to rise until the various characters are set by stops. The selected dies are then driven forward onto the paper. The obvious extension is, of course, to turn the bar into a wheel as in the Bull printer, shown in Fig. 2. The selection of the character is a complicated procedure of two-zone latching, and despite such an elaborate

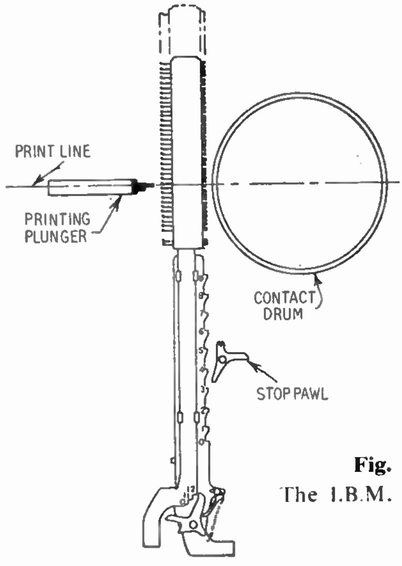


Fig. 1.
The I.B.M. type bar.

mechanical assembly the machine is very reliable. The speed is 150 lines/min.

Both the above mentioned printers move the type vertically onto the paper, and we come now to the next extension which is to hit the type "on the fly" as in the Shepard printer shown in Fig. 3. (Versions of this device are made by other manufacturers.) The device is extremely simple mechanically and relies for its action on accurate electronic timing of the hammers, which is relatively easy to accomplish. The mechanical parts are the type roll, which is a continuously rotating cylinder with a line of each character in the repertoire along its length, the hammer bank, and the code generator. The code generator consists of two toothed wheels both with magnetic pick-up heads; on one there are as many teeth as characters, whilst on the other there is a single tooth which acts as a datum. By counting the number of teeth from the datum (electronically) the next character to come over the printing station can be found, and the output information can be searched accordingly to fire the hammers in the positions required. The line of print is printed in several operations each involving the printing of the same character at the required positions along the line.

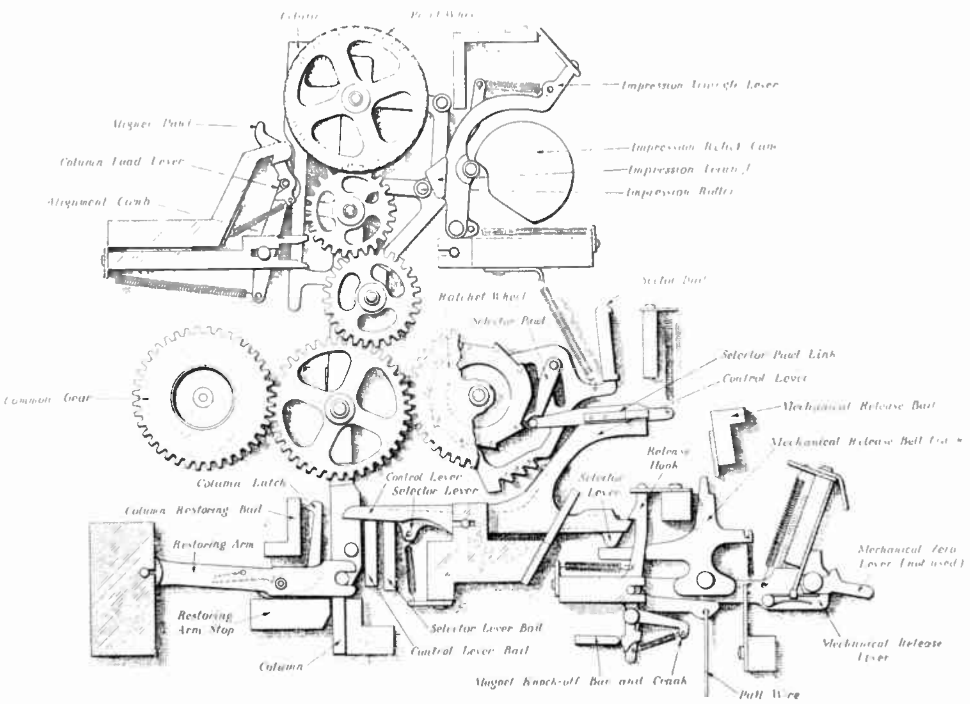
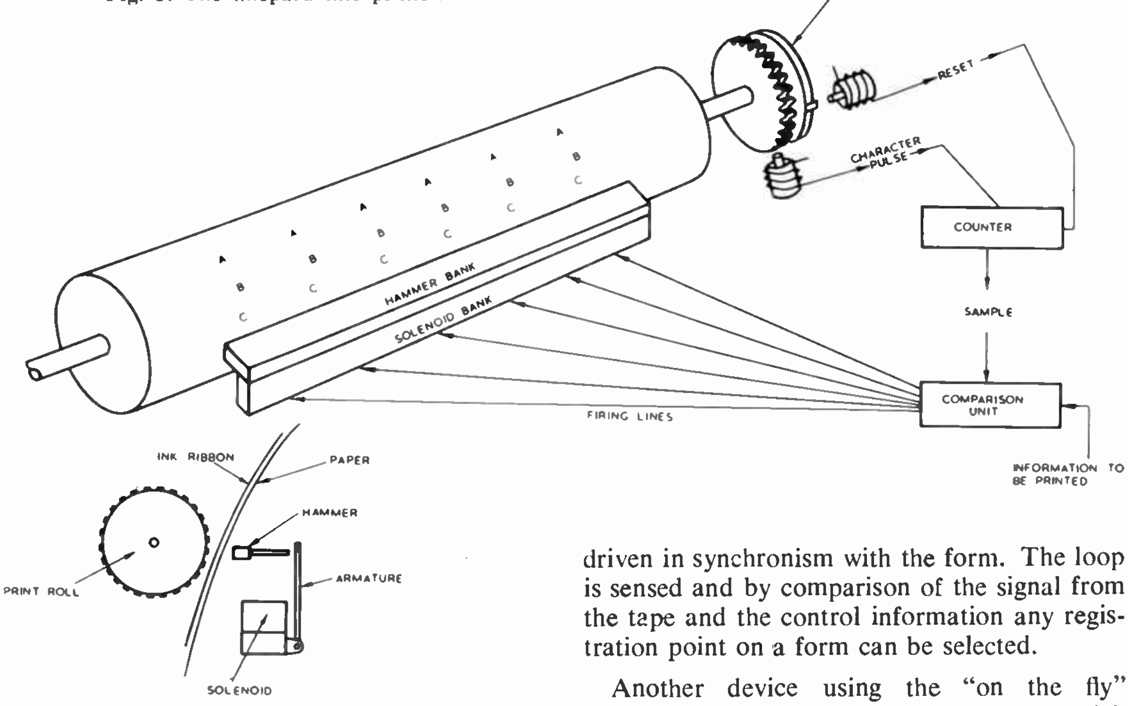


Fig. 2. The Bull printer—print wheel mechanism.

Fig. 3. The Shepard line printer.



These printers are capable of about 600 to 1,000 lines/min though it must be stated that the speed of printing depends on many factors, for example, the repertoire. It will be seen that the smaller the repertoire, the smaller the wheel and consequently the higher the speed of revolution of the type roll for the same circumferential speed. It is also interesting to note that the printing part of the cycle of these devices is variable in duration and as soon as all the characters in a given line have been printed (which can be checked by a count) the next part of the cycle can commence without waiting for a zero on the type-line. Similarly the printing part of the cycle can commence with a search for any character which happens to be present above the hammers, and this means that if, say, the machine is printing numeric information only there is a useful speed increase; consequently the speed also depends on what is required to be printed.

Two at least of these devices are very reliable, and one version has a particularly elegant method of vertical tabulation in which a six-hole tape loop of the same length as the form is driven in synchronism with the form. The loop is sensed and by comparison of the signal from the tape and the control information any registration point on a form can be selected.

Another device using the "on the fly" principle is the Potter Flying Typewriter which operates at about 600 lines/min. This is shown in Fig. 4. One type wheel rotates across the line, and selection must be made for the character as well as the position in the line.

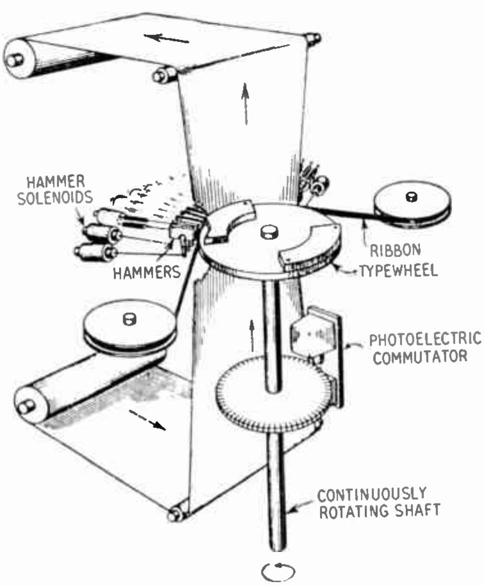


Fig. 4. Potter flying typewriter.

Yet another using the same principle is the Japanese OKI printer which has a band replacing the wheel of the Potter and operates at about 300 lines/min.

All these on-the-fly printers have a tendency to give waviness in the lines of print due to slight discrepancies in the time of flight of the various hammers. These discrepancies can, however, be "tuned" out in most makes, and on one in particular, the specification states that the tops of the highest characters must be less than 0·030 in. higher than the tops of the lowest characters in any line of print. The characters are approximately 0·100 inches overall, and when properly adjusted, the wave is not easily detected by eye.

4.1.2. Stylus and matrix printers

Obviously one of the speed limitations of a printer with permanent type stems from the conflicting requirements of getting through the repertoire fast, and yet having each character available for long enough to print on it. To obviate this difficulty printers have been developed in which a stylus is used to place dots as required in a matrix of available positions, and the characters are formed as a pattern of dots, although, of course, there is a certain amount of merging and the dot structure should only be apparent on close examination. There are two matrix printers made by I.B.M. running at 1,200 lines/min, one by Burroughs, and one by I.C.T. known as the Samastronic, running at 300 lines/min.

One of the basic difficulties with a matrix system is that although six bits of information are sufficient to specify a character, a seven-by-five matrix requires thirty-five bits to specify it and so the printed character. The neatest solution to the problem is probably that in the Samastronic, shown in Fig. 5, in which there is one stylus per character position. This stylus oscillates continuously across the width of the character and also across the direction of movement of the paper. The paper is moved during printing and consequently the stylus scans the paper. The stylus is activated at intervals along this path by one of the fifty character discs (one for each character in the repertoire) which are discs with metal inserts, read by brushes. Any number of styli can be controlled from the signals from one character disc.

The Samastronic has many valuable extras including twin webs of paper with independent control and switchable electrical connection units. It now appears to have reached the stage of development where it can stand up to the exacting role of an output device for an electronic computer.

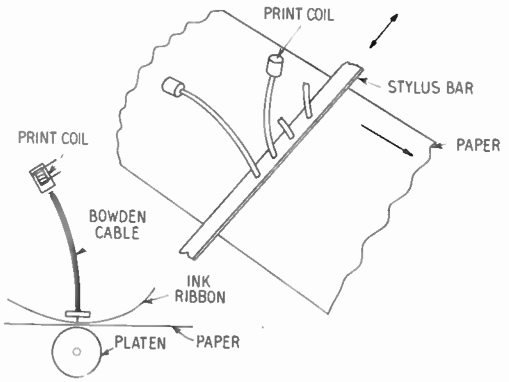


Fig. 5. The Samastronic printer.

4.2. *Non-mechanical Printers*

In the non-mechanical printers, the object is to get away from the necessity to hit the paper with any sort of mechanical hammer, shaped or otherwise.

The non-mechanical printers select the character, select its position in the line, and form it without any mechanical motion in the true sense of the word. This evidently has great advantages in the speed of formation of the characters, but unfortunately the character when formed usually requires some type of "developing" and "fixing" process before the document required is usable. Most of these printers have such high speeds of character formation that they are used in the serial mode.

4.2.1. Electrostatic printers

To date the electrostatic printers appear to be the most successful of the non-mechanical types. There are two methods of electrostatic printing in use: firstly, that in which charge is laid down on the paper directly and secondly that in which a photo-electric medium is used as an intermediary. In both cases the latent image of the character formed by a charge is made visible by dusting with a powder and fixed by heating some thermo-plastic material associated with either the powder or the paper.

The first method is typified by the Burroughs Electrographic Printer/Plotter for Ordnance Computing (BEPOC) which is a stylus printer and, apart from a quite elaborate system of character formation done mainly by the programmer, is much like the Samastronic printer already described, except that the oscillating bar and single stylus per character are replaced by seven styli per character. The printing speed is approximately 1,200 to 1,800 lines/min of 100 characters each, and in this case the paper is coated with a thin layer of transparent thermo-plastic which also acts as a high resistivity layer for charge holding.

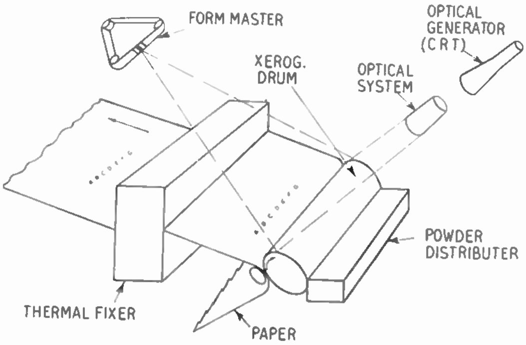


Fig. 6. Xerographic printer.

More elegant are the electrostatic printers using the Haloid xerographic process, shown in Fig. 6. In this, a precharged photo-conductive selenium drum is exposed to a pattern of light from a cathode-ray tube which discharges selected areas. Charged powder is then cascaded on to the drum, and adheres to the selected areas, forming the pattern in powder. Paper is brought into contact with the drum and the powder is transferred electrostatically. Finally, the powder which contains a thermoplastic is fixed by heating.

One version, the Xeronic made by Rank Xerox, operates in the range 2,000 to 4,000 lines/min, and another using a rather less neat method of character generation (in light) is rated at 5,000 lines/min.

The xerographic principle lends itself very easily to printing also the fixed information on a form, such as the titles and demarcation lines. This is done by projecting onto the selenium drum a photographic positive of the pattern required and is a very useful feature.

These printers are organized as serial printers but due to the fixing process are perforce of the continuous running variety. This means that their use as on-line printers is, in general, precluded. One other disadvantage is that only one copy of the document is available, though working on a half-width basis, two may be printed simultaneously. The print quality can be exceedingly good, and special paper is not required.

4.2.2. Electromagnetic printers

Two methods of electromagnetic printing have been tried in America, though neither are in production yet. Again these methods, like the electrostatic, are of the type in which the paper (or rather coating) is magnetized directly (N.C.R.), and of the type in which a medium, in this case magnetic, is used to form a powder pattern which is transferred to paper (G.E.). The latter process is known as Ferromagnetography, and does not appear to be very far advanced. In the N.C.R. version shown in Fig. 7, an interesting method of character formation is employed. Permeable pins are arranged in a helix round a drum and their ends pass close to a bar which can be magnetized in accordance with given signals. The paper is placed between the pins and the bar and if the bar is magnetized a strong field exists between the point of the pin and the bar, which magnetizes the special paper. A c.r.t. with the repertoire cut out of a mask is scanned in time with

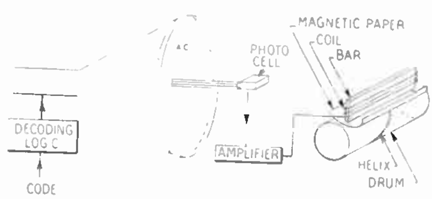


Fig. 7. N.C.R. magnetic printer system.

the passage of the pins past the bar, and the resulting scans are photo-electrically sensed, amplified, and made to govern the field of the bar. The action is somewhat similar to that of a lawn-mower, with the point of interest moving across the line of interest. Seven pins are used for each character and speeds of approximately 1,500 lines/min have been accomplished so far. It is of course a serial printer.

4.2.3. Other types of non-mechanical printers

Photographic printers have in fact been made and a speed of printing of 9,000 lines/min has been claimed for such a printer in the LARC system. The method is to photograph the output of a character generating c.r.t., and though exceedingly fast the running costs of such a system are of course very high.

Studies are being conducted by the Standard Register Co. of America into a spray printer in which charged particles of pigment are attracted directly onto the paper, with the paper forming the covering of an oppositely-charged photo-electric plate. Little, however, is known of this project.

Somewhat surprisingly, no electrochemical printer has yet been developed though there are several such processes that could be tried.

5. Checking

As machines get faster, lost time represents even more lost work. Besides the need for reliability of a very high order, it is important to check the performance, not only so that an error may be found as soon as it occurs, but also in such a way that diagnosis and rectification of the fault may be carried out as quickly as possible. As well as checking for actual faults, exhaustion of the various consumables in the printer, such as paper and ribbon in the mechanical printers, should also be checked, and the printer stopped in the correct position for easy re-loading. This last point is particularly important when pre-printed stationery is used since this must be aligned in the printer to coincide with the information to be printed.

There is considerable scope for ingenuity when devising checks in the mechanical and electronic parts of the machine and the value of these checks cannot be overstressed, even though they may add considerably to the cost of the device. Some checks which are known to have been applied specifically to printers are: a runaway check, to detect malfunctioning of the paper shifting mechanism; a check that the correct printing solenoids are energized only when required; and a check for any irregularity in the electronic circuitry, based on what should be true in the various beats of the machine cycle. As well as these, there can be various checks such as parity on information transfer, and comprehensive power supply checking, which apply in general to electronic data processing systems.

6. Future Outlook

As has been stated printing systems capable of 10,000 lines/min are already being considered, and even this will probably not be the highest speed attainable. However, it would seem that the amount of output produced is getting so large at rates such as these, that the organization for distributing and using the information produced would be unnecessarily centralized, and possibly the print-out is being used as a dump for the computer store. At present, it would appear that non-mechanical printers capable of about 5,000 lines/min for producing a variety of forms with large amounts of fixed information are all that are required in the way of very high-speed printing, and these could conveniently be of the continuous running type, preferably with a fairly wide choice in fixed speeds. These speeds are readily attainable since the rate of paper-movement for a printing speed of 6,000 lines/min corresponds to about fifteen in./sec at standard spacing (6 lines/in.), which is well below newspaper printing rates. Present speeds attainable with discrete movement of the paper are about one line in 15 to 20 millisec, or about 8 in./sec, and there does not seem to be much room for improvement. If, however, the printing time could be reduced, and speeds of 1,500 to 2,000 lines/min achieved with a discrete running printer this would probably be sufficient for most general applications. However, there is still considerable scope for cheap and reliable printers running at very much lower speeds.

To date, high-speed printers have been regarded as more or less absolute output devices for electronic data processing systems, as opposed to paper tape or card outputs which are capable of being re-processed. It would seem probable that there will soon be printers capable of producing documents which have some method of recording data in machine language on them, as well as legible information, so that the documents are capable of re-entry to the machine. What form the recording will take, it is difficult to foresee, and in fact it might be that some form of character recognition, as in the Solartron ERA, may be preferable to the more obvious magnetic and electric sensing for bringing the legible output of a system back to machine language, and so completing the chain.

7. Acknowledgment

The author wishes to express his gratitude to the Directors of Elliott Brothers (London) Ltd. for permission to prepare this paper.

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The closing date for entries to the May 1961 Examination at oversea centres is November 1st.

Energy Stabilization of a 4-MeV Electrostatic Accelerator using Controlled Corona Discharge †

by

E. C. FELLOWS, GRADUATE ‡

Summary: Beam energy is stabilized by detecting beam displacements, due to potential changes at the high voltage terminal, on a horizontal slit situated at the exit of the electrostatic analyser. Differential currents, due to off-centring of the ion beam on this slit, are amplified and used to control the magnitude of corona discharge loading via the corona triode. Thus beam movements alter the loading on the generator and so regulate its output voltage. This system controls the energy of the particles emerging from the exit of the electrostatic analyser to an accuracy of one part in 10^3 over long periods.

1. Introduction

An investigation to improve the voltage performance of the 4-MeV pressurized electrostatic generator at the A.E.I. Research Laboratory led to the design of a new electrode configuration in the accelerator tube. The detailed design and advantages of this tube over its predecessors has been made the subject of a paper by D. R. Chick *et al*[1], and will not be discussed here. A direct consequence of using this tube is the necessity to change the existing fast-acting voltage control system, which stabilized the energy of the ion beam in conjunction with the spray current control.

During the past few years the ion beam energy has been stabilized very successfully by a combined feedback system, developed by Millar *et al*[2], in which an electron beam loading the generator high voltage terminal is used as a fast-acting control device and slow changes are corrected by the spray-current servo loop. Fast control of the top terminal potential by the electron beam method is impracticable due to the "waisted" configuration used in the electrode design of the new accelerator tube. The required energy stability is now achieved by an alternative feedback system which involves controlling the corona current loading at the high voltage terminal[3, 4]. The ion energy is monitored by electrostatic deflection and energy errors are converted into electrical signals which, on amplification control the magnitude of corona current loading at the high voltage electrode. As with the previous system, the overall measurement accuracy and stability of the ion beam energy is better than 0·1 per cent.

2. Detailed Description of the Method of Energy Control

A schematic diagram of the energy control system is shown in Fig. 1. The absolute energy of the particles accelerated by the 4-MeV electrostatic generator is determined by deflecting them through a 63·2 deg electrostatic analyser, the deflecting potential of which is accurately known and highly stable[5]. The system functions by intercepting a small fraction of ion beam on two molybdenum plates forming a horizontal slit for the beam to pass through at the exit of the analyser. The spacing between the slit is set to give the required energy resolution. The energy of the ion beam passing through the analyser exit slits is given approximately by the expression

$$eV = \frac{v\,e\,r}{2D}$$

where eV is the particle energy in electron-volts, v is the voltage applied to the deflector electrodes by the electrostatic analyser, r is the mean radius of these electrodes and D is their separation.

† Manuscript received 29th January, 1960. (Paper No. 581.)

‡ Associated Electrical Industries Ltd., Research Laboratory, Aldermaston, Berkshire. Communicated by Dr. D. R. Chick (Member).

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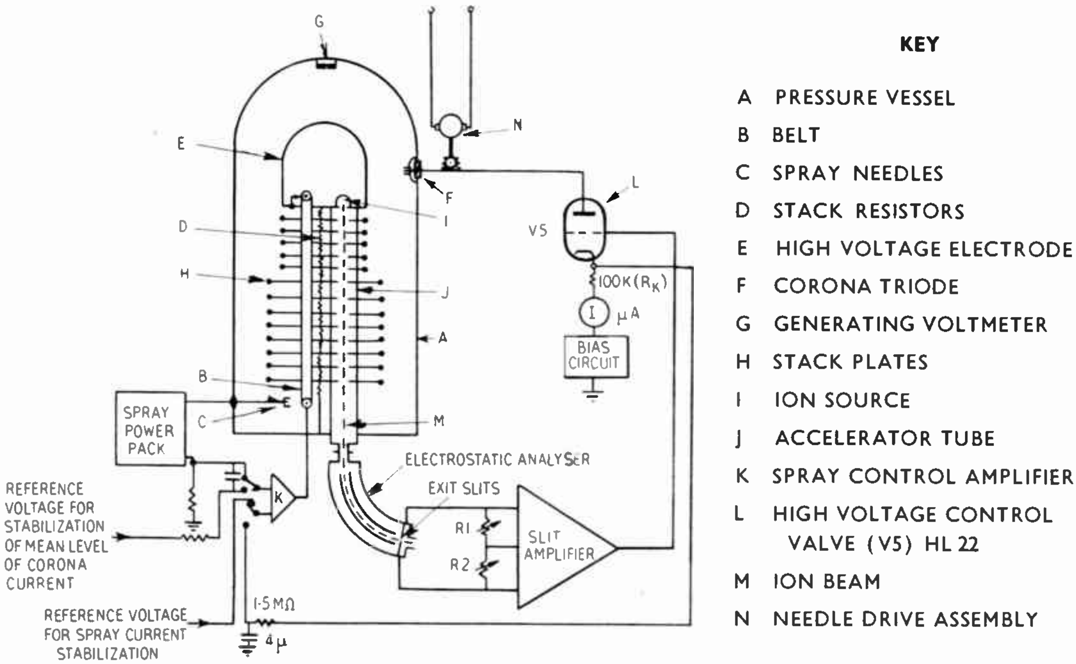

Fig. 1. Diagram of energy control system using corona current loading.

Each slit is returned to earth through a 2-megohm variable resistor, the values of which are adjusted until the maximum beam of the required mass is obtained. Movements in beam position, which correspond to energy errors, produce differential voltage signals between the two plates. This error signal is then amplified in a balanced d.c amplifier, whose output is fed to the grid of a high voltage triode. The anode of this valve is connected in series with a set of movable corona points, and its cathode to earth, thus forming a variable loading path between the high voltage terminal and earth.

The spray current stabilizer, developed by Millar[2], is incorporated in the system without modification. Spray is applied to the generator belt through a set of sharp needles which are placed 3/16 in. from the belt and opposite the bottom pulley. The potential to the spray needles can be controlled manually over a range 0 to +75 kV d.c.; the voltage to the bottom pulley, which is variable over a range 0 to +14 kV, is controlled electronically to maintain the spray current at a value determined by either a manually-operated reference voltage or the mean value of corona discharge current. In the latter case, a d.c. signal proportional to the mean corona current is developed across a 100-kilohm resistor connected between V5 cathode and earth. This voltage is compared with manually-adjusted reference voltage and any unbalance is amplified and used to vary the bottom pulley potential. Thus a change of load on the generator immediately produces a compensating change in corona current. This is followed by a slower change in spray current, so that the mean corona current returns to very near its normal value.

3. Stability Considerations

Fluctuations of generator terminal voltage, due to any cause, will produce variations in ion beam energy and will have to be reduced by the stabilizing circuits. These fluctuations can be separated into two classes:

(a) Fast voltage changes due mainly to varying surface conditions of the charging belt, local corona conditions on the high voltage electrode and insulating columns and effects of ionization currents in the insulating gas.

(b) Slow voltage changes due to the integrated change in the conditions mentioned in (a).

With belt speed, charging current and other input conditions held as constant as is practical, the unregulated voltage of the generator varies by $\sim \pm 2$ per cent. over long periods. These variations must be reduced by the feedback system to less than $\pm 0{\cdot}1$ per cent. before the accelerator can be successfully used as a research tool for nuclear physics. High-frequency voltage fluctuations are sufficiently attenuated by the long integrating time-constant ($\sim$ 2 sec) of the high voltage terminal. However, adequate loop gain should be available at a frequency of 3 c/s, at which frequency joins in the belt produce an objectionable ripple. Many factors, which are not strictly controlled, affect the loop gain of the system, e.g., beam current, beam geometry, terminal voltage, etc. (see Appendix for approximate d.c. loop gain calculation). To satisfy the stability requirements, the zero frequency loop gain should be at least 500, the loop gain at 3 c/s being about 10. Allowing a reasonable margin for stability the working d.c. loop gain of the stabilizer is in the region of 10^3.

4. The Corona Triode

The study of negative point to positive plane corona discharge is well advanced and has been published extensively[6, 7], etc. It is not therefore necessary to deal with the complex physical processes involved in the action of a corona triode in a pressurized gas.

If a group of sharp points are suitably inserted in the wall of the pressure vessel opposite the high-voltage electrode it will become a source of corona current to the electrode. This corona discharge may be controlled in two ways:

(a) by mechanically adjusting the distance between the points and the h.v. electrode. Figure 2 shows a few of the voltage-current characteristics obtained;

(b) by varying the potential of the points with respect to the earthed grid.

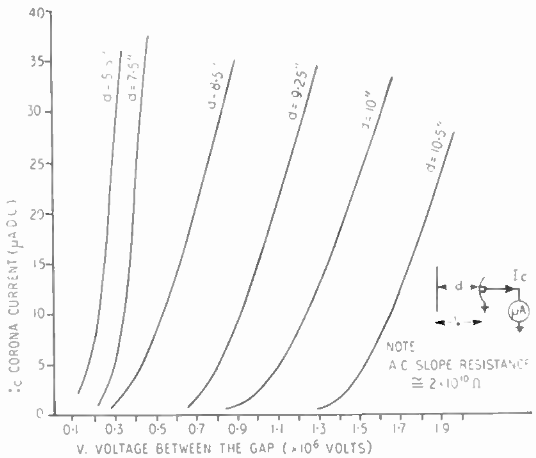

Fig. 2. Voltage/current characteristics of corona triode with gap distance as parameter.

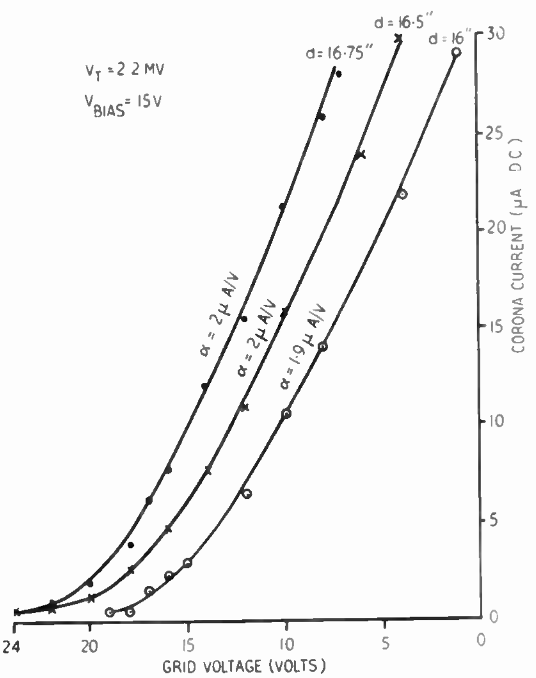

Fig. 3. Mutual conductance characteristics of the corona triode and its associated control valve.

When the top terminal voltage is changed through large limits, the position of the corona points with respect to the terminal must be so related to the actual terminal potential as to cause V5 to draw 25 microamps from the terminal. This quiescent current is the centre

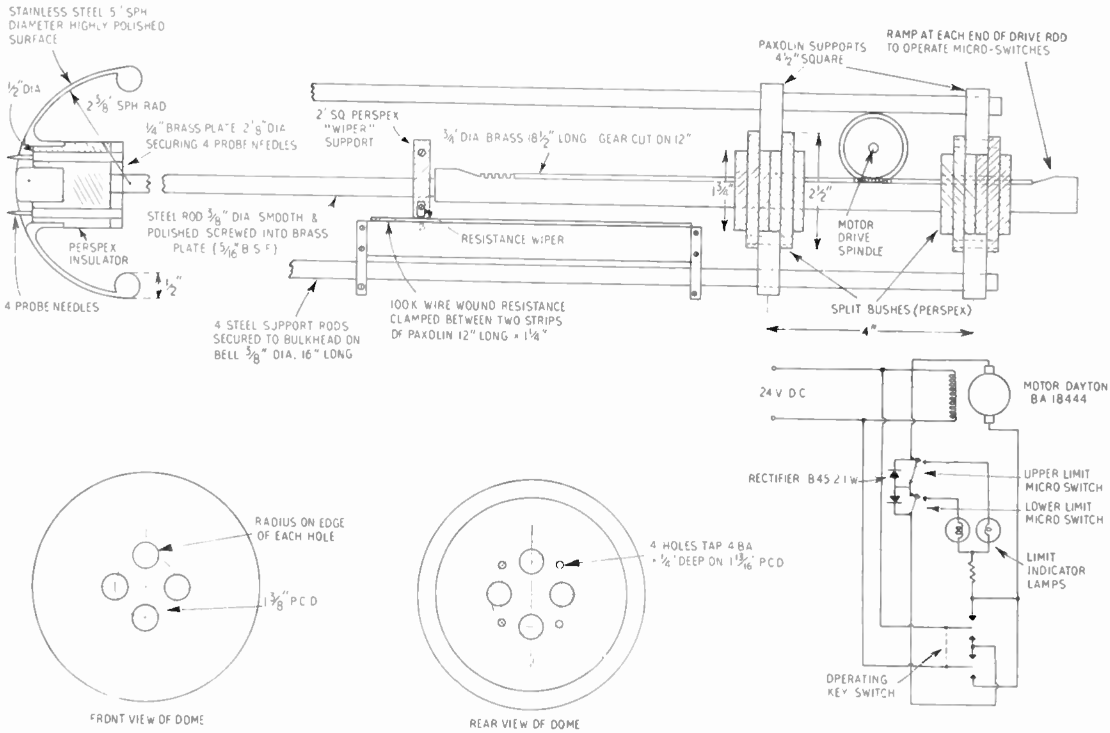

Fig. 4. Geometry of the corona triode.

of its control range and is indicated on a meter. Raising the potential of the points several kilovolts above earth produces a redistribution of the field lines from the electrode, so that the field strength at the discharge point is very much reduced. This is easily achieved by connecting the corona points, which are insulated, to the anode of the high voltage triode. Variation of corona current is effected by changing the grid potential of V5. Several static d.c. characteristics were measured and a few of these are presented in Fig. 3. It is noted that the effective g_m, α, of the corona triode and high-voltage triode in series is relatively constant for different gaps, bias and high voltage electrode potentials. A typical figure for α is 1·5μA per grid volt to the HL.22. A change of 1μA loading varies the high voltage electrode by 10 kV. Therefore, the effective control range is ±250 kV.

The time taken for the ions formed by corona discharge to cross the high-voltage gap is characterized by a delay and this was checked experimentally by observing the response of the corona triode and its control valve under transient conditions. The output was monitored across the cathode resistor (100 k) of V5 and an input step of 10 V was applied to its grid. The measured delay was approximately 0·5 millisec.

4.1. *Mechanical Details of the Corona Triode*

A diagram illuustrating the geometry of the triode is shown in Fig. 4. It consists essentially of a set of four sharp points (the cathode) inserted through and insulated from an earthed, hemispherical, steel shell (the grid). The high voltage electrode forms the anode. The grid-cathode assembly is completely moveable over a range of 10 in. and can be remotely controlled by a 24 V motorized drive unit. When the assembly is fully extended from the h.v. electrode, the corona points are in line with the inner surface of the pressure vessel; this distance is 17·5 in. Limit switches, which are mounted at the extremities of the needle travel and connected in series with the motor's d.c. supply, provide protection against the motor overdriving the assembly. The position of the corona points is monitored continuously by using a simple d.c. potentiometer system and displayed on meters in the Target and Remote Control Room.

5. Static and Dynamic Analysis of the Energy Control System

5.1. *Approximate Zero Frequency Loop Gain of Corona Discharge Feedback System*

The zero frequency loop gain has been analysed and is discussed in the Appendix. The required voltage gain, A, of the differential amplifier, for a given loop gain, is

$$\frac{\text{LOOP GAIN} \cdot V_T \cdot d}{2\alpha \cdot I_B \cdot R_1 \cdot r(1-\cos\theta)} \left[\frac{R_S R_C + R_S R_B + R_B R_C}{R_C R_S R_B}\right]$$

For a loop gain of 10^3 and substituting typical values for all parameters in the above expression,

e.g. $V_T = 2 \times 10^6$ volts, $d = 1$ mm, $r = 910$ mm, $\theta = 63{\cdot}2°$, $\alpha = 1{\cdot}5\ \mu A/V$, $I_B = 5\ \mu A$, $R_1 = 10^6 \Omega$, and

$$\frac{R_C R_S R_B}{R_S R_C + R_S R_B + R_B R_C} = 2 \times 10^{10} \Omega,$$

one obtains the result that the voltage gain of the amplifier must be in the region of 20. Experimentally the loop functioned satisfactorily, from a stability viewpoint, with an amplifier gain of 60.

5.2. *Stability Analysis*

The effective time-constant of the high-voltage electrode is about two seconds, produced by an effective resistance of approximately 2×10^{10} ohms in parallel with the capacitance of the top terminal to tank which is calculated to be 100 pF[8]. As this time-constant is inherent in the machine, use is made of dominant lag techniques to stabilize the feedback system, which is essentially a three lag type[9]. To ensure stability, the time constant of the dominant lag (T_D) must be greater than $2/\pi$ times the sum of the other time constants (ΣT) in the loop times the Z.F. loop gain,

$$\text{or} \quad G_{\text{CRIT}} = \frac{\pi}{2} \frac{T_D}{\Sigma T}$$

The sum of the other time constants in the loop is approximately 0·52 millisec and is made up of 15 microsec for the slit amplifier and about 0·5 millisec for the corona triode and its associated control valve (V5). Thus the critical loop gain is in the region 6×10^3, which is above the value of 10^3 in which the system is operating.

The presence of a time delay in the system as opposed to a time constant does not significantly affect the loop stability, since for small phase shifts the characteristics of the lag and delay are almost identical. The delay may cause the Nyquist diagram to encircle the origin a number of times, but the dominant lag does ensure that this spiral never reaches a radius greater than unity.

Experimental measurements of the dynamic behaviour of the complete loop were not made, due to the inherently poor frequency response of the electrostatic generator. However, when the circuit was checked experimentally, it was stable and its performance agreed reasonably well with design figures. The time constant of the machine was checked by observing its transient response. A step voltage was applied to the grid of the control valve, V5, and the output waveform, which was observed between a slit and earth, showed an exponential rise with a time constant of $\sim 2{\cdot}5$ sec.

5.3. *Spray Current Control*

Consider the control of spray current by the corona discharge current loop (see Fig. 1). Here, the input voltage signals to the control amplifier (K) are d.c. coupled from the corona discharge current and reference voltage and a.c. coupled from the spray current, the latter coupling restricting rapid fluctuations in spray current.

The zero frequency loop gain of the system is dependent on a number of factors, namely: amplifier gain (κ), resistance (R_K) and the effective conductance of the spraying system,

$$\text{i.e.} \quad \frac{\text{change in spray current}}{\text{change in pulley potential}}$$

This ratio was determined experimentally as 30 μA/kV and takes into account effects due to temperature, gas pressure and the geometry of the needles.

A typical figure for the zero frequency loop gain for the spray control path is approximately 10^4 and ~ 40 for the loop stabilizing the mean level of corona discharge current.

As the corona-discharge and spray feedback loops are effectively in parallel it is necessary, in order to achieve stability, to control the gain-phase characteristics of the spray loop in such a manner that the transmission falls to less than that through the corona-discharge path before the time delay due to the transit time of the belt becomes significant. This is achieved primarily by the capacitively-coupled feedback from the spray current.

6. Slit Amplifier

Errors in ion beam energy appear as difference voltages between the exit slits of the electrostatic analyser. These voltages provide the input signal to a balanced, three-stage, d.c. amplifier with differential input (V1A, V2A) and cathode follower output (V4). As the loop gain of the energy control system varies with beam current, top terminal voltage and other factors not strictly controlled, the amplifier gain is made variable. This is achieved by the application of overall negative voltage feedback, whereby a selected fraction of the output voltage is fed back through a resistance attenuator to both differential pairs in the input stage (V1B, V2B), (see Figure 5). The output of this amplifier is used to control the magnitude of corona current loading at the high voltage terminal via a high voltage triode (V5). The gain control of the amplifier will give a variation of sensitivity from 10^7 to 10^9 volts/ampere difference to the input.

Effects due to changes in heater voltage and common mode variation, for example fluctuations in ion beam intensity, are minimized by the differential input arrangement. The "amplifier balance" potentiometer is adjusted for zero output with the input open circuited, thus compensating for any offset in bias voltage or grid currents between the differential inputs to the amplifier. Observations have shown that short-time drifts at maximum gain are less than 0·001 microamp, which corresponds to less than 1 per cent. of the minimum usable ion beam current. The measured amplitude/frequency responses of the amplifier for the various gain positions are shown in Fig. 6. Normally an amplifier gain of 60 provides adequate regulation and the bandwidth with this gain is about 10 kc/s. The effective capacitance of the input circuit is reduced by connecting the braid of the coaxial cable to the cathodes of the input valves (V1A, V2A). Slit resistors, R1 and R2, are adjusted approximately to allow the maximum value of the wanted mass component of the beam to pass through the exit slit of the analyser[10].

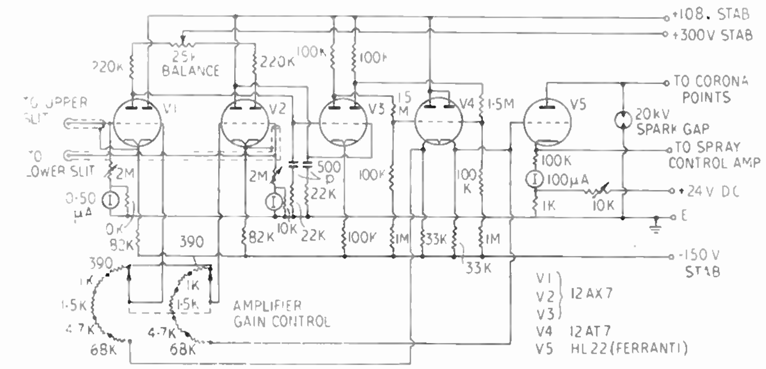

Fig. 5. D.c. slit amplifier and h.v. control valve.

7. Accuracy and Performance

Many factors affect the accuracy and performance of this stabilizing system. It is evident that the analyser geometry and applied voltage are the primary parameters in the determination of the energy of the ion beam. Analyser errors have been estimated by Hunt *et al*[5] and an overall accuracy of one part in a thousand was ascribed to the energy determination. As the inherent regulation of the machine is tolerably good (±2 per cent.) the value of applied loop gain reduces energy fluctuations to less than 0·01 per cent., which exceeds the required specification.

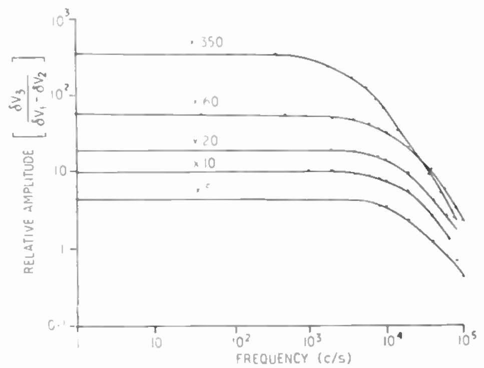

Fig. 6. Amplitude response characteristics of d.c. slit amplifier.

8. Conclusions

The system described has been used continuously for eighteen months and provides a stable ion beam at a selected energy in the range 0·3—3·25 MeV. The upper limit is, at present, set by voltage breakdown of the electrostatic analyser. The loss of beam current depends to a very large extent on the focusing of the beam spot at the entrance to the analyser and the alignment of the analyser on the axis of the beam. Under optimum conditions this loss has been as low as 10 per cent.

9. Future Developments

While this system functions satisfactorily, it has the disadvantage that the axial position of the corona needles has to be adjustable to permit satisfactory operation over a range of top terminal potentials. This disadvantage can be avoided by using a corona triode arrangement[11] (see Fig. 7) where a true grid is situated between the corona needles and the high voltage terminal. A positive bias potential (V_g) applied between grid and needles causes corona discharge from the needles. The fraction of this current which is collected on the high voltage terminal depends on the grid transmission and the h.v. potential. The presence of the grid, which will consist of 16-mesh copper spaced $\frac{1}{8}$ in. from the four corona needle points, makes the corona discharge from the needles substantially independent of the high voltage potential. As before, a series control valve will regulate the flow of corona current from the needles in accordance with the error signal.

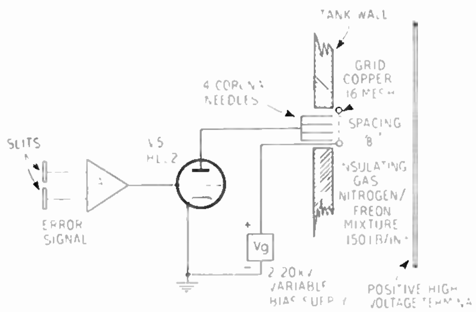

Fig. 7. Proposed modification to corona triode arrangement.

At the present time, the generating voltmeter is used solely as an auxiliary voltage measuring device. It is proposed to modify the generating voltmeter circuits, developed by Millar[2], for coarse error detection and incorporate the altered system in the feedback arrangement.

10. Acknowledgments

The author is indebted to many of his colleagues for assistance received during the progress of the work, in particular Dr. S. E. Hunt, Dr. D. R. Chick, Mr. D. Keith-Walker and Mr. B. Millar for helpful discussions. The geometric design of the corona triode is based largely on one in existence at A.E.R.E., Harwell. Thanks are also due to Mr. W. W. Evans who operated the machine, Mr. G. Burrell and Mr. D. De Costa who carried out the construction and installation work of the equipment and Mr. H. A. Strevens for his part in manufacturing the corona triode. The author would also like to thank Dr. T. E. Allibone, C.B.E., F.R.S., Director of the Laboratory, for permission to publish this work.

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12. Appendix

Approximate Zero Frequency Loop Gain of Corona Loading Feedback System

Glossary of Symbols

V_T top terminal potential

V_1 voltage applied to electrode of electrostatic analyser

D separation of the electrodes of the electrostatic analyser

R_S stack resistance

R_B effective beam resistance

R_C effective corona resistance

R_1 slit resistors (assumed equal)

I_B ion beam current

I_C corona discharge current

d vertical dimension of the ion beam

S1 and S2 upper and lower slits respectively

δI_1 and δI_2 incremental currents due to beam energy errors

δV_1 and δV_2 incremental voltages developed across R_1

δV_3 incremental output voltage of slit amplifier due to input signal $\delta V_1 - \delta V_2$

A = voltage gain of slit amplifier $= \dfrac{\delta V_3}{\delta V_1 - \delta V_2}$

$\alpha = \dfrac{\text{change in corona current}}{\text{change in grid voltage to h.v. triode}} = \dfrac{\delta I_C}{\delta V_3}$

r = radius of deflection of the electrostatic analyser

θ = deflection angle of electrostatic analyser

A block diagram of the loop is shown in Fig. 8(a).

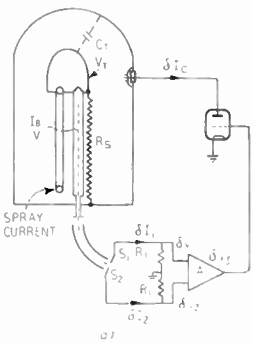

Fig. 8(a). The principal components involved in the approximate loop gain calculation.

Consider the loop broken at the exit of the electrostatic analyser and imagine a change δd of ion beam position on the slits. Under normal conditions the area of the beam striking the slits is of rectangular shape with dimensions as shown in Fig. 8(b).

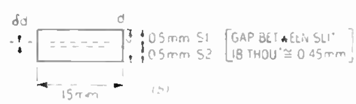

Fig. 8(b). Geometry of the ion beam striking slit system.

Consider S1,

incremental current $\delta I_1 = +\delta d/d \,.\, I_B$

and S2,

incremental current $\delta I_2 = -\delta d/d \,.\, I_B$

Hence incremental voltage at S1

$= +\delta d/d \,.\, I_B \,.\, R_1 = \delta V_1$

and incremental voltage at S2

$$= -\delta d/d \,.\, I_B \,.\, R_1 = \delta V_2$$

Now differential amplifier gain A

$$= \frac{\delta V_3}{\delta V_1 - \delta V_2}$$

$$\text{Therefore } \delta V_3 = 2A \,.\, I_B \,.\, R_1 \frac{\delta d}{d} \quad \text{............(1)}$$

If the "effective g_m" of the corona triode and its high voltage control triode is

$$\alpha = \frac{\delta I_C}{\delta V_3}$$

then from eqn. (1)

$$\delta I_C = 2\alpha \,.\, A \,.\, I_B \,.\, R_1 \,.\, \frac{\delta d}{d} \quad \text{.......(2)}$$

Assuming the belt impedance is infinite, the equivalent resistance network R' at the high-voltage electrode, under working conditions, is the parallel combination of R_B, R_S and R_C, where

$$R' = \frac{R_C \, R_S \, R_B}{R_S \, R_C + R_S \, R_B + R_B \, R_C}$$

Change in terminal voltage (δV_T) due to a change in corona discharge current, δI_C, is therefore.

$$\delta V_T = \delta I_C \, [R'] \quad \text{.........(3)}$$

It is required to find Δd (compensating change in beam position at exit slits for δV_T change at the high voltage terminal).

$$\text{For electrostatic deflection } V_T = \frac{V_1 r}{2D} \quad \text{.........(4)}$$

As the electrode potential of the analyser is constant for a particular energy

$$V_T = \kappa r \text{ where } \kappa = \frac{V_1}{2D}$$

A change in beam potential produces a change in radial deflection of the ion beam:

$$dV_T = \kappa dr = \frac{V_T}{r} dr \quad \text{.........(5)}$$

To obtain the resultant deflection Δd at the exit slits of the analyser, consider ΔABC in Fig. 8(c).

Here	AX	=	r
	BC	=	$r + dr$
	AB	=	dr
	AC	=	x (unknown)

Applying the cosine law

$$(r + dr)^2 = (dr)^2 + x^2 + 2x \, dr \cos\theta$$

Therefore $x^2 + 2dr\cos\theta \; x - (r^2 + 2rdr) = 0$.

From which

$$x = -dr\cos\theta \pm r\left(1 + \frac{dr^2\cos^2\theta + 2rdr}{r^2}\right)^{\frac{1}{2}}$$

$$= -dr\cos\theta \pm r\left(1 + \tfrac{1}{2}\left\{\frac{dr^2\cos^2\theta + 2rdr}{r^2}\right\} + \ldots\right)$$

Take the positive sign

$$x = -dr\cos\theta + r\left(1 + \tfrac{1}{2}\left\{\frac{dr}{r}\right\}^2\cos^2\theta + \frac{dr}{r} + \text{second and higher } \left\{\frac{dr}{r}\right\}^2 \text{ terms}\right)$$

$$\text{Thus } x = -dr\cos\theta + r\left[1 + \frac{dr}{r} + \ldots\right]$$

$$\text{Thus } \Delta d = XC = x - r = dr(1 - \cos\theta) \quad \text{......(6)}$$

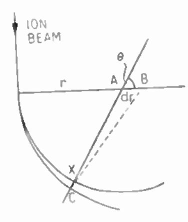

Fig. 8(c). Resultant beam displacement at exit slits when beam potential changes.

Substituting eqn. (6) in eqn. (5)

$$dV_T = \frac{V_T}{r} \cdot \frac{\Delta d}{(1 - \cos\theta)} \quad \text{.........(7)}$$

Hence, from eqns. (2), (3) and (7):

$$\Delta d = \frac{r(1 - \cos\theta)}{V_T} \,.\, 2\alpha \; A \; I_B \; R_1 \frac{\delta d}{d} \; [R']$$

Thus loop gain

$$\frac{\Delta d}{\delta d} = \frac{2\alpha A \; I_B \; R_1}{V_T} \cdot \frac{r(1 - \cos\theta)}{d} \; [R']$$

LONDON'S RADIO SHOWS

For the first time, two public radio exhibitions were held in London during the same week. The National Radio and Television Exhibition opened at Earls Court on 24th August for the customary ten-day period, while Pye Limited who for various reasons had decided not to participate in the annual industry function, held their own show from August 22nd-24th at the Royal Festival Hall. Public interest in these two exhibitions was considerable: the attendance at the National Radio Show of 340,276 was over 35,000 greater than in 1959 while the attendance at the Royal Festival Hall Show was estimated at 175,000.

Transistorized portable television receivers were featured at both shows and provided the most striking technical feature in television development this year. The Pye receiver has a 14 in. screen, covers all the usual B.B.C. and I.T.A. channels and included a built-in aerial for use in reasonably strong signal areas. The set has 26 transistors, plus 11 germanium diodes, 3 silicon diodes and 1 e.h.t. thermionic diode; its weight is about 38 lb. The receiver operates exactly like any other when used connected to a mains supply, but has in addition a 4-position selector switch: internal battery operation only; mains operation with trickle charging of batteries; full mains charging only; external 12 V battery operation only.

Ferguson's portable is smaller and lighter (20 lb.) and has a 7 in. tube. The complement of semiconductor elements is 24 transistors and 15 diodes with 2 e.h.t. rectifiers; battery life is 4 hours and a charging unit is incorporated. There is a 13 channel tuner and the circuit employs amplified d.c. vision a.g.c.; the speaker is underneath and in operation the receiver is tilted slightly upwards on a rest.

This year sees the incorporation in the television receivers of several manufacturers of the automatic contrast control introduced by Mullard at the last Show.* This consists of a small photosensitive resistor which adjusts the vision a.g.c. voltage according to variation in ambient light.

Several manufacturers showed remote controls for television receivers. Some employ a wire connection, but ultrasonic control, using either a transistorized oscillator or a mechanically energized reed permits complete freedom to the user. Frequencies employed are from 40-45 kc/s and the microphone in the receiver actuates a step-by-step control on the volume control or on the channel change switch using slightly different frequencies (± 3 kc/s) for the different functions.

At the Institution's 1959 Television Engineering Convention a paper was presented by a Pye engineer associated with a French manufacturer on a dual standard television receiver. In expectation of gradual introduction in Great Britain of 625 line transmissions in Band IV, Pye showed a 405/625 receiver which is immediately switchable from one standard to the other.†

In the field of sound radio, transistorized table v.h.f. receivers and portable v.h.f. receivers are now being produced by a few manufacturers and the number of transistorized car radios is increasing. Among the latter is the Ever-ready model which operates in the car using the car battery, aerial and speaker but can be removed—without interrupting operation—to function as a portable using its own built-in aerial, battery and speaker.

A large Audio section was again an important feature of the Earls Court Show and among the many stereophonic equipments the G.E.C. showed a three-speaker arrangement in which the centre speaker takes part of the signal of each channel and combines it, thus "filling the gap." Tape recorders are another field in which transistors are being successfully employed and useful battery economy is being achieved. Four-track tape recorders were shown for home use.

The Pye exhibition included numerous exhibits of the category usually termed "professional equipment," notably a remote handling closed circuit television chain with a stereophonic attachment employing a mirror beam splitting system. A low cost closed-circuit television equipment by Nash and Thompson appeared at Earls Court as an adjunct to the stands of some of the set exhibitors. It operates with standard domestic receivers and the camera incorporates the control unit, the size being only 12 in. × 7 in. × 6 in. and weight 16 lb.

Some of the uses of radio in the three Services, the Post Office and the Police Force were shown, and among these the contribution by the R.A.F. Technical College, Henlow, of a number of electronic training aids was particularly interesting. These included dekatron counters and a demonstration of the synthesis of waveforms from multivibrators. A new type of exhibit of an educational character this year was a display showing in simplified terms the theory of operation of transistors and other semi-conductor devices. Some typical transistorized equipments were also shown and the feature was well worth examination.

* "The 1959 British Radio Show," *J. Brit.I.R.E.*, **19**, pp. 553-4, September 1959.

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Features of Cylindrical Waveguides containing Gyromagnetic Media †

by

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Summary: A number of results are presented of computations of the electromagnetic field components and density of energy flow, as functions of position in the transverse plane, for the H_{11} mode in a cylindrical waveguide of radius a containing a concentric ferrite rod of radius b. Typical values are chosen for the ferrite properties, and three values of a (normalized with respect to wavelength) that are likely to be found in practice. Values of b/a ranging from 0 to 1 are taken.

This paper continues and concludes the work published earlier by the author on cylindrical waveguides with ferrite. In the present work, the aim is not only to present field components and power distributions for given values of a and b, but also to show how these vary as a and b vary. The results are discussed in relation to each other and to the phase constant curves previously obtained. It is concluded that the behaviour of these cylindrical systems is mainly dependent not on the ratio b/a but on b alone.

List of Symbols

- a — waveguide radius.
- b — ferrite radius.
- λ_0 — wavelength in an infinite extent of the medium that occupies the part of the waveguide not occupied by ferrite.
- μ, α, ε — respectively the diagonal and off-diagonal elements of the relative permeability tensor and the relative permittivity of the ferrite rod; these quantities are relative to the properties of the medium which occupies the part of the waveguide not occupied by ferrite.
- β — phase constant $= 2\pi/\lambda_0$
- λ_g — wavelength in the guide.
- $\bar{\beta}$ — normalized phase constant $= \lambda_0 \beta/2\pi = \lambda_0/\lambda_g$.

M.K.S. units are used, so that λ_0, λ_g, a, and b are in metres.

1. Introduction

In an earlier work[1], the mode spectra and phase constants of cylindrical waveguides containing concentric ferrite rods were studied. That work was published in three parts, and the present paper might be regarded as a fourth and final part of the work. It is our aim to study the properties of the H_{11} mode in such systems, and to see how the distribution of density of energy flow and the field components, obtained as functions of position in the transverse plane, vary as the radius ratio b/a increases from 0 to 1. These results are compared with the values of the phase constant, and it is shown that the behaviour of the phase constant as b/a varies is related to the behaviour of the field components.

2. Calculations and Results

2.1. *Field Components*

Formulae for the field components were published in the previous work, and these were used in the present work to compute the various field components. The values so obtained contained an arbitrary scale factor, different for each set

† Manuscript received 18th November 1959. (Paper No. 582.)

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U.D.C. No. 621.372.852.22

of results. The energy flow in the guide was calculated as in Section 2.2, and from this normalization factors were obtained. The results of the field component calculations are now given in Figs. 1, 2, and 3, scaled so that the total power in the guide cross-section is λ_0^2 watts if λ_0 is measured in metres. For given values of a and λ_0, the results for the appropriate value of a/λ_0 should be taken, and the given values of the field components should be divided by λ_0 to give the values when the power in the guide is 1 watt. For example, if λ_0 is 3 cm = 0·03 metres, the field components given in this paper should be divided by 0·03 to give the values for which the power in the guide is 1 watt.

Only the magnitudes of the field components are given in Figs. 1, 2, and 3. The relative phases are shown in Table 1. In particular, it should be noted that E_r and H_θ have maxima on the line $\theta = 0$, while E_θ and H_r have maxima on the line $\theta = 90°$. The values given in Figs. 1, 2 and 3 are the maximum values of the field components. E_z, for example, has the values given on the line $\theta = 0$, in the plane $z = \pi/2\beta$, at time $t = -\pi/2\omega$. The values given for the

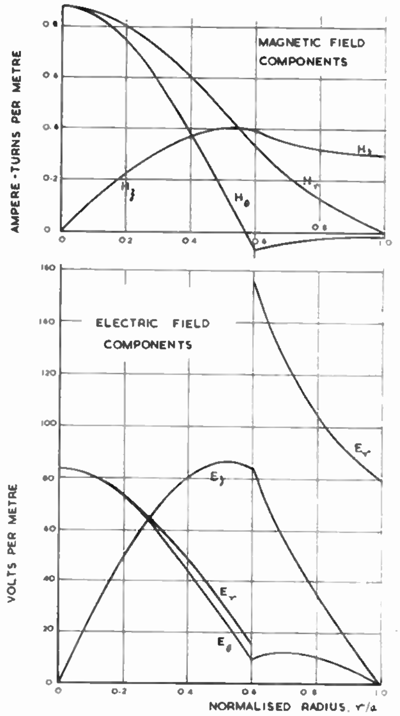


Fig. 1. (a) Field components, $a/\lambda_0 = 0{\cdot}2$, $\varepsilon = 10$, $\mu = 1$, $\alpha = 0$, $b/a = 0{\cdot}6$.

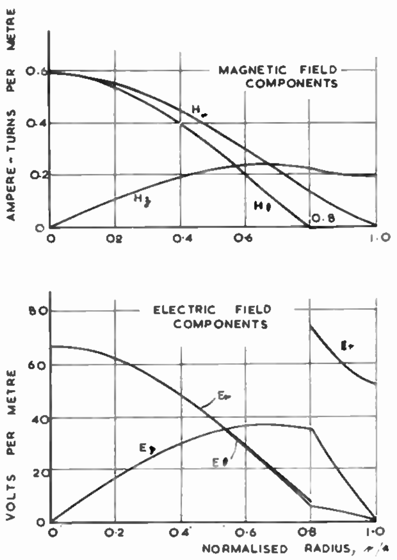


Fig. 1. (b) Field components, $a/\lambda_0 = 0{\cdot}2$, $\varepsilon = 10$, $\mu = 1$, $\alpha = 0$, $b/a = 0{\cdot}8$.

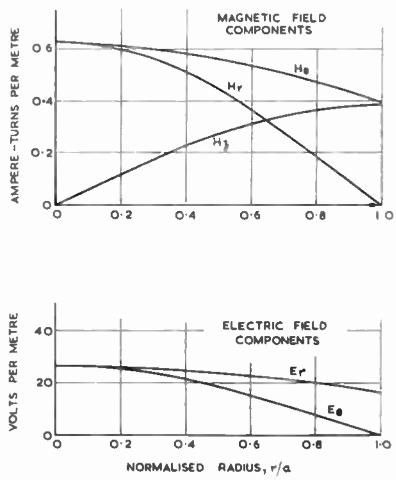


Fig. 1. (c) Field components, $a/\lambda_0 = 0{\cdot}2$, $\varepsilon = 10$, $\mu = 1$, $\alpha = 0$, $b/a = 1{\cdot}0$.

field components must therefore be multiplied by factors $\begin{Bmatrix} \cos \\ \sin \end{Bmatrix} \theta, \begin{Bmatrix} \cos \\ \sin \end{Bmatrix} \beta z, \begin{Bmatrix} \cos \\ \sin \end{Bmatrix} \omega t.$

Table 1

Phase Factors of the Field Components

Field Component	Phase in θ	Phase in z	Phase in t
E_z	0	$\pi/2$	$-\pi/2$
E_r	0	0	$\pi/2$
E_θ	$\pi/2$	0	$\pi/2$
H_z	$\pi/2$	0	0
H_r	$\pi/2$	$\pi/2$	0
H_θ	0	$\pi/2$	0

2.2. *Power Distribution*

The power per unit area at a point in the cross-section of a simple waveguide is usually expressed as $\mathbf{E}\times\mathbf{H}^*$, the asterisk (*) denoting the complex conjugate. This expression is an appealing way of expressing $\mathbf{E}\times\mathbf{H}$ with the factors $e^{-j\beta z}$, $e^{j\omega t}$, dropped. In the case of a homogeneous simple perfect (h.s.p.) waveguide, the two expressions amount to the same thing, since the functions of r and θ comprised in $\mathbf{E}$ and $\mathbf{H}$ are real. By a homogeneous waveguide, we mean one in which a single homogeneous medium is contained within a boundary surface. By simple, we mean that all media present have only scalar properties. By perfect is meant that the properties of all media are real, or imaginary and infinite, but not complex—i.e. the media are lossless. A h.s.p. waveguide is a cylinder (of any cross-section) of homogeneous lossless scalar dielectric or magnetic material, the boundary surface being everywhere in contact with a perfect conductor. Homogeneous simple waveguides are well-known, with metallic boundary surfaces which approximate to perfect conductors, so that the well-known waveguides approximate to perfect waveguides.

When a waveguide is considered that is not homogeneous, or not simple, or not perfect, in the above senses, the functions of r and θ involved in the expressions for $\mathbf{E}$ and $\mathbf{H}$ are in general no longer real, and $\mathbf{E}\times\mathbf{H}^*$ is not the same thing as $\mathbf{E}\times\mathbf{H}$ with the z- and time-dependence dropped. The latter expression must now be used, not $\mathbf{E}\times\mathbf{H}^*$. This is an example of the fact that the waveguide theory presented in elementary text-books, which is applicable to h.s.p. waveguides, is often not valid for waveguides which are not homogeneous or simple or perfect. The h.s.p. waveguide is a trivial case of a more general waveguide, and the mathematics is correspondingly simple. In dealing with non-h.s.p. waveguides, the habits of thought that are built up in studying h.s.p. guides must be suppressed if difficulties are to be avoided. We shall see other examples of the breakdown of the orthodox approach in Sections 3.1 and 4.

When the product $\mathbf{E}\times\mathbf{H}$ is formed, with $e^{-j\beta z}$ and $e^{j\omega t}$ dropped, the z component is found to be $|E_rH_\theta|\cos^2\theta+|E_\theta H_r|\sin^2\theta$, where for E_r, H_θ, E_θ, and H_r, only the functions of r are taken. Integration with respect to θ gives the power in an elementary ring dr of radius r as $\pi r\left\{|E_rH_\theta|+|E_\theta H_r|\right\}$ dr. Further integration with respect to r gives the total power in the guide. In the previous work[1], the total power was given analytically; it is, however, much simpler to use the numerical results for E_r, H_θ, E_θ, H_r, and to integrate graphically. The latter procedure was adopted in the present work. No loss of accuracy is entailed; the limiting factor on accuracy is the accuracy of the values of normalized phase constant, $\bar{\beta}$, given in reference 1. It is estimated that the error inherent in the numerical integration process is about 0·5 per cent., while the computed field components are accurate to perhaps 1 per cent. due to the inaccuracy of $\bar{\beta}$. The overall accuracy is therefore not greatly degraded by the graphical integration. On the other hand, if the analytical expressions for power had been used, it is not likely that the accuracy would have been greater than that of the field components, and the labour of computation would have been much greater than in the method that was actually used.

The total power in the guide which is obtained as a result of the graphical integration gives normalization factors for the power per unit area and for the field components. With this normalization, the power per unit area on the lines $\theta = 0°$ (given by E_rH_θ) and $\theta = 90°$ (given by $E_\theta H_r$) are plotted in Figs. 4, 5, 6, and 7. The units are watts per square metre, such

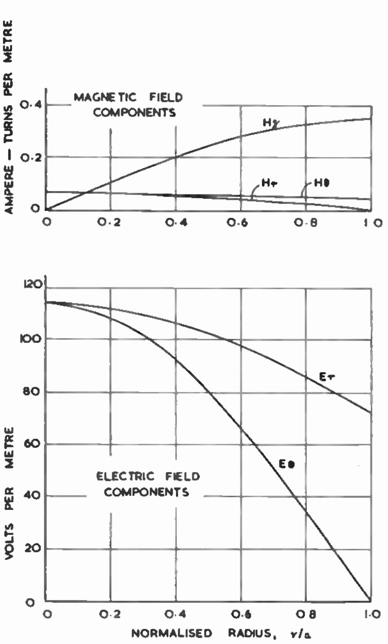


Fig. 2. (a)

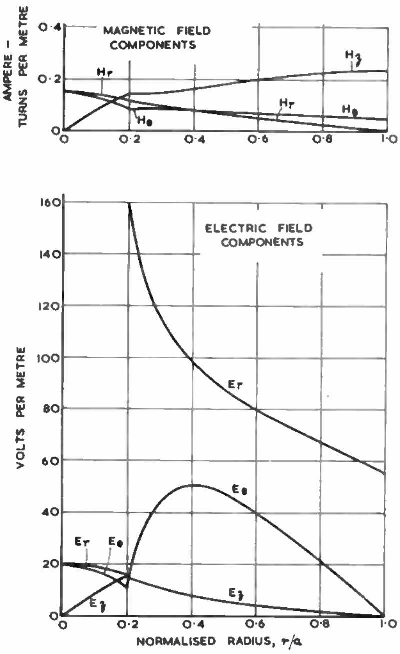
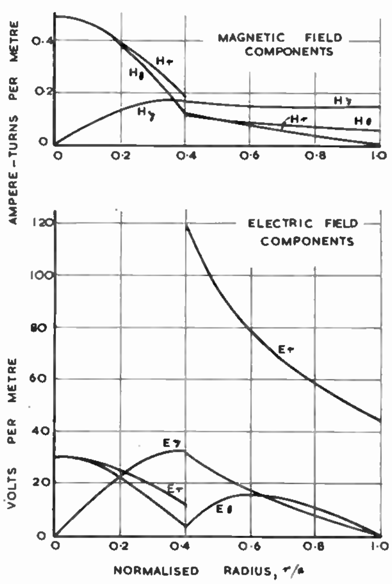


Fig. 2. (b)



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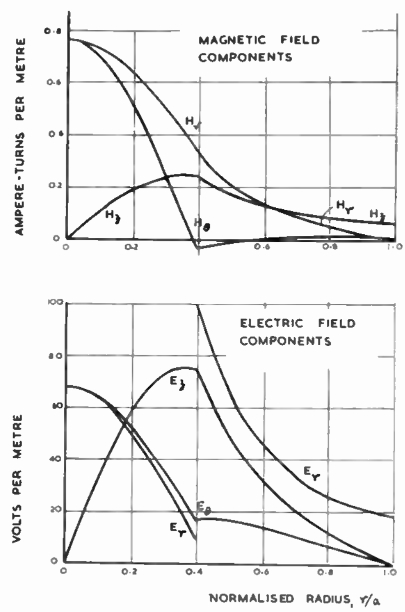

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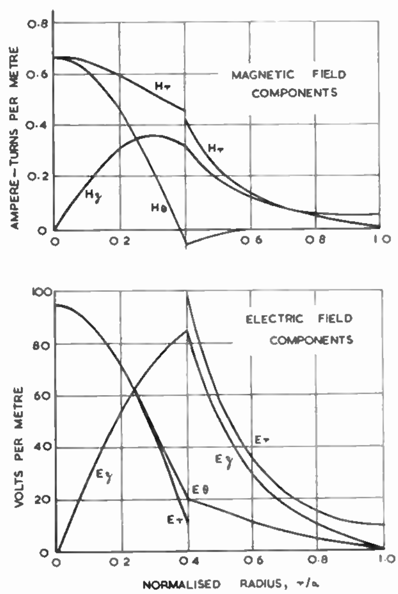

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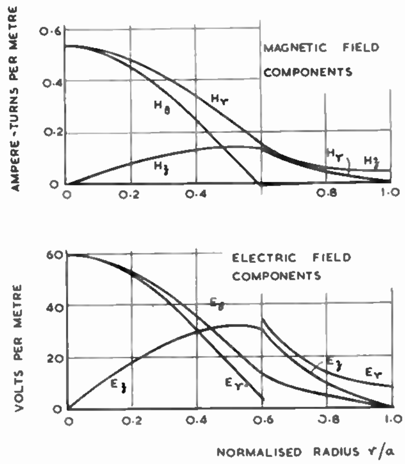

Fig. 2. (f)

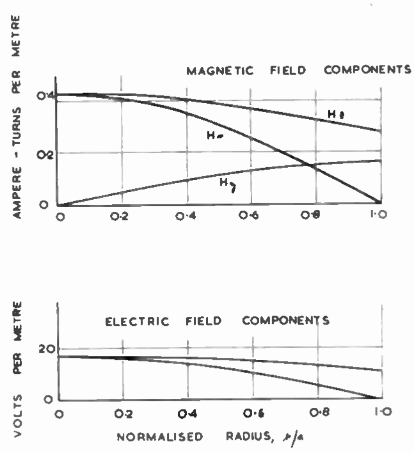

Fig. 2. (g)

Fig. 2. (a) Field components, $a/\lambda_0 = 0{\cdot}3$, $\varepsilon = 10$, $\mu = 1$, $\alpha = 0$, $b/a = 0$.
(b) Field components, $a/\lambda_0 = 0{\cdot}3$, $\varepsilon = 10$, $\mu = 1$, $\alpha = 0$, $b/a = 0{\cdot}2$.
(c) Field components, $a/\lambda_0 = 0{\cdot}3$, $\varepsilon = 10$, $\mu = 1$, $\alpha = -0{\cdot}5$, $b/a = 0{\cdot}4$.
(d) Field components, $a/\lambda_0 = 0{\cdot}3$, $\varepsilon = 10$, $\mu = 1$, $\alpha = 0$, $b/a = 0{\cdot}4$.
(e) Field components, $a/\lambda_0 = 0{\cdot}3$, $\varepsilon = 10$, $\mu = 1$, $\alpha = +0{\cdot}5$, $b/a = 0{\cdot}4$.
(f) Field components, $a/\lambda_0 = 0{\cdot}3$, $\varepsilon = 10$, $\mu = 1$, $\alpha = 0$, $b/a = 0{\cdot}6$.
(g) Field components, $a/\lambda_0 = 0{\cdot}3$, $\varepsilon = 10$, $\mu = 1$, $\alpha = 0$, $b/a = 1$.

that, as with the field components, the total power in the guide is λ_0^2 watts. If λ_0 is known, the power per unit area, such that the total power in the guide is 1 watt, can be obtained by dividing the given values by λ_0^2. For example, if λ_0 is 3 cm, divide by 0·0009.

3. Discussion of the Fields and Powers

3.1. *Field Components*

As a starting-point for discussion, we can consider the empty waveguide. For $a/\lambda_0 = 0{\cdot}2$, the empty guide is cut off, so we can only take $a/\lambda_0 = 0{\cdot}3$ and 0·4 (Figs. 2(a), 3(a). The field components for the empty guide are, of course, well known, but it is convenient to include the results here for completeness and as a basis for comparison. Let us recall certain features of the field components in the empty waveguide.

(1) At $r = 0$, E_θ and E_r are equal and have zero slope.

(2) At $r = a$, E_r and $\partial E_r/\partial r$ are finite and $E_\theta = 0$.

(3) At $r = 0$, H_z is zero, and as r increases from zero H_z increases at first linearly.

(4) At $r = a$, $\partial H_z/\partial r = 0$.

(5) At $r = 0$, H_r and H_θ are equal and have zero slope.

(6) At $r = a$, H_θ and $\partial H_\theta/\partial r$ are finite and $H_r = 0$.

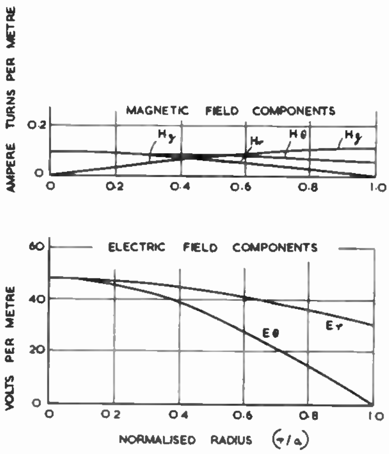

Fig. 3. (a)

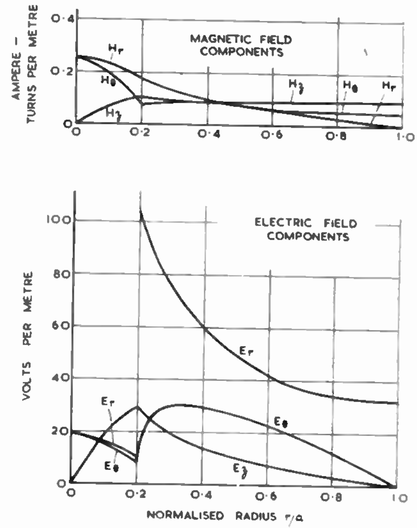

Fig. 3. (b)

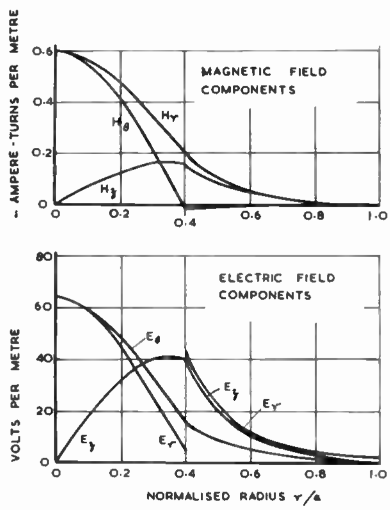

Fig. 3. (c)

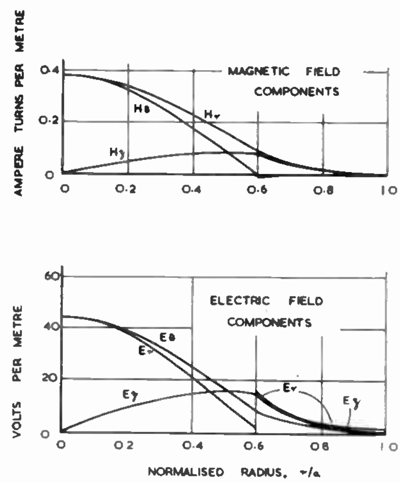

Fig. 3. (d)

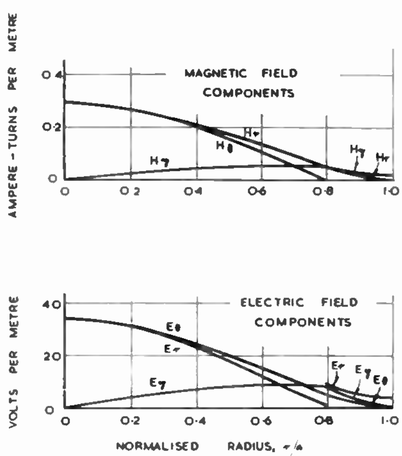

Fig. 3. (e)

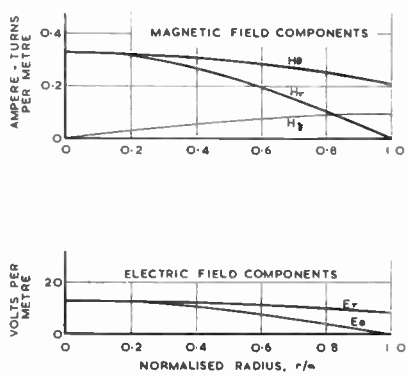

Fig. 3. (f)

These properties of the empty guide, or more generally the h.s.p. guide, also hold for a guide which is not homogeneous and/or not simple, as long as it is perfect. This can be seen to be the case on examining Figs. 1, 2, and 3.

A further feature of the h.s.p. guide is

(7) For all r, $E_z = 0$.

This does not hold in the case of a guide which is not homogeneous and/or not simple, as can be seen from Figs. 1, 2, and 3; although we do not consider the case in this paper, it is also true that E_z does not vanish for all r if the guide is not perfect, whether or not it is homogeneous or simple. Since the guides used until recently have been exclusively h.s.p., or very nearly so, a great deal of importance has been misguidedly attached to the vanishing of E_z in H modes and H_z in E modes. This vanishing is a trivial result, and to attach importance to it can be misleading in a more general case.

In general, there are both E_z and H_z components in a waveguide. There are two series of modes, which for convenience can be called E modes and H modes. It happens that for E modes H_z becomes zero, and for H modes E_z becomes zero, when a general waveguide is reduced (mathematically) to a h.s.p. guide by changing the properties of all the internal media to those of free space, and of the walls to those of a perfect conductor. Looked at in this way, the phenomena are seen to be mathematical accidents of no great significance.

The importance that has hitherto been attached to the vanishing of either E_z or H_z probably arises from an error of thought that is committed in most text-books on waveguides, e.g. Lamont's[2]. From Maxwell's equations, the wave equations for the h.s.p. guide are obtained as a pair, one involving only H_z, the other only E_z. In solving them it is assumed at the outset that solutions can be obtained involving only E_z or only H_z. That this technique works in the case of a h.s.p. waveguide is a matter of sheer luck, for contrary to popular belief the validity of the assumption does not follow from the existence of separate wave equations in E_z and H_z. No argument has ever been put forward to justify the assumption, and in general it is wrong, as we shall now show. For in any waveguide it is possible to write the equations in such a way that one contains only E_z, the other only H_z, and when this is done the operators operating on E_z, H_z respectively, in the two equations are identical. This was actually done in reference 1 for the cases of a cylindrical guide partly filled with ferrite or dielectric, or filled with ferrite. Although the equations were obtained for the lossless case, they can readily be extended to cover the lossy case by taking μ, α, and ε to be complex. If the above assumption were correct, it would immediately follow that for a non-h.s.p. guide E_z would be zero in H modes and H_z in E modes. That this is not the case is evident from the results of this paper for the H_{11} mode, and the result could fairly easily be generalized analytically to all modes from the theory given in reference 1. Evidently for a non-h.s.p. guide the simple technique given in most text-books will not work, and the fact that it does work for the h.s.p. guide is chance.

Conversely, it has been claimed by Kales[3] and by Suhl and Walker[4] that, since the wave equations for a guide containing ferrite can be written as second-order equations only if both contain both E_z and H_z, it follows that neither E_z nor H_z can vanish. While it is true that neither E_z nor H_z does vanish in a guide containing ferrite, this does not follow from the form of the wave equations. This is evident from the preceding paragraph, since by rearranging the wave equations we can, if the usual assumption were true, arrive at precisely the opposite conclusion. Further, if α is put equal to zero in the second-order form of the wave equations that Suhl and Walker and Kales used, they reduce to one containing only E_z and one containing only H_z. According to the well-known assumption used by Lamont, and also according to Kales's and to Suhl's and Walker's arguments, therefore, the modes for a guide

Fig. 3. (a) Field components, $a/\lambda_0 = 0{\cdot}4$, $\varepsilon = 10$, $\mu = 1$, $\alpha = 0$, $b/a = 0$.
(b) Field components, $a/\lambda_0 = 0{\cdot}4$, $\varepsilon = 10$, $\mu = 1$, $\alpha = 0$, $b/a = 0{\cdot}2$.
(c) Field components, $a/\lambda_0 = 0{\cdot}4$, $\varepsilon = 10$, $\mu = 1$, $\alpha = 0$, $b/a = 0{\cdot}4$.
(d) Field components, $a/\lambda_0 = 0{\cdot}4$, $\varepsilon = 10$, $\mu = 1$, $\alpha = 0$, $b/a = 0{\cdot}6$.
(e) Field components, $a/\lambda_0 = 0{\cdot}4$, $\varepsilon = 10$, $\mu = 1$, $\alpha = 0$, $b/a = 0{\cdot}8$.
(f) Field components, $a/\lambda_0 = 0{\cdot}4$, $\varepsilon = 10$, $\mu = 1$, $\alpha = 0$, $b/a = 1{\cdot}0$.

containing a dielectric rod should have either E_z or H_z zero. This conclusion is not borne out by the results of this paper.

The correct way to demonstrate the non-vanishing of both E_z and H_z in the non-h.s.p. guide is to consider the modifications that must be made in the field components of the h.s.p. guide in order that Maxwell's equations shall be satisfied when it is changed to a non-h.s.p. guide. This will require changes in all the field components, including both E_z and H_z, which can therefore not remain zero. That either E_z or H_z will be zero in the h.s.p. guide follows from the fact that the solutions for the wave equations, which are expressions for E_z and H_z involving arbitrary constants, are linearly independent. This is so not only because the wave equations themselves contain only E_z or only H_z (which is a necessary but not sufficient condition, and in any case can, as we have seen, always be satisfied), but because, too, the same wave equation holds over the whole cross-section, and because the medium is isotropic.

Returning now to Figs. 2a, 3a, let us consider what happens when a thin unmagnetized ferrite rod is introduced; we choose the typical properties $\varepsilon = 10$, $\mu = 1$, $\alpha = 0$. The magnetic field components in Figs. 2(b) and 3(b) are clearly slight distortions of those in Figs. 2(a) and 3(a). The electric field components, however, show considerable distortion, which in the cases of E_θ and E_r is attributable to the high value of ε. Near the surface of the waveguide, E_r and E_θ are not greatly altered; the perturbation—the introduction of the rod in the centre of the guide—naturally has least effect at some distance from itself. The result thus confirms one of the basic assumptions of perturbation theory. The condition must be satisfied that at the surface of the rod εE_r in the rod is equal to E_r outside the rod. This is achieved partly by the drastic reduction of E_r in the ferrite, and partly by a steep increase of E_r outside the ferrite, as the ferrite surface is approached.

Since at the centre of the rod $E_r = E_\theta$, the value of the latter in the rod suffers the same drastic reduction as that of E_r. At the surface of the rod E_θ must be continuous, and this condition is satisfied by a drastic reduction in E_θ outside the ferrite, as the ferrite surface is approached.

Figures 2(b) and 3(b) show that an appreciable z-component of electric field has already appeared when $b/a = 0{\cdot}2$, with a peak value at the surface of the ferrite. Near the waveguide wall, and indeed some way in from it, E_z is approaching zero.

Now let us consider the case of a thicker rod ($b/a = 0{\cdot}4$). Figure 2(d) shows that the **E** components are of the same general form as in Fig. 2(b), although E_z has become relatively more important. Figure 3(c) represents a more advanced stage; the maximum of E_θ for a value of r/a greater than b/a has now disappeared. At first sight, Figs. 2(d) and 3(c) appear to indicate drastic changes in the forms of the components of **H**, but these are only continuations of the process we have seen starting to take place in Figs. 2(b) and 3(b). Consider H_z. In Figs. 2(b) and 3(b), there is a zero of $\partial H_z/\partial r$ for a value of $r/a > b/a$, a point of inflection for a greater value of r/a, and finally another zero of $\partial H_z/\partial r$ at $r = a$. In Figs. 2(d) and 3(c), the discontinuity of slope at $r = b$ and the first zero of $\partial H_z/\partial r$ have changed places. H_z takes much smaller values outside the ferrite because of the concentration of power in the ferrite due to the high value of ε. This effect occurs most rapidly for values of b/a ranging from about 0·2 to about 0·4; thus a considerable reduction of H_z outside the ferrite is observed for $b/a = 0{\cdot}4$, while for $b/a = 0{\cdot}2$ H_z is roughly the same as in the empty guide. H_r, it will be seen, is not greatly altered in general form for $b/a = 0{\cdot}4$, although there is a marked tendency to become greater in the ferrite and less outside it. H_θ really appears to have undergone a drastic change, actually changing sign over a range of values of r/a. However, the curves are of the same general form as for $b/a = 0{\cdot}2$, only more so.

The drastic change in the field components for values of b/a between 0·2 and 0·4 is clearly related to the values of the phase constant. This does not change much from the empty-guide value for values of b/a up to about 0·2; in this range Faraday rotation is very small and perturbation theory is more or less valid. Somewhere about $b/a = 0{\cdot}2$, the phase constant starts to increase rapidly with b/a, the Faraday rotation increases to practically significant values, and perturbation theory, just where it would be of most value, breaks down—not gently, but abruptly. These effects can be attributed to the rapid change in form of the field components.

It may be noted at this point that the changes that have occurred in the field components have gone somewhat further in the case of $a/\lambda_0 = 0{\cdot}4$ than in the case of $a/\lambda_0 = 0{\cdot}3$. Because the power is becoming mainly concentrated in the ferrite, the presence of the waveguide wall has far less effect on the behaviour of the waves, so that the behaviour of the system is primarily dependent on the ferrite radius, and much less so on the guide radius. For $a/\lambda_0 = 0{\cdot}4$, $b/a = 0{\cdot}4$, we have $b/\lambda_0 = 0{\cdot}16$, while for $a/\lambda_0 = 0{\cdot}3$, $b/a = 0{\cdot}4$, we have $b/\lambda_0 = 0{\cdot}12$. The greater departure of Fig. 3(c) from 3(a) than of Fig. 2(d) from 2(a) is attributable almost entirely to this difference in b/λ_0. It may also be stated here that once b/a becomes sufficiently large to give a large Faraday rotation, i.e. when the phase constant curves begin to rise steeply, the Faraday rotation is largely dependent on b/λ_0 and only slightly on a/λ_0. This is readily found to be so on calculating the specific rotation from the values of normalized phase constant given in reference 1.

The general form of the field component curves is now established, and very little significant change occurs as b/a increases up to $b/a = 0{\cdot}8$. At this value of b/a, E_z has again become relatively smaller than E_r and E_θ, and is clearly on the way to being zero in the filled guide. E_θ and H_r are also approaching their filled-guide forms. E_r and H_θ do not seem to be falling into line very well, and it can be expected that they will go very suddenly to the filled-guide forms. Indeed, the $r = a$ end of the H_θ curve must change direction rapidly to get from almost zero to nearly the value it has at the centre of the guide. H_z can be straightened out with a flick of the tail.

This burst of activity as b/a approaches unity accounts for the sudden upward flick in the phase constants of reference 1, and for the fact that when a guide containing a dielectric rod of nearly the same radius is taken as a perturbation of the filled guide (also treated in reference 1), the perturbation result is only valid extremely close to $b/a = 1$.

For $a/\lambda_0 = 0{\cdot}2$, the results are clearly similar to those for 0·3 and 0·4, in so far as results are obtainable. One might, for example, compare Fig. 1(a) with Fig. 2(d), the values of b/λ_0 being the same for these two cases. For $a/\lambda_0 = 0{\cdot}2$, cut-off occurs for $b/a = 0{\cdot}546$. There is no indication in Fig. 1(a), for $b/a = 0{\cdot}6$, that the field components are much affected by the nearness to cut-off. This is presumably related to the rapid initial rise of $\bar{\beta}$, so that although b/a is near the cut-off value, $\bar{\beta}$ is not near zero.

Figures 2(c) and 2(e) show the effect of non-zero values of α. Comparing these with Fig. 2(d), the effect of a steady progression in the value of α is seen to be roughly equivalent to a steady increase in the value of b/a. The most obvious difference is the discontinuity in H_r due to the change in permeability; the boundary condition to be satisfied is now that $\mu H_r - j\alpha H_\theta$ in the ferrite is equal to H_r outside the ferrite. However, H_θ is fairly small at the surface of the ferrite, so that the discontinuity is not very marked.

3.2. *Power Distribution*

The distribution of energy flow is what one may immediately expect from the field component curves. Examination of Figs. 5 and 6 shows that at first, as b/a increases from zero, there is no great tendency for energy to concentrate in the ferrite; this corresponds with the very slight increase of the phase constant from the empty-guide value when b/a is fairly small. For rather larger values of b/a, energy becomes increasingly concentrated in the ferrite, corresponding to the rapid increase in phase constant that was observed in reference 1.

The maximum concentration of power occurs somewhere in the neighbourhood of $b/a = 0{\cdot}4$, and here the phase constant is approaching the value that it would have in an infinite ferrite, although it still has some way to go. Further increase in the radius of the ferrite leads to a reduction in the energy concentration. The energy is still concentrated in the ferrite, but since the ferrite is larger the energy is spread over a larger region and so the maximum energy flow per unit area falls, until in the filled guide the power distribution curves become identical with those for the empty guide. However, although for higher values of b/a the *maximum power density* is falling, the *total power* in the ferrite is still increasing, and so the phase constant continues to rise slowly.

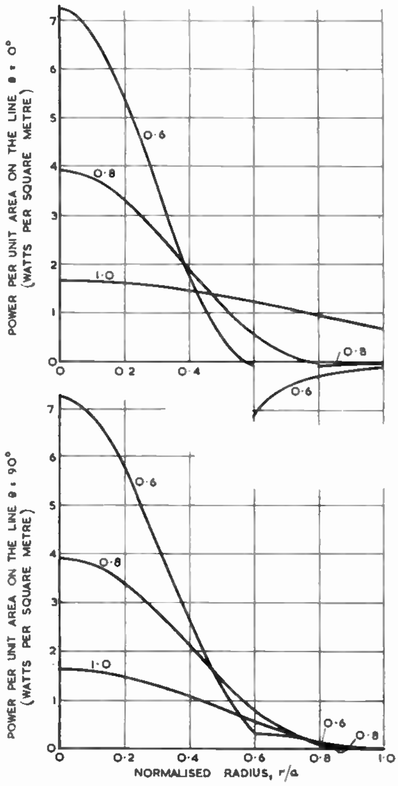

Fig. 4. Power flow, $a/\lambda_0 = 0{\cdot}2$, $\varepsilon = 10$, $\mu = 1$, $\alpha = 0$, and stated values of b/a.

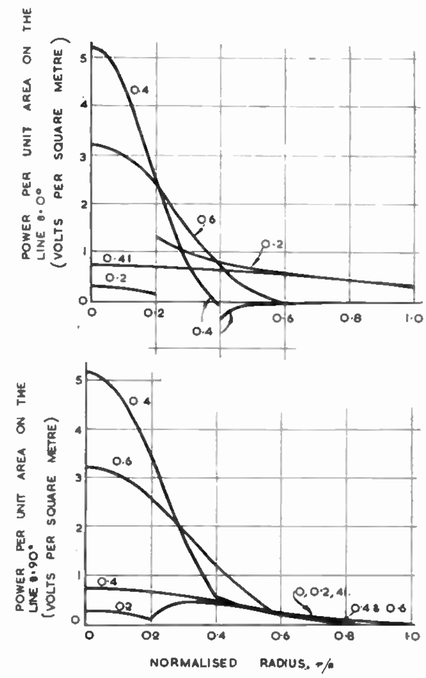

Fig. 5. Power flow, $a/\lambda_0 = 0{\cdot}3$, $\varepsilon = 10$, $\mu = 1$, $\alpha = 0$, and stated values of b/a.

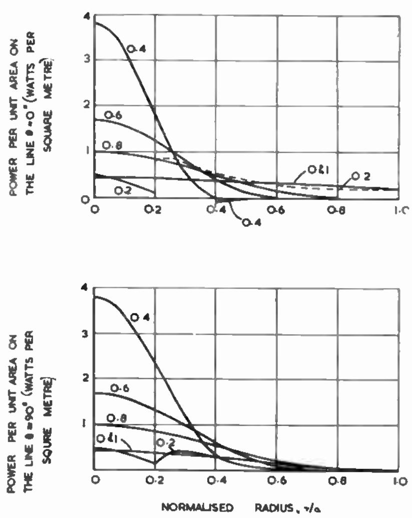

Fig. 6. Power flow, $a/\lambda_0 = 0{\cdot}4$, $\varepsilon = 10$, $\mu = 1$, $\alpha = 0$, and stated values of b/a. The dashed curve is only approximate.

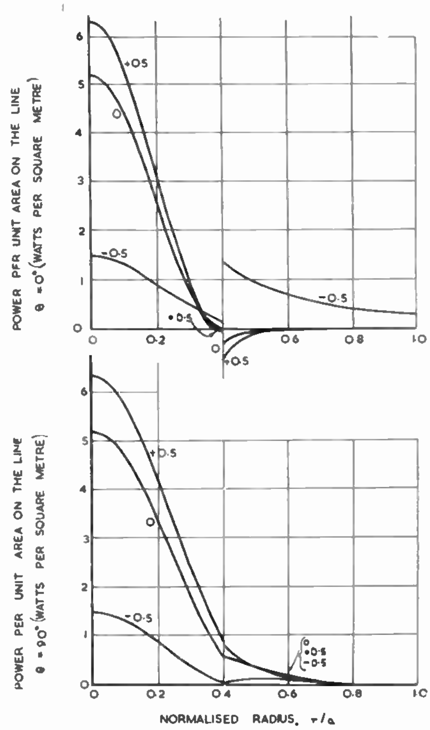

Fig. 7. Power flow, $a/\lambda_0 = 0{\cdot}3$, $\varepsilon = 10$, $\mu = 1$, $b/a = 0{\cdot}4$, and stated values of α.

As with the field component curves, we may note that for a given value of b/a the curve for $a/\lambda_0 = 0{\cdot}4$ has evolved further than that for $a/\lambda_0 = 0{\cdot}3$, provided that b/a is sufficiently great for a substantial portion of the energy to be concentrated in the ferrite. This is in keeping with the fact noted above that for sufficiently large b/a it is b/λ_0 rather than b/a that governs the behaviour of the system.

For $a/\lambda_0 = 0{\cdot}2$, the power curves show the same general behaviour as for $a/\lambda_0 = 0{\cdot}3$ and $0{\cdot}4$, for values of b/a above the cut-off value.

So far, we have only been considering power flow in a waveguide containing a reduced ferrite, i.e. with $\alpha = 0$. Figure 7 shows the effect of varying α. These curves do not differ in any startling degree from those for $\alpha = 0$. The effect of a steadily increasing value of α is more or less the same as that of a steadily increasing value of b/a or ε. It appears at first sight that negative α has more effect than positive α, but this may not be the case. It may be that the power density at the centre of the guide goes through a maximum for a value of α between 0 and $+0{\cdot}5$. It was seen above that there is a maximum power concentration, when $\alpha = 0$, for a value of b/a near $0{\cdot}4$. It is quite likely that the value of b/a at maximum is altered if α alters. This sort of behaviour would account for the results of Fig. 7.

For sufficiently large values of b/a and/or α, it can be seen that over certain regions of the waveguide the power is negative. This means that energy flows backwards along the guide towards the generator. It may be shown on forming the product $\mathbf{E} \times \mathbf{H}$ that in certain regions of the waveguide there is a transverse component of real power. Thus the energy does not all flow steadily along the guide; some of it flows round and round in loops.

4. Impedance

In a h.s.p. guide of circular cross-section, the wave impedance is defined by

$$Z_0 = E_r/H_\theta = -E_\theta/H_r$$

E_r and H_θ contain as factors the same functions of r and θ, which therefore cancel; the same is true of $-E_\theta$ and H_r. Thus Z_0 is a constant which is independent of the position in the cross-section at which it is measured. If two h.s.p. guides of different Z_0—say Z_1 and Z_2—are joined, and if their radii are equal, a reflection coefficient ρ can be defined at the discontinuity by

$$\rho = \frac{Z_1 - Z_2}{Z_1 + Z_2}$$

A knowledge of such a reflection coefficient is necessary in designing microwave apparatus. Similarly, if a guide with impedance Z_0 changes its radius abruptly, the new impedance being Z_0', it is possible to represent the system in circuit language as a line of impedance Z_0 coupled through a four-terminal network to another line of impedance Z_0'.

For the non-h.s.p. guide, E_r/H_θ and $-E_\theta/H_r$ are not the same, and neither is independent of radius. This is evident for the inhomogeneous guide from the results of this paper. Thus the "impedance" of such a guide is a function of r and θ, and it is not possible to define a reflection coefficient as above nor to represent the junction with a finite number of circuit elements. A similar difficulty has been noted for the case of curved waveguides[5].

It therefore appears that impedance is a useful concept only in the case of straight h.s.p. guides. This is a lucky accident, and is another example of the breakdown of waveguide theory in its familiar elementary form when non-h.s.p. guides are treated. This confirms the view that the author has long held, that the proper description of waves is in terms of wave functions, not circuit theory.

5. Conclusion

The behaviour of the field components and power distributions has been discussed in relation to the phase constant as the radius of a rod of ferrite, concentrically placed in a cylindrical waveguide, is varied. When the rod radius becomes sufficiently large that a substantial portion of the power travels in the ferrite, it is chiefly the rod radius that governs the behaviour of the system, the waveguide radius being only of secondary importance.

Certain aspects of the theory of waveguides homogeneously filled with lossless scalar media (h.s.p. guides) are shown to be inadequate in treating guides containing more than one medium, or a tensor or lossy medium. Care is needed in calculating power flow, the impedance concept breaks down, and modes do not exist in which E_z or H_z vanishes. That E_z or H_z vanishes, that the power is $\mathbf{E} \times \mathbf{H}^*$, and that it is possible to define an impedance, in the case of an h.s.p. guide, are happy accidents.

6. Acknowledgments

The author wishes to thank Miss A. Gentry, Mr. P. C. Beanland, and particularly Miss H. M. Stephens and Mr. M. G. Allen, who have carried out most of the computations. Permission to publish this paper was given by the Engineer-in-Chief of Marconi's Wireless Telegraph Co., Ltd.

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CORRECTION

Page 704: **Figs. 4, 5, 6 and 7:** The ordinates for these graphs should be multiplied by a factor of 10.

"Field Components and Power in Cylindrical Waveguides Containing Ferrites"

A short contribution under the above title was given by Mr. R. A. Waldron at the XIIIth General Assembly of the International Scientific Radio Union (U.R.S.I.) in London earlier this month. The contribution was presented to a joint session of Commissions VI and VII (Radio Waves and Circuits, and Radioelectronics, respectively) during the discussions on the properties of ferrites at microwave frequencies. Some results were given of computations of the electromagnetic field components and density of energy flow, as functions of position in the transverse plane, for the H_{11} mode in a cylindrical waveguide containing a concentric rod of ferrite. Mr. Waldron's contribution was based on his papers on this subject which have been published in the *Brit.I.R.E. Journal*.

THE TRAINING OF RADIO APPRENTICES

The Proceedings of a Symposium organized by the South-Western Section of the Institution, and held at No. 1 Radio School, Royal Air Force, Locking (by kind permission of the Commandant) on 7th October, 1959.

In the Chair: The President, Professor E. E. Zepler, Ph.D.

Over 100 members and visitors concerned with apprentice training, both in industry and in Government and Service Departments, were welcomed by Air Commodore H. G. Leonard-Williams, C.B.E., Commandant, R.A.F. Locking.

Professor Zepler then introduced the contributors and three formal contributions were presented: "The Training of R.A.F. Radio Apprentices" by Wing Cdr. D. J. Garland; "The Training of Apprentices in the Electronics Industry" by A. J. Robb; and "Priorities in the Training of Maintenance Technicians" by H. C. A. Dale. In addition two short informal contributions were made: "The Army Apprenticeship Scheme" by Lt. Col. R. T. Barfield, and "Training of Operators and Maintainers in the B.B.C." by K. R. Sturley, Ph.D.

THE TRAINING OF R.A.F. RADIO APPRENTICES†

by

Wing Commander D. J. GARLAND, B.SC., ASSOCIATE MEMBER‡

1. Aim of the Training

There is a three-fold aim in the training of radio apprentices in the Royal Air Force :

(a) to produce a fitter capable of servicing radar equipment;

(b) to produce an airman with his place in a fighting Service;

(c) to produce a citizen.

The training given is designed to develop such qualities of character—sense of responsibility, leadership and pride of service—as will fit apprentices for a progressive career in the Royal Air Force.

2. Entry to an Apprenticeship

The age limits are normally 15 to 17 years, and either G.C.E.(O) with at least mathematics and one science subject, or the Air Ministry qualifying examination, has to be passed.

Those who have the necessary qualifications are called for interview, where they are medically examined, given intelligence and aptitude tests and shown typical workshops in which they will be trained. The boy then chooses his main trade group, namely Radio, Aircraft, Electrical and Instrument, or Armament Engineering, and is then interviewed by officers connected with training in his chosen trade. The results of his tests and personal interview are used to assess the candidates' suitability for his chosen trade, and if he is suitable he is accepted. For radio a rather better-than-average showing in mathematics and science is expected.

3. The Apprentice Course

The course is three years' full-time training, and is, of course, residential. Entries are accepted three times each year, in September, January and May, and so in any term there are nine entries in the school. Apprentices are given free accommodation, food, uniform and sports gear and are paid generally according to their age on the following basis :

† Manuscript received in final form 3rd June 1960. (Contribution No. 29.)

‡ Training Officer (Aircraft Apprentices), No. 1 Radio School, Royal Air Force, Locking, near Weston-super-Mare, Somerset.

U.D.C. No. 331.862 : 358.43 : 621.37/9.

1st year	-	£1 18s. 6d. per week
2nd year	-	£2 9s. 0d. „ „
Age 17	-	£3 10s. 0d. „ „
Age 17½	-	£6 2s. 6d. „ „

There are over 1,000 apprentices at Locking at present.

On joining an apprentice undertakes to serve until the age of 30 years; he may stay on much longer than this if he wishes—up to age 55 or even more. An apprentice who finds that Service life is a great mistake for him can purchase his discharge for a small sum during his first three months.

The school is a sort of combination of technical college and factory floor, where technical, theoretical and practical instruction is given. Each week twenty-eight hours are spent on these subjects, and in addition there are hours allowed for drill, combat training, physical training, sport, religious instruction, English and citizenship training.

3.1. *Trades of Radio Apprentices*

Three types of radio apprentices are trained at Locking—Air Radio Fitter, Ground Radar Fitter and Ground Wireless Fitter—according to the type of equipment they will be servicing after training.

Air Radio Fitters deal with all radio and radar equipment in aircraft from r.t. communication sets to Doppler navigational aids.

Ground Radar Fitters deal with early warning radars, g.c.i. radars and the ground equipment of navigational and landing aids such as g.c.a.

Ground Wireless Fitters deal with all ground communication installations both air/ground and point-to-point. Equipments such as s.s.b., f.s.k. and multi-channel apparatus are included.

4. Technical Subjects

The technical subjects taught and the times devoted to each are shown in Fig. 1. Theoretical subjects predominate in the first half of the course and practical subjects in the second half, the reason being that theory and practice are closely integrated and a fair amount of fundamental theory is necessary before the first equipment can be tackled. In the diagram radio theory also includes three hours per week laboratory work on fundamental experiments, ranging from simple ones on Ohm's Law to the more complicated on waveguides, transmitter and receiver measurements, etc.

Some details of individual subjects are given below.

Radio Theory : This, together with the practical work on equipments, is the main subject of the course, with a correspondingly high proportion of the time. Teaching starts at the beginning, with atoms and electrons, although the early stages are meant to be revisionary. All apprentices follow the same syllabus for the first year or more, the subjects covered being d.c. and a.c. theory, electrical machines and electronics. At the end of the first year division into the three types of fitter takes place, according to choice of the apprentice as far as possible, and thereafter syllabuses diverge. Air Radio Fitters and Ground Radar Fitters are taught communication transmitter and receiver principles, radar circuits, transmission and propagation and microwave techniques. Ground Wireless Fitters are taught communication transmitters and receivers (both a.m. and f.m.), telegraphy and telephony, and transmission and propagation. Modern developments such as transistors, microwave links and scatter propagation are also covered.

As new, improved equipments are accepted into the Service, training on them is introduced. The new is therefore always replacing the old and syllabuses are constantly being altered to keep them up-to-date with new developments.

Radio Equipments : This expression refers to the training given on specific R.A.F. communi-

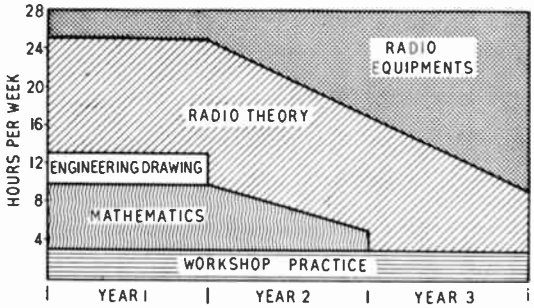

Fig. 1. Time allotted to technical subjects in the R.A.F. radio apprentices course.

cation, navigation and radar gears. Apprentices are taught in detail the circuits and mechanical details of the gears, and how to service them, i.e. incorporate modifications, test and locate and repair faults. The remarks made about keeping up-to-date with new equipment apply with equal force to this phase of training.

During the training in radio theory and equipments great care is taken to see that theory and practical work run side by side.

Workshop Practice: The usual subjects of drilling, filing and soldering are covered, special attention being paid to soldering miniature components and soldering in confined spaces.

Mathematics: For simplicity in the diagram under this heading are included mathematics, mechanics and a little on heat, light and sound. Mathematics includes complex numbers and calculus in the later stages of the course.

Technical Drawing: The syllabus follows closely the City and Guilds Telecommunication Technicians' syllabus for this subject.

5. Progress through the Course

Examinations are held every term on radio theory and practical work, and less frequently on other subjects. These aid the staff in assessing an apprentice's progress. Those who fall behind are discussed by a board consisting of the officers responsible for training, and the apprentice is interviewed. He may be exhorted, put back a term or in extreme cases withdrawn from training, depending on the individual reasons for poor progress.

During the course apprentices are encouraged to take the City and Guilds Telecommunications Technicians' Intermediate Examination. In 1959 about 120 apprentices sat 220 City and Guilds examination papers and 79 per cent. were successful.

At the end of the three-year course, apprentices have to pass a trade test, in theory and practice, in order to qualify as a Junior Technician Radio Fitter. The testing is carried out by an independent examining board which specializes in this work.

6. Other Aspects of Training

Training is given in the humanities, general service matters, combat training and drill. There are sports facilities for all imaginable games and activities, and one afternoon in the middle of the week is devoted to sport.

7. Opportunities

Apprentices who do well on the course are eligible for many benefits. Opportunities exist for rapid promotion on leaving, winning of prizes and so on and better apprentices may be selected to be officer cadets at the R.A.F. College, Cranwell, or the Technical College at Henlow. An ex-apprentice normally moves steadily up the promotion ladder and it is not many years before he is a senior N.C.O and in charge of a section of men on maintenance work. Once an apprentice has passed the course and is posted as a tradesman opportunities always exist for commissioning.

8. The Future of Apprentice Training

There are at present two opposing factors which influence thought on apprentice training. The first is that equipment is steadily growing more and more complicated, and that unless the training course is made uneconomic in length, pupils of higher standard are needed to be able to understand the complexities of modern gear. The second is that there is also a need for those whose natural aptitudes and ability will preclude them from reaching the highest technician levels, but who can undertake and supervise work of a more routine kind under the direction of more highly qualified technicians.

To cater for these two needs it is intended to run apprentice training at two levels, aimed at the two categories mentioned. The course will still take three years, but there will be a place for boys who would find the present course too difficult, and it will enable the really bright tradesman to develop his abilities to the full.

Postscript

Since the Symposium was held a slightly different selection procedure has been introduced. The interviewing on entry is now carried out by a permanent board of officers who deal with all apprentices and boy entrants.

The two-level training mentioned has now been introduced.

THE TRAINING OF APPRENTICES IN THE ELECTRONICS INDUSTRY†

by

A. J. ROBB‡

1. Introduction

There is little doubt that the best training for industry is in industry and by industry. Naturally, the academic training will, in general, be obtained at universities, colleges of technology and technical colleges, but in all cases training in industry must follow or be carried out concurrently. Despite the population "bulge", which creates the impression of a surfeit of potential apprentices, there is still, as always, a dearth of top class material. This creates a seller's market for the best lads, who judge a company, not on its products or salary, but on its facilities for training, and the competition between companies for such people has raised the general standard of training. Whatever the reasons, there is a great deal being gained by all participants because of the increased amenities and broad training which all major companies now provide.

There are now fairly well defined schemes within industry for the training of apprentices. They certainly have their own characteristics, and will vary in detail from company to company, but in principle and objective they are much the same. There are three schemes which cover the main ranges of apprentice training with titles which are easily recognizable.

2. The General Engineering Apprenticeship

This is a five-year apprenticeship which provides for the training of craftsmen and technicians. The usual age of entry is 16 years with entry qualifications ranging from a "good" G.C.E. with a scientific bias to that qualification usually described by the phrase "aptitude and sound personal qualities". This is as its title implies a "general" scheme where the first half of apprenticeship is concerned with giving the apprentice sound basic training in manufacturing methods and allied skills such as inspection, testing, draughtsmanship, etc., followed by specialized training in the second half of apprenticeship to qualify him for a career within the industry.

Most companies of any size now possess a training school. Usually it comprises at least a workshop, drawing office and classroom. Some companies possess far more imposing premises and some do not even possess this much.

It is usual for an apprentice to spend the first year or so of his apprenticeship in a training school learning the rudimentary techniques employed within the industry and then to spend periods of four to six months in diverse departments building up experience and following this with the specialized training mentioned earlier. The first year in a training school is perhaps the most important of an apprentice's career, for it is here that he is instructed not only in basic engineering but also in the ways of the Company. It eases the transition from school to work.

Academic work is usually done on a day-release basis, where apprentices attend local technical colleges one day a week on a National Certificate course in electrical or mechanical engineering. Alternatively, they may follow a technician's course, normally a City and Guilds of London Institute course, such as those for Telecommunication Technicians, Electrical Technicians, or Machine Shop Engineering.

3. Student Apprenticeship

This again is usually a five-year apprenticeship, although it may in some cases be a four year one—there are two courses within this scheme.

† Manuscript received 7th October 1959. (Contribution No. 30.)

‡ Training Officer, E.M.I. Electronics Ltd., Wells, Somerset; now with the Plessey Co. Ltd., Ilford.

U.D.C. No. 331.862 : 621.37/9.

(a) 1–3–1 or University Sandwich Course

This course provides a pre-university year of industrial training followed by a three-year period of university study, and concluded with a year of post-graduate works training. The course is intended to produce the professional engineers or designers, who are the group from which the technical executives will come.

Entrants to such a scheme are 18 years of age and at the time of entry have fulfilled university entrance requirements and indeed have obtained a place at university for the year after commencement of apprenticeship to read for a degree in Engineering, Physics or Mathematics. The first year of training aims at teaching the student the rudiments of manufacturing methods and providing him also with an insight into his chosen career. The emphasis is, however, on giving an appreciation rather than in teaching a skill, in providing the backcloth against which his career will be enacted.

Almost all entrants to such a course are public and grammar school boys, whose main preoccupation has been the acquisition of theoretical knowledge and the subsequent passing of examinations. Their practical knowledge is usually very slender.

This scheme is valuable since it allows the student to get away from the restrictions and rarified atmosphere of school life. It introduces him to the environment and type of work on which he will be employed and it does this *before* his studies commence, thus giving these studies a greater meaning and purpose than they would otherwise have. It gives study a vitality which would otherwise be missing.

Against this, of course, it can be said that students who spend a year in industry between school and university lose the habit of study and to obviate this we provide day-release facilities, whereby students may attend a Mathematics and Physics course at Inter.B.Sc. level during this year. Even if this were not done, however, a student and potential graduate should be capable of sufficient self-discipline to keep up with his studies and if he is not his prospects are limited. During the period of university study students in the main are responsible for their own maintenance, usually by State or County Scholarships, although in some cases companies provide scholarships themselves. It is also common practice for students to be required to undertake employment during the long vacations. Sometimes it is emphasized that they should do this with their own Company, and in other cases with any company but their own. The post-graduate year is spent in the Company's laboratories or similar location, preparing the student to take up his career. In many ways he is indistinguishable at this stage from the qualified man except that the term apprenticeship puts learning as the first priority and allows for a breadth of experience, almost freedom, which is not possible if the student were regarded primarily as contributing to the productive effort. Students in this final year may also qualify by further part-time study for membership of a professional institution.

Broadly speaking, an apprenticeship must have two aims: to provide an appreciation of the function of the particular industry and to provide the apprentice with the means to carve out his future career. These aims must be properly balanced, for the error is often made of paying too much attention to one or other of them.

(b) The Thick Sandwich or Diploma Sandwich Course

This is the second course available within the Student Apprentice category and is, usually, a five-year apprenticeship, but it may be of four years' duration. Entry qualifications are G.C.E. "A" level in mathematics and physics with strong supporting "O" level passes, including English, or an Ordinary National Certificate with what is usually called "distinct merit".

Students who enter via the "A" level avenue are public, grammar or technical school boys of 18 years of age, whereas O.N.C. entrants are mostly General Engineering Apprentices promoted to student apprentice grade because of outstanding performance in the early years of training. There is another avenue of entry, namely by the means of the Ordinary National Diploma, which is obtained by students who after achievement of "O" level G.C.E. follow a two year full-time technical college course in preference to taking up an apprenticeship or staying at school for "A" level studies.

Within this Diploma Sandwich Course framework there is yet another sub-division, as students may study either for a Diploma in Technology (Dip.Tech.) or a Higher National Diploma (H.N.D.). Usually within the electrical/electronic engineering group of companies studies are in electrical engineering, although mechanical engineering, physics and applied mathematics courses are not uncommon.

Both Dip.Tech. and H.N.D. courses are similar in pattern, each involving six months' full-time study at technical college and six months in works' training, for four years in the case of a Dip. Tech student and three years in the case of the H.N.D. student. This is then supplemented by full-time works training over the balance of the apprenticeship period.

Once again the practical training covers the "basics" of manufacturing processes and ancillary production services followed by design and development experience or whatever specialized training is appropriate, depending on the Company's function. Students who follow such a course receive a salary from their Company whether they are at college or at work receiving practical training.

The remarks so far concerning the Dip.Tech. and H.N.D. courses refer to "works based" students, and in the case of Dip.Tech. courses there are also "college based" students. The "college-based" student is distinguished by the fact that he is responsible for his own financial position whilst at college, either by scholarship or by some other means, and his works training is not assured, that being the responsibility of his Head of Department at college.

From this type of Sandwich Course emerges what is now called the technologist, who is likely to be indistinguishable in future years from the university graduate.

4. Graduate Apprenticeship Schemes

The third apprenticeship scheme is intended for university graduates or people who have taken an equivalent full-time course at technical colleges. This was the forerunner of the 1–3–1 University Course and is distinguished from it only by the arrangement in time of practical training and academic study. It is a two-year course of practical training, again aimed at providing industrial appreciation on the one hand, and career preparation on the other. The main feature of such a scheme should be the provision, as far as possible, of an individual training programme planned to give the graduate what equipment he needs. Thus the programme for an engineering graduate should not be identical to that for a physics graduate, assuming both are to take up similar work.

5. Future Trends in Industrial Training

One significant trend in the training of apprentices in industry is the increased "liberalization" of the training. The fact that several industrial executives who are now responsible for apprentice training schemes are called education and training officers or simply education officers may be significant. The trend is to educate and train, provide the "why" as well as the "how", and introduce what is mostly called "general studies", which may include such things as English Grammar disguised as Technical Report Writing, or Civics, History of Science, Company Organization, Economics and Physical Training.

Industry is likely to spend more money on training in the future. It must do so to provide for its future skilled manpower and to keep pace with the rapid advances of science and technology. It is these very advances which are creating difficulties, since in terms of non-productive capacity the long-term investment industry must spend more than ever before in research and development, with the result that its resources are being stretched to the limit. This, of course, is at a time when there is a relative boom. The possible answer to this problem, and one which seems to be most favoured, is Government subsidy, but there the question arises as to what measure of control would be required in exchange.

Training is industry's business, and whilst it would be a good thing if the Government did help financially, perhaps the best way would be for a channel to be set up whereby a training scheme could achieve recognition, on fulfilling certain requirements with regard to facilities, etc., and hence qualify for a subsidy based on the idea of a premium. There was a time when an apprentice's parent paid a sum to the employer. Could we not revert to this system now with the Government paying instead of the parent?

THE ARMY APPRENTICESHIP SCHEME†

by

Lieutenant Colonel R. T. BARFIELD, R.E.M.E. ‡

There are 236 trades in the Army, over 30 of which are open to apprentices trained at one of the four Army Apprentice Schools at Chepstow, Harrogate, Arborfield and Carlisle. At present each school has approximately 850 apprentices under training and this will increase to 1,000.

All trades for the Royal Engineers are trained at Chepstow, those for the Royal Corps of Signals are trained at Harrogate. Carlisle and Arborfield train those trades required for R.E.M.E., Carlisle covering the Mechanical Trades and Arborfield the Electrical and Electronic trades and some Vehicle Mechanics.

The aim of the Army Apprentice Schools is to give boys the necessary grounding to fit them, with further experience, for senior warrant and non-commissioned ranks of the technical arms and services of the Army, and in some cases subsequently for specialist-type commissions.

Over the three years of training, approximately 50 per cent. of the instruction time is spent on technical training, 25 per cent. on general educational subjects, and 25 per cent. on games, leadership and regimental training.

Education

The Army has laid down certain minimum general educational standards for each rank throughout the Army. Since the aim of Apprentice Schools is to produce future Warrant Officers and N.C.O.'s, the first target must be the Army Certificate of Education 1st Class, which satisfies the general education requirement for promotion to Warrant Officer Class I. This is slightly below G.C.E. "O" level, and apprentices who have obtained the latter certificate in the necessary subjects are exempt. After reaching this standard, apprentices study for G.C.E. "O" level in mathematics, physics and English. At Arborfield apprentices who arrive at the school with a suitable educational background may commence an O.N.C. course at Reading Technical College at S1 or S2 level. This is taken in addition to the normal trade studies at the school and one day each week is spent at the college for this purpose.

Technical Training

The syllabus followed is geared to the Army Class II Trade Test requirements although apprentices take the Class III Trade Test only whilst at the school. An explanation of Army Trade Classifications will give an idea of the standard. All engineering trades in the Army are classified into three levels of skill, Class III, II and I:

A Class III Tradesman has been trained in his trade but lacks experience of its practice and needs guidance and supervision.

A Class II Tradesman is fully trained and experienced and capable of performing any task appropriate to his trade efficiently without detailed supervision.

A Class I Tradesman is a highly skilled and experienced tradesman with specialist knowledge or capable of taking charge and supervising others. If he is an N.C.O. he is comparable to the charge-hand in civil life.

The standard can be judged from the fact that an Army Tradesman who has passed his Class II Trade Test and has had two years' experience in addition to his apprenticeship is eligible for membership of the skilled section of the appropriate union when he leaves the Army.

There is a much higher technical grade in the Army which we hope that the majority of apprentices will reach within five or six years after leaving the school. This is the Artificer Grade, given after the successful completion of an 18-months course which is approximately H.N.C. level, in their particular trade.

† Manuscript received 3rd March 1960. (Contribution No. 31.)

‡ Chief Instructor, Army Apprentice School, Arborfield, Berkshire.

U.D.C. No. 331.862 : 358.2 : 621.37/9.

The type of training at the school is very similar to that described by Wing Commander Garland. We differ slightly in that we tend to concentrate the majority of general workshop practice training in the first year and during this period approximately half the time is devoted to practical work and the remainder to general education. This enables us to bring the apprentice to an acceptable level in mathematics, physics and English, and also provides plenty of opportunity for re-assessing the potentialities of the students before they commence their technical studies proper.

As with all training establishments we have plenty of problems. The one most relevant to the discussion is that of civilian equivalent standards. The Army is always keen wherever possible to aim its courses at recognized civilian examinations as well as Army qualifications. The electronics field does not seem to be very well covered at the moment. The O.N.C. does not really cover our requirements for an Electronics Apprenticeship either in scope or in sequence, and the minimum age limit of 16 is a serious disadvantage in an apprenticeship scheme which can be entered at the age of 15.

The City and Guilds Telecommunication Technicians' Course seems to be nearer our requirements, but unfortunately appears to be confined to the requirements of the G.P.O. A similar but broader course covering all basic techniques of Telecommunications, Radar and Electronic Control, or alternatively separate papers in these subjects, would be ideal for our purpose.

Postscript

Since the Symposium took place, a new grade of Technician has been announced. All electronic tradesmen are now graded as Technicians and pass out of the School as Lance Corporals.

TRAINING OF OPERATORS AND MAINTAINERS IN THE B.B.C.†

by

K. R. STURLEY, PH.D.‡

The aims of any training organization can be summed up quite briefly under three headings:

(1) To improve the efficiency of the individual and of the organization as a whole.

(2) To develop skills and abilities so that an individual finds full satisfaction in his work and avoids the wastage of learning by trial and error.

(3) To overcome resistance to new ideas.

We in the B.B.C. have problems which are similar to those encountered by the R.A.F. in the training of apprentices but, unlike the R.A.F., we are unable to give three years to full-time instruction. Normally a maximum of seven months' basic and advanced full-time training is available, made up of two 14-week periods in a residential establishment. The end product must always be kept in mind; for the B.B.C. it is an artistic production and technical staff must be made to realize that their work is aimed at helping the programme producer to achieve the artistic results he desires.

For broadcasting sound and television programmes two types of staff are required, one known as the operator and the other the maintainer, and our recruitment policy recognizes that these two types are generally distinguishable even during a short preliminary interview. In any case a satisfactory personality and teachability are regarded as more important criteria than present technical knowledge, but a failed maintainer is not automatically regarded as a possible recruit to the operator grade.

† Manuscript received 3rd March 1960. (Contribution No. 32.)

‡ Head of Engineering Training Department, British Broadcasting Corporation.

U.D.C. No. 378.962 : 621.396.97.

The operator must have quick reactions in an emergency, a good memory for procedure and an interest in people. Training must provide him with an overall picture of the programme chain, alternative ways round the chain when fault conditions arise and it must point out and give him time to discover the limitations of his apparatus so that he can exploit its capabilities to the fullest degree. The maintainer may have slower reactions when operating apparatus, is more reflective and is interested in logical analysis. Training must provide him with basic principles as well as experience on the apparatus which he will have to service. He must also be given the elements of worshop practice with hand tools and soldering.

The 14-week courses are divided into two almost equal parts, one dealing with the radio fundamentals applicable to broadcasting engineering and the other with the apparatus which has to be operated or serviced. With short duration courses it is essential that methods of teaching should be as efficient as possible. Demonstrations are used in classrooms and laboratories to reinforce formal instruction and half the day is spent in practical work, illustrating principles in Part I and actual practice in Part II.

Every attempt is made at integration so that inter-relationships can be quickly appreciated. Thus a ripple tank can illustrate sound shadows produced by a microphone or v.h.f. radio shadows produced by obstacles. The correspondence between standing sound waves in a room and a mismatched aerial feeder can also be emphasized.

Editorial note:—Dr. Sturley read a paper dealing in much greater detail with the subject of the above contribution at an Institution meeting in London on 27th January, 1960. This paper, which was given in collaboration with Mr. A. E. Robertson, will be published in the November 1960 issue of the *Journal.*

PRIORITIES IN THE TRAINING OF MAINTENANCE TECHNICIANS†

by

H. C. A. DALE‡

The first consideration in training is to decide upon the exact nature of the job the student will be called upon to do. The maintenance technician has to handle equipment which has been designed and developed and produced elsewhere. When it comes into service it is known to be capable of performing a function for which it was intended, and the task of the technician is to keep it going.

A maintenance technician will have to perform three quite separate jobs:

(a) routine or preventive maintenance,
(b) fault finding or remedial maintenance;
(c) specification testing.

The first and last of these present a negligible training problem. The key job is fault-finding and if a training scheme can produce efficient fault finders then it has succeeded in its most difficult task.

Fault-finding as a job depends on the maintenance policy in operation and the design of equipment, for example it may be of the throw-away module design. This obviously requires less highly skilled men to locate the faults and correct them than in the case where the technician is required to find and replace the actual component.

† Manuscript (abridged) received 10th October 1959. (Contribution No. 33.)

‡ Medical Research Council, Applied Psychology Research Unit,, Cambridge.

U.D.C. No. 371.38.

Some investigations have been carried out with the object of seeing how untrained persons will tackle the kind of problems confronted by the fault-finder. It was first necessary to determine what a fault-finding task is. After some consideration it was decided to analyse the essential arguments involved in fault-finding on present day equipments. Interest was centred on the general way technicians collected evidence about the state of faulty equipment and reasoned their way to a faulty part.

Problems were designed like that shown in Fig. 1. Here the person being tested had to locate the faulty stage in a complex flow system. The experimental technique was very simple: the subject was required to lift small counter-like objects marked on the underside as "correct" or "faulty". Figure 2 shows a good solution and Fig. 3 a solution given by one of the subjects (a highly qualified man). From the results of this experiment untrained persons cannot be expected to solve this kind of problem in the best possible way. They do not even solve the more simple kind of problem shown in Fig. 4 in the best way. In this problem the various items are all independent and the only sensible strategy is to begin at one end and work along. Few subjects do this however. Figure 5 shows one particular attempt.

The implications of the results of this experiment are quite important. The fact that persons do not solve their problems in the best way means that they need instruction in the way to tackle the basic problems involved in fault finding.

The problems used were, if anything, more simple than the problems which arise on the actual job. If, however, persons fail to solve these simple problems efficiently they are likely to handle problems which are more complex even more inefficiently.

Consideration of these findings leads the writer to propose that instruction in the best ways of solving the fundamental problems which arise on the job should be at the core of the training maintenance technicians are given. The training must emphasize the methods of fault-finding, and these should be treated as fundamental. Radio and electronics theory, which at present enjoys the status of being the core of training, should be displaced.

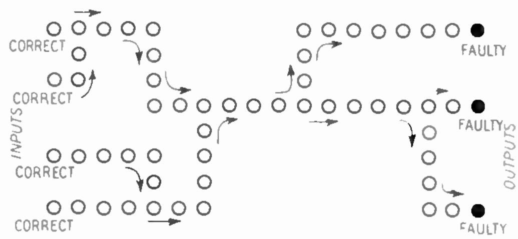

Fig. 1. A complex problem: The faulty stage has to be located with as few moves as possible.

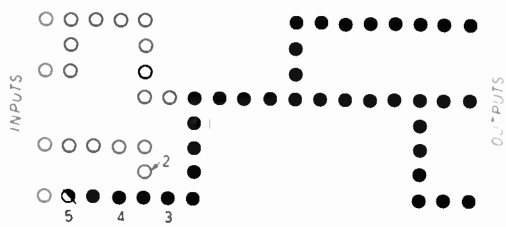

Fig. 2. A good solution: The stage is found in five moves.

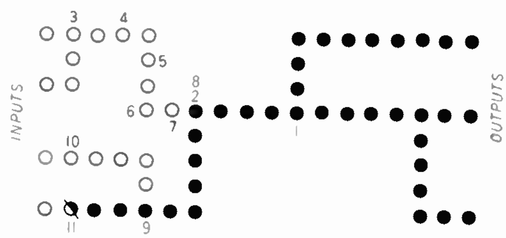

Fig. 3. What one person did.

Fig. 4. One item is faulty, all the others are normal. The faulty item is to be found in as few moves as possible.

N.B. These items are quite separate from each other, there is no signal flow.

Fig. 5. The way one person tackled the simple problem: The numbers indicate the order of his moves.

*After this move the subject said "I've done the lot." The experimenter reasserted that one item was faulty and he then continued.

It is suggested that students should be taught about the block functioning of equipment and the best way of isolating a block which is faulty at the very beginning of their course. By using this technique of beginning with the job their interest will be aroused for they will be dealing with what is basic to their employment right from the start.

Such a technique has two chief virtues: (i) it is geared to the job; (ii) it promotes motivation. Both factors are vital to any kind of training. The traditional approach to training of maintenance technicians ignores both of these factors. No attempt is made to analyse the task that the students will have to perform. Instead some basic requirements are thought up in isolation and the student is given a background to academic engineering, rather than any specific training. The fact that the student's interest might flag is not considered at this point, but later some secondary goals are set for him, i.e. examinations are introduced. In other words instead of promoting interest in the job, an attempt is made to promote interest in gaining examination success.

To evaluate the suggested method of training it should be put to practical test. Final evaluation must be made from information fed back from the employer. This is the only way of seeing how efficient is the training. Any training scheme which is introduced without this feedback is blind. Passing out examinations are no substitute for their results are meaningless without direct reference to the student's eventual performance on the job.

DISCUSSION

Sqdn. Ldr. A. T. Prince: At what stage is the decision made as to whether a man should be a student apprentice or take a general engineering apprenticeship?

Mr. A. J. Robb (*in reply*): People come from outside into either general engineering or student apprenticeships, but there is a pathway between the two and general engineering apprentices can gain promotion to student apprenticeships.

Replying to **Dr. K. R. Sturley**, Mr. Robb said that industry did have some residential facilities, which were becoming more common, and which he thought a very good thing.

Wing Cdr. S. Linnard: I rather get the feeling from what Mr. Robb said that in civilian apprenticeships, whilst the actual training of the lad is closely guarded, the personal aspects are not so carefully looked after. Perhaps we have more time in the Services to look at the character of the trainee, and we do try to lead him on the right road. Is there any connection in civilian life with the personal life of the apprentice?

Mr. Robb (*in reply*): The distinction is that in the Services the Training Officer plays the role of both trainer and parent. In industry there is a triangle—training officer, boy and parent. I like the parents to be interested in their son's progress, for them to come to initial interviews, and thereafter for regular discussions on their son's progress so that I may give reports on the progress of his training. There is a sharing of responsibility too with the Personnel Officer, for if a lad has some personal problem his work is likely to suffer, and industry is just as keen to find the solution of the personal problem as the Services.

Flt. Lt. K. Hebborn: I should like to ask what form of contract, if any, you have with your apprentices, as we in the Services have a guarantee that we get so many productive years' service from an ex-apprentice.

Mr. Robb (*in reply*): Personally, I would not have any form of contract, though I know some companies would like to have a contract with their apprentices stating that they will remain with the firm for a certain number of years at the termination of their apprenticeship, some £1,500 having been spent on their training. To me this is not worth the paper it is written on; the distinct moral responsibility is pointed out to the lad that he owes a lot to the firm, but we train boys for the sole benefit of the industry rather than our own individual company. Additionally we feel that movement and change bring experiences and long-term benefits to our Company and the industry as a whole. We generally encourage boys to move after two or three years, if not to another firm then to a different branch of our own Company.

Mr. R. S. Trevelyan: Is there any single organization in operation, or in the process of being set up, that sets and supervises standards of general apprenticeships, as they vary so enormously with the various firms? What advice would Mr. Robb give to a parent choosing a career for his son.

Mr. Robb (*in reply*): A parent should write to various firms for their brochures, but should remember that it is a fallacy that the glossier the brochure the better the training scheme. I would then advise the parent, with his son, to visit the firm of his choice for an interview and decide whether he agrees with the attitude and philosophy. The interview should be a two-way matter, with both interviewer and parent asking and answering questions, and entering the boy in an apprenticeship should be a joint matter.

There is an Industrial Training Council, and various other organizations who claim to have knowledge of what training schemes are, and what they should be. I should like to see one body to whom reference might be made by the firms as well, but with the proviso that this body should not control the industry but only give advice.

Sqdn. Ldr. E. A. Law (Associate Member): It seems to me that one of the fundamental differences between industry and the Services is a difference of responsibility; where the industry does not really mind whether it turns out a qualified apprentice, the Services are under continued compulsion to turn out a highly qualified man. I think industry leaves it more to the man or boy himself to make the grade, whereas the Services are compelled to turn out a required number of successes. Is this a reasonable opinion?

Mr. Robb (*in reply*): Industry is, of course, terribly concerned with turning out a successful apprentice to make things worthwhile, but I think we advocate more self-discipline on the individual's part, and try to set our apprentices as far up the ladder as they can go, according to their abilities. In the Services you are required to turn out a certain number of people, and therefore you continually drive people to get perhaps beyond their particular ability.

Wing Cdr. D. J. Garland (Associate Member): We are at present introducing two-stream training, and therefore hoping to repair this failing.

Commander T. A. Collier (Associate Member): How many of your original apprentices get through in the end?

Mr. Robb (*in reply*): The set-up in our industry is entirely different from the Services; we take people because they want to come, and they stay as long as they want, and if a lad wants to leave we let him go. It is difficult to be accurate about the results—in the last three years we have had between 71–75% success in individual examinations. Of those who have *completed* their apprenticeships over the past five years three people have left immediately because they did not fit in.

About 40% of our apprentices obtain a Higher National Certificate, 40% obtain an O.N.C., and of the remaining 20%, 15% go into machine shop engineering, and the last 5% fail to get any qualifications.

At the conclusion of the Symposium, delegates were conducted on a tour of selected parts of the radio apprentice training facilities at No. 1 Radio School, Royal Air Force, Locking.

AVIATION ELECTRONICS

This year's Flying Display and Exhibition of the Society of British Aircraft Constructors, held at Farnborough, Hampshire, from September 5th-11th, presented once again a comprehensive view of British activity in the field of aircraft communications and radar. While guided missiles are featuring more prominently at the Exhibition their technical interest to the radio and electronic engineer is of course limited through security restrictions, although proposals for using the Blue Streak/modified Black Knight combination for putting a communications satellite in orbit were featured at the stand of the Hawker Siddeley Aviation Group. It seems likely however that more conventional aeronautical applications of electronics will predominate at the Exhibition for some years to come.

Vertical take off and landing is currently one of the main aims of the Aircraft Industry and it is interesting to record that, in connection with the Short SC-1 v.t.o.l. aircraft which was flown in public for the first time at the Display, electronic simulation played a vital part in achieving stability of this inherently unstable machine. Some of the considerations involved in the project are shortly to be described in a paper to the Institution.*

A radio telemetry system for use in guided weapons was shown which has been designed by the Signals Research and Development Establishment to provide large channel capacity and wide information bandwidth, with an overall accuracy of 1 per cent. Seven high frequency signal channels and two calibration and synchronizing channels are provided by time division multiplexing with a sample rate of 8 kc/s in each signal channel and 4 kc/s in the calibration channels. Each signal channel has an information bandwidth of 0 to 3·5 kc/s, and, if desired, may be sub-multiplexed by a mechanical switch that samples a group of 24 channels 120 times a second. The multiplexed information is used to modulate a radio transmitter either by direct frequency modulation of a 10-W carrier, or by frequency modulation of a sub-carrier which is then used to amplitude modulate a 7½-W carrier.

Another exhibit of telemetry for aircraft, shown by the Royal Aircraft Establishment, is very modest in its requirements of radio bandwidth. It copes with a number of instruments by a flexible combination of frequency multiplexing and one stage of time multiplexing, using sub-carriers which extend up to 15 kc/s.

One of the aircraft attached to the Radio Department of the Royal Aircraft Establishment is a De Havilland Comet Type 2E which has been extensively modified to form a "flying radio laboratory," in which various systems and equipments can be quickly installed for airborne experimental work. The system currently installed is now being used to obtain basic data on some of the problems of radio propagation at very low frequencies (20 kc/s). This is associated with the development of an accurate and very reliable world-wide navigation system in which phase comparison of transmissions from v.l.f. beacons provides a hyperbolic network. The technique was briefly described at the inaugural meeting of the Institution's Radar and Navigational Aids Group last year.†

An automatic data link, developed by Cossor Radar and Electronics for air-to-ground communication, was on view. When triggered by associated ground equipment, this is intended to transmit automatically information on height, position, destination, etc., of the aircraft in which it is installed. The purpose of the present equipment is to provide an assessment of the reliability of digital data transfer systems under operational conditions. No ground to air message will be transmitted other than an interrogation signal which embodies identity characteristics which the airborne unit will recognize. Upon recognition the airborne unit will encode and transmit a pre-arranged binary coded digital message together with a synchronization pattern. In the ground equipment the synchronization pattern will be identified, accepted and used as a trigger for reception and decoding of the airborne message. The work is being carried out in conjunction with B.O.A.C.; the Institution's Radar and Navigational Aids Group is to hold a meeting during the coming session at which Mr. W. E. Brunt of the Corporation will discuss the problems involved in automatic air/ground/air communication systems.

An important new device on the Marconi stand was an electron beam parametric amplifier, developed by the English Electric Valve Company, which promises to give a range improvement of up

* C. Snowdon, "Electronic Simulation and Computer Techniques in the Design of Automatic Control Systems." Paper to be read at the South Western Section Convention on "Aviation Electronics and its Industrial Applications" in Bristol on October 8th.

† C. Williams, *J. Brit.I.R.E.*, **20**, page 425, June 1960.

to 25 per cent.—equivalent to more than doubling the power—on 50 cm radars. Crystal control is employed for both the pump and signal frequency and a significant improvement is claimed because the pump frequency is maintained at exactly twice the signal frequency. Under these conditions the effective noise input power is halved because the idler and signal channels, which are symmetrically spaced on either side of half the pump frequency, now coincide. This results in a considerable improvement in the signal/noise ratio of the amplifier output. Apart from considerations of mechanical and electrical robustness, which includes the fact that it is extremely unlikely that power spikes from the transmitter will harm the tube, the other inherent characteristics can be exploited where a fully coherent moving target indicator system is used.

Decca demonstrated a 10 cm high definition, double-beam surveillance radar of advanced design, which incorporates two 800 kW transmitters feeding an aerial system consisting of separate high and low cover aerials, mounted back-to-back. The radar provides gap-free coverage, high definition and data rate, and p.p.i. picture of high quality. A separate receiver channel is associated with each aerial and receiver signals are displayed on main traces spaced 180 deg apart on the p.p.i. displays. This "cartwheel" type of display permits a continuous and simultaneous presentation of echoes from both beams.

The Decca radar was shown in operation with recordings from a radar tape recorder. This recorder plays back radar data with very high fidelity, employing a video tape recorder developed by Ampex for television recording. The recordings demonstrated at Farnborough showed the air situation at Arlanda, near Stockholm, where an air surveillance radar is in service. The system is capable of recording and playing back the data from a single beam surveillance radar with a bandwidth of approximately 4 Mc/s, together with speech within a bandwidth of 50 c/s—10 kc/s.

Television technique offers many advantages for information display in air traffic control and is being widely adopted. The display equipment for the new Standard Telephones & Cables automatic triangulation system employs closed-circuit television in conjunction with a ground-based aircraft position-finder. Each d.f. station—up to 12 may be used—transmits its bearings automatically and virtually instantaneously over a telephone line or radio link to a control centre, where they are displayed on one of a number of small cathode ray tubes in a "triangulation picture synthesizer." Here the bearing indications are combined optically with elements of an illuminated map.

Pye Telecommunications showed a new radio-directed television system for airfield application, which is completely transportable and independent of cables. The system permits control tower staff to observe the assembly areas, taxi-ways and runways, especially during operational periods of low visibility. The distance between the control point and the unattended camera is almost unlimited for most practical purposes, the control system being achieved over a 450 Mc/s u.h.f. link and the pictures fed back along a microwave link.

Magnetic tape data recording equipment for use in missiles was demonstrated by the Ministry of Aviation. The equipment consists basically of an 8-track recorder and a variety of encapsulated units incorporating transistors from which a measuring system is assembled. It is designed to withstand severe missile environments and to permit the recovery of the recorder tape. Two recorders are available. The one for general use has an armoured cassette containing 105 ft of $\frac{1}{2}$ in. wide magnetic tape driven at a pre-determined speed of $3\frac{3}{4}$ or $7\frac{1}{2}$ in./sec by a 400 c/s synchronous motor supplied from a transistorized 3-phase oscillator. The second recorder is considerably smaller and lighter. This is achieved by omitting the flywheel, driving the tape with a d.c. motor operating from a stabilized 24 volts supply, and reducing the tape capacity to 22 ft. Its recording head allows the use of the "carrier erase" technique in applications where the volume of the frequency modulators cannot be accommodated.

The Ferranti Airpass II is an airborne radar for interceptor aircraft, which is stabilized in pitch and roll, and scans a sector of sky covering a wide angle in elevation and azimuth on either side of the flight path and extending many miles ahead of the fighter. Once the target is located and seen on the search display the radar is locked-on and begins to track. A computer in the Radar Unit automatically works out the best approach course for the pilot for attack with guns, rockets or guided weapons. Steering signals from this computer are presented on the Pilot's Attack Sight in the form of an Aiming Mark and Target Spot. The Display also includes a Range Scale and a closing Speed Scale. On completion of the approach the display automatically ensures that the weapons are correctly aimed even though the target may be still invisible to the pilot. At the same time the attack can easily be completed visually if the target should come into view, since the pilot is already looking forward through the sight.