JOURNAL OF

The British Institution of Radio Engineers

(FOUNDED IN 1925 – INCORPORATED IN 1932)

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

Vol. XII (New Series) No. 8 AUGUST 1952

EDUCATION FOR ENTRY TO THE RADIO INDUSTRY

The shortage in Great Britain of qualified engineers and research workers has recently been the subject of a report issued by the Parliamentary and Scientific Committee. Following the debate on the report in the House of Lords, a deputation was received by the Lord President of the Council.

Many industries have now taken steps to remedy the shortage of engineers and technologists, and the Radio Industry Council has also been concerned with the establishment of new three-year courses in radio engineering. Organized by the Ministry of Education, these courses will start in September, 1952, at five centres, three in London, and one each in the Midlands and the North.

These courses have been devised specially to meet the needs of the industry, the objective being to provide students so well trained in the theory and practice of electronics that they will be able, on completion, to take their places at once as assistants to qualified research and development engineers.

In the session beginning in September next, courses will be held at:

Northern Polytechnic, Holloway Road, London.

Norwood Technical College, London, S.E.27.

E.M.I. Institutes Ltd., London, W.2.

Coventry Technical College, The Butts, Coventry.

Bolton Technical College, Bolton, Lancs.

The appropriate examinations of the City and Guilds of London Institute and of the British Institution of Radio Engineers will be taken during the course at all centres. In addition, successful completion of the course will in most cases carry a college diploma.

The courses have the support of the Radio Industry, Council and the various local education authorities concerned may find it possible to offer grants-in-aid in special cases.

Details of the courses are obtainable from the principals of the colleges concerned.

Apprenticeship and Trainee Schemes

In agreement with the Ministry of Labour and National Service, the R.I.C. is also promoting an industry scheme of training for technical personnel. Trainees will register with the R.I.C. at the age of 16 or 17 and will be issued with a nationally recognized certificate on completion of training at the age of 21. The scheme has the approval of the Ministry of Labour and trainees will be eligible for deferment from military service, thus maintaining the numbers already in training.

In a memorandum to its officers throughout the country the Ministry of Labour states that:

"Trainees are to be given progressive training through workshops, followed by a period in test departments and/or laboratories. The trainee should not normally be employed on lengthy repetition work except where such work is progressive and only as a stage in the training. The final year should be spent in the laboratories or test room, or on test equipment maintenance or prototype construction, all work being arranged in stages so as to provide an orderly course of training to the technician level as defined."

Trainees are also to be released for one day or two half-days per week for Technical College courses for approved examinations.

This scheme has been approved by the British Radio Equipment Manufacturers' Association, the British Radio Valve Manufacturers' Association, the Radio and Electronic Component Manufacturers' Federation and the Radio Communication and Electronic Engineering Association. The proposed syllabus of training does not supplant any apprenticeship scheme operated by individual companies and recognized by local offices of the Ministry of Labour.

The scheme aims primarily at producing more junior engineers, or technicians, who should not be confused with the servicing and installation mechanics for whose training the Radio Trades Examination Board in conjunction with the City and Guilds of London Institutes have for some 12 years operated examinations based on appropriate syllabi.

In view of the editorial in the *Brit.I.R.E. Journal* of June 1949 (p. 201), it is of interest to note the following definition of a radio technician as framed by the Ministry of Labour:

"A radio technician is a person who carries out in a responsible manner approved techniques which are either common knowledge amongst those who are technically expert in his branch of industry or specially prescribed by professional radio engineers. These techniques are *not* those of the craftsman, though they may involve manual skill; in many cases they include the skilled use of delicate and complicated instruments and may also require the intelligent and accurate use of approved methods of calculation. They involve practical experience of some limited branch of radio engineering combined with the ability to complete the details of a project using well-established practice.

"To become a radio technician a person must have received a technical education up to a standard at least, and preferably beyond, that of the Ordinary National Certificate in Electrical Engineering, and in addition must have had training and experience in the particular sphere of radio engineering in which he is to work."

Encouragement to Trainees

These announcements are an indication of the concern felt by the radio industry and the Government at the present shortage of trained technical personnel. Supplementing these plans, the Technical Training Committee of the Radio Industry Council will include a technical training display at the forthcoming National Radio Show.

Demonstrations will be given by the following organizations: Imperial College of Science and Technology, Norwood Technical College, Northampton Polytechnic, E.M.I. Institutes, and Marconi College.

A leaflet on careers in the industry* is in preparation for the occasion and the Radio Industry Council hope that pupils will come to the show, individually or in parties.

The steps now being taken by the radio industry in collaboration with the Ministry of Education are of particular interest in view of the several reports of the Institution on the inadequacy and often the complete absence of training facilities. Reference is particularly made to the following Institution publications:

Post-War Development Report, Part II (*J. Brit. I.R.E.*, Vol. 4, pp. 151-161). Published in 1944, this report drew attention to the post-war needs of the industry and the necessity for providing professional training and qualifications.

Annual Report 1949 (*J.Brit.I.R.E.*, Vol. 9, pp. 245-246). This histogram of entries and results in the Graduateship Examination over ten years pointed to low standards of training and reaffirmed the opinion stated in the *Post-War Development Report*.

Annual Report 1950 (*J.Brit.I.R.E.*, Vol. 10, pp. 265-266). The considerable growth in interest in radio training was shown by the very large increase in the number of candidates in the radio examinations of the City and Guilds of London Institute, particularly after 1946.

Education and Training in the Radio Industry (*J.Brit.I.R.E.*, Vol. 10, pp. 290-294). As a result of an investigation by the Education and Examinations Committee a special article was published in the August/September 1950 *Journal* which was widely requested by students and technical colleges.

More recently the Council has set up a Committee of Education and Training whose terms of reference are: (*a*) To report to what extent the recommendations contained in the *Post-War Development Report* have been implemented; (*b*) To examine the existing arrangements at universities, technical colleges and schools; (*c*) To review the existing practical and training courses operated by industry, the Services and Government departments; (*d*) To examine the research facilities at present available in universities, Government departments and industrial establishments.

The Institution has therefore particular interest in the decisions which have been taken and will gladly collaborate in the interests of the profession.

* Probably on the lines of *Choice of Careers*, published by H.M.S.O.

GRADUATESHIP EXAMINATION MAY 1952

FIRST PASS LIST

This list contains the results of all the home candidates and those of the oversea candidates available on July 18th, 1952.

Eligible for Transfer or Election to Graduateship or Higher Grade of Membership
(These candidates have now satisfied the Examiners in all subjects of the examination).

ADAMS, Hubert Charles Barton. (S) *London, N.13.*
BARTLETT, Thomas Henry (S) *Sheringham, Norfolk.*
CRETCHLEY, Ronald Richard (S) *Swindon, Wiltshire.*
DAVEY, Norman Charles. *Thornton Heath, Surrey.*
EYET, Hubert. *Tadworth, Surrey.*
FAULKNER, Harold John. *Stockport, Cheshire.*
HEAD, Reginald Edward Albert. (S) *Wolverhampton, Staffordshire.*
HODGSON, John. (S) *Bournemouth.*
JONES, John Morgan. (S) *London, N.3.*
JOSHI, P. S. (S) *Bombay.*
MAYHEW, Kenneth Walter Stewart. *Surbiton, Surrey,*
MILNE, James. (S) *Glasgow.*
MOTHERSOLE, Peter Leonard. (S) *Calne, Wiltshire.*
NAMBIAR, Padmanabhan K. P. (S) *London, W.4.*
PEARSON, Gordon Pitt. (S) *Limpsfield, Surrey.*
RAJKUMAR, G. M. (S) *Colombo.*
SIVARAMAKRISHNAN, K. S. (S) *Chelmsford, Essex.*
SKINNER, Leonard Malcolm. (S) *London, E.5.*
SMITH, Darrell Alfred. *Milton-u-Wychwood, Oxfordshire.*
STREET, Derek Ewart. *Worcester.*
TOUCH, Clifford William. (S) *Ashford, Middlesex.*
WILKINSON, William Dinsdale (S) *London, S.W.16.*

The following candidates are required to succeed in Part IV only in order to qualify for election to Graduateship.

COULTAS, Francis William. (S) *Great Malvern, Worcestershire.*
EVANS, Hugh Maitland (S) *Newbridge, Monmouthshire.*
McCRIRRICK, Thomas Bryce. *Isleworth, Middlesex.*
RANGANATHA, R. (S) *London, N.W.10.*
REIDY, Kevin John. (S) *London, N.16.*
SAMUEL, Duncan Roy. (S) *Whitchurch, Glamorgan.*
SLATOR, Sidney Lipscombe. *Dublin.*

The following candidates are required to succeed in Part IIIb only in order to qualify for election to Graduateship.

BORUM, Per Anton. (S) *Windhoek, South Africa.*
HASELDEN, Frederick George. *Crewkerne, Somerset.*
SWORDS, Sean. (S) *Dublin.*
SZKUTNICKI, Z. R. (S) *Carshalton, Surrey.*
WILLIAMS, Peter Brundell. (S) *London, N.19.*
WILLIAMS, Cyril George. (S) *Sidcup, Kent.*

The following candidates are required to succeed in Parts I and IIIb only in order to qualify for election to Graduateship.

HARRIS, Peter Michael. *Sidcup, Kent.*
STUBBS, John. (S) *Liverpool.*

The following candidates are required to succeed in Parts I and IV only in order to qualify for election to Graduateship.

BETTERIDGE, John Edward. (S) *Stoneleigh, Surrey.*
DELANEY, Norman James. (S) *Castlecomer, Co. Kilkenny.*

The Following Candidates Passed Parts I, II and IIIa.

MAGUIRE, James Patrick. (S) *Dublin.*
PORAT, Dan Israel. (S) *Ramat-Gan, Israel.*
SARDAR, Singh. (S) *Catterick Camp, Yorkshire.*
SENIOR, Eric. (S) *Halifax, Yorkshire.*

The Following Candidate Passed Parts I and II

POVER, Brian Sydney. *Plymouth.*

The Following Candidate Passed Parts II and IIIa

TAYLOR, Frank Howard. (S) *North Weald, Essex.*

The Following Candidates Passed Part I Only

BOLTON, John Marshall. (S) *Blackburn, Lancashire.*
BRIDGEMAN, James Neville. (S) *Croydon, Surrey.*
BYRNE, John. (S) *Malvern, Worcestershire.*
CHAPMAN, David Stanley John. (S) *Malta, G.C.*
CORLETT, William Edward. *Southampton.*
CRANFIELD, Ronald Frederick. (S) *Bristol.*
DAWANCE, Eugene Julian. *Accra, Gold Coast.*
DOYLE, Martin Edward. (S) *Cork.*
DUNLOP, Edward Goodwin. (S) *London, N.4.*
GILVARY, David Francis (S) *Bray, Co. Wicklow.*
HARKNETT, Maurice Richard. (S) *Southsea, Hants.*
HIRD, Edward John. (S) *Portsmouth.*
JAMES, Brian Harry Laurence. (S) *London, S.E.27.*
JEYNES, Graham Frank. (S) *London, S.W.16.*
LEWIN, John Ernest. (S) *Bromley, Kent.*
MAGUIRE, Brian. (S) *Dublin.*
McCREADY, Kennedy Lemar. (S) *Crayford, Kent.*
NEWMAN, Robert Hanmer. (S) *London, S.E.27.*
PANJACHARAM, Thampoo. (S) *Singapore.*

The Following Candidates Passed Part II Only

AYIVORH, Samuel Clifford. (S) *London, W.2.*
BROOKS, William Gilbert Ernest. (S) *Chichester, Sussex.*
CLARKE, Leonard Roy. (S) *London, N.W.2.*
COFFEE, Ronald Alan. (S) *Thornton Heath, Surrey.*
CROSSLEY, Arthur Alan. (S) *London, W.6.*
MASTER, Minoo Ratansha. (S) *London, W.2.*
NICHOLSON, Michael David. *Guernsey, C.I.*
SCOULDING, William George. *Romford, Essex.*
SHORT, Thomas. (S) *Dublin.*
SOOD, Shiv Dutt. (S) *London, W.2.*
STEPHENS, James Henry Victor. *Chard, Somerset.*

The Following Candidates Passed Part IIIa Only.

BAMPFIELD, Geoffrey. (S) *Huddersfield, Yorkshire.*
COATES, George Frederick Rudolph. (S) *London, S.E.19.*
DUNNE, Michael Joseph. (S) *Eastcote, Middlesex.*
HALL, Ephraim. *Southampton.*
JAHANBIN, Ahmad Ali. (S) *Wembley, Middlesex.*
MARTIN, Arthur William. (S) *London, N.4.*
NARASIMHAMURTI, Chatti Butchi. (S) *Vizagapatam, S. India.*
PADMANABHA, Iyer Rama Iyer. (S) *Jabalpore, India.*
SAMUEL, Harris Chandra. (S) *Trivandrum, India.*
SUBRAMANIAN, V. (S) *Allahabad, India.*
WILLIAMSON, Robert. (S) *Didcot, Berkshire.*

The Following Candidate Passed Part IV Only

BURKILL, Arthur Herbert. (S) *London, N.W.10.*

(S) denotes a Registered Student of the Institution.

EDUCATION AND EXAMINATIONS COMMITTEE—II

Douglas Richard Chick was born in 1916 at St. Leonards, Sussex, and received his technical education at the Dartford Technical College and Woolwich Polytechnic.

He was apprenticed with Messrs. Johnson & Phillips, Ltd., and took a four-year "sandwich" course and obtained a B.Sc.(Eng.) degree.

In 1937, Mr. Chick joined the Signals Experimental Establishment and two years later he was transferred to the Bawdsey Research Station with the rank of Junior Scientific Officer, where he worked until 1941 on the pioneer development of coastal defence radar. He was then transferred to research on searchlight control radar and other anti-aircraft applications.

Mr. Chick left Government service in 1946 to head a section developing high-energy nuclear accelerators at the Research Laboratory of Associated Electrical Industries, Ltd. His work led to a thesis which gained him the M.Sc. degree of London University in 1950.

Elected an Associate Member of the Institution in 1948, Mr. Chick transferred to full Membership in October last year. He has served on the Education and Examinations Committee since June, 1951.

Robert Sydney Roberts, who was born in London in 1906, obtained his engineering education at Hackney Technical Institute. In 1923 he joined Messrs. Wright & Weaire Ltd., as an engineer, and after serving as Chief of Test, he was in charge of the Technical Department with responsibility for the research, design and testing of electrical and electronic components.

In 1937 he left to become a lecturer at the Northern Polytechnic, having already lectured in radio and electrical subjects at evening classes. In 1942 Mr. Roberts was seconded to the Ministry of Aircraft Production for radar development, returning to the Northern Polytechnic in 1945. He is now senior lecturer in the Department of Radio and Musical Instrument Technology at the Polytechnic. Mr. Roberts has been responsible, as a consultant engineer, for a number of important design projects for industrial organizations.

He was elected an Associate Member of the Institution in 1937, and in 1941 was transferred to full Membership. He was the Institution's examiner in Advanced Radio Engineering for the Graduateship Examination from 1947 until 1950. Mr. Roberts continues to serve on the Education Committee to which he was first appointed in 1947.

Maurice Ernest Claxton was born at Great Yarmouth in 1910 and received his technical education at Borough Road College, Isleworth, obtaining the B.Sc. degree of London University in 1931, with honours.

Up to the outbreak of war he was a science teacher in London and also carried out research on ozonolysis at Northern Polytechnic for a higher degree.

In 1940 he joined the R.A.F.V.R. and up to 1947 he was an instructor at the Officers' Signals School, Cranwell. He was then granted a permanent commission and for two years was in charge of Laboratory Development and Construction at the Aircraft Apprentices School. Shortly after the formation of the R.A.F. Technical College in 1949, Sqn. Ldr. Claxton received his present appointment as an officer in charge of the Electrical Engineering and Science Department of the Signals Division. As a result of educational research work, he secured the degree of M.Ed. of Durham University in 1950.

Sqn. Ldr. Claxton was elected an Associate Member of the Institution in 1943 and has recently been transferred to full Membership. He has been a member of the Education and Examinations Committee since 1948. In 1951 he became an examiner in Advanced Radio Engineering for the Graduateship Examination.

MAGNETIC RECORDING IN FILM PRODUCTION*

by

N. Leevers, B.Sc., A.C.G.I.†

A Paper presented at the Sixth Session of the 1951 Radio Convention on September 4th at Earls Court, London

SUMMARY

A very high standard of recorded quality can only be obtained by attention to details of mechanical and electronic design which are common to magnetic recorders irrespective of a particular application. Additionally, there are two fundamental requirements for the adaptation of magnetic recorders for sound films: the sound record must at all times be held in accurate synchronism with the associated picture and yet, at the same time, it must be physically separate to permit editing.

The paper describes an equipment for this purpose which makes use of a twin-channel magnetic tape carrying synchronizing signals. The synchronizing signal, lying between 1000 and 5000 c/s, is pulse modulated at picture frequency or a multiple thereof (24 or 48 c/s).

1. Introduction

The three most important methods of recording high-quality sound available to us to-day are the disc, the photographic film, and the magnetic tape or film. Each of these systems embodies the results of many years of research and development concerning the problems peculiar to itself, yet to-day, when the three systems are compared, using the most advanced technique in each case, we find that no marked differences exist. Each ranks as a high-fidelity system. Each is capable of recordings which are not readily distinguishable by ear from a direct-line communication.

The choice of a system for a particular purpose is, therefore, far more dependent upon strictly practical factors such as methods of manipulation, than upon differences in sound quality obtainable.

In film production the two most important practical requirements are ease of editing, and synchronization. In the early days, it was these factors more than any questions of sound fidelity, which forced studios to abandon sound-on-disc in favour of sound-on-film. To-day, it is these factors, more than any others, which have delayed the adoption of the magnetic system in studios for so long after the system was capable of high-fidelity results.

Editing is the process in which maybe hundreds of different scenes are assembled in sequence. It calls for a soundtrack which is physically separate from the picture image, yet which is of a form easily matched against that image. It is also desirable that the waveform of the sound recording be visible.

For many years photographic track on film stock has been used, and this forms the basis of current editing techniques. Perforated film stock having a magnetic coating, together with a visible envelope trace,[1, 2] may later come into general use, but up to the present the usual method of employing magnetic recording is to make the original recordings only on magnetic track, and to re-record on to photographic film as soon as possible, so as to enable the editing and later processes to be carried out in the orthodox manner.

This procedure does not make full use of all the attractive features of the magnetic system, but it does at any rate reduce film stock and processing costs, and it enables a very high standard of original recording quality to be maintained with certainty.

2. The Magnetofon

The Germans were probably the first to make extensive use of magnetic recording in film production. In the period immediately following the last war, film stock and processing facilities were scarce and expensive, whereas tape recorders of the Magnetofon type were available. Film production was therefore undertaken, using these machines which were fitted with synchronous capstan motors. Many production units still use them.

* Manuscript received August 31st, 1951.
† Leevers, Rich, Ltd.
U.D.C. No. 621.395.625.3:778.5.

Reports of difficulties encountered at the time, and of experiences in this country since then, have all emphasized that synchronism cannot be relied upon with this system.

The layout and tape path of a Magnetofon machine is shown in Fig. 1. The tape travels from the left-hand spool round a spin-wheel to the heads, passing in contact with the poles of the erase, record and play-off heads in turn, and then between the capstan spindle and pinch-roller to the take-up spool. The capstan spindle is, in fact, the extended shaft of the synchronous driving motor and the tape is held in close contact with this spindle by the pinch-roller.

It might therefore be expected that the tape speed would be strictly proportional to the spindle diameter, and that recordings made on one such machine would replay at precisely the correct speed on a similar machine, having a capstan ground to within close tolerances of the recording capstan. In practice, not only is it difficult to adjust two machines to maintain the same linear tape speed, it is usually impossible to replay a tape on the same machine on which it was recorded without some degree of speed drift occurring, and this drift is liable to become serious if there is a time lapse of more than one day between recording and playback !

There are two major causes of speed drift. They are tape stretch, and slippage at the capstan. Tape stretch usually occurs in storage. In the machine described, the tape is wound at a tension of several pounds in order to form a self-supporting roll. The tape material is plastic and will, in time, gradually alter its length.

Slippage is governed by the arrangement at the capstan and by the relative tensions applied to the tape by the take-up spool motor on the one hand, and by the hold-back, or feed-spool motor on the other. (A back-voltage is applied to the feed-spool motor in order to hold the tape against the heads.)

In the layout of the Magnetofon (and in many later machines based on the original design) it will be seen that the tape must be threaded with the coating in contact with the hardened steel capstan spindle, while the smooth uncoated side is in contact with the rubber pinch wheel.

The coating is abrasive, and the capstan spindle soon becomes very highly polished in use. Under these conditions, the friction between the tape and driving spindle becomes very much less than that between tape and rubber roller, and instead of the spindle driving the tape direct, it imparts motion to the rubber wheel where it overlaps the tape, and the rubber in turn transmits the drive to the tape.

The tape drive therefore tends to take place in two stages rather than one, and the slippage can occur in both, particularly if the smooth side of the tape is presented to the rubber. Measurements of slippage were therefore made under dynamic conditions, first with the usual arrangement of coating towards the capstan, and secondly with the tape reversed to bring the coating in contact with the rubber. Over a series of six separate comparative tests the results showed that the slippage with the second arrangement was less than 40 per cent of that occurring in the normal arrangement. This important point has been borne in mind in the design of the machine to be described later.

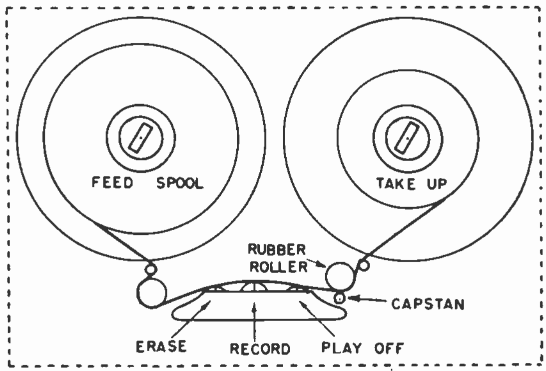


Fig. 1.—Layout of Magnetofon.

Synchronizing errors due to both slippage and tape stretch tend to be cumulative during a recording, and therefore, although this type of machine is simple to operate and suitable for many purposes where synchronism is not vital, it cannot be used with full confidence for normal dialogue in film production.

3. Perforated Tape or Film

The orthodox solution to the problem of synchronizing is to use perforated tape, that is, kinematograph film carrying a magnetic coating. This involves the use of sprockets to control the film speed, the sprockets being driven by a positive gear drive from the synchronous motor. Several makes of recorder working on this system are now available and are being used in studio installations.

There are, however, several difficulties which must be borne in mind. Driving the film by gears and sprocket teeth imparts flutter to the film motion. Therefore a suitable mechanical filter system must be used to isolate such disturbances from the film actually passing over the recording head. This involves a machine of some mechanical complexity, which will be as large as a photographic film recorder, and probably just as expensive to make.

The coated film stock is also bulky and expensive, being about 10 times the price of the same footage of tape and about 10 times the volume and weight. These are all important factors, particularly on mobile work. Some saving in bulk on the recording material may be achieved by the use of 17·5-mm or 16-mm coated film, but even this is still cumbersome compared with tape.

Finally, intimate contact between the magnetic coating and the recording or play-off head is essential for good high-frequency response. Magnetic tape is only about 0·002 in thick and very "limp" so that it rides snugly against the head. Material as thin as this has not the mechanical strength for being driven by sprocket teeth and perforations without tearing, so the normal film base of 0·005 in. thickness is used. This is relatively stiff and springy, and raises problems of head contact which are not easy to solve.

Clearly, although perforated film solves the synchronizing problem, it means compromising on several of the attractive features of the tape recorder, particularly its simplicity and portability.

4. Reference Signal Method

Several methods of synchronizing have been described in which the correct speed at which to replay tape is indicated by a separate timing signal on the tape. This signal may take several alternative forms, but the principle is the same in each case. This principle is best illustrated by describing the use of striped tape.

The magnetic tape used in this method has a normal magnetic coating over one surface, and a visible stripe pattern on the reverse. The pattern is dimensioned so that when viewed under a lamp connected to the same a.c. supply which drives the camera, the correct running speed is indicated by the stroboscopic effect.

When re-recording to film, the same stroboscopic indication is used to adjust tape speed in relation to the a.c. supply driving the recording camera.

The stripes are just as much a physical part of the sound record as sprocket holes on a sound film, and the synchronizing is therefore unaffected by slippage or tape strength. The method does, however, involve accurate speed control in *both* the recording and in the reproducing processes, and also necessitates the use of an a.c. power supply for camera and interlock. These awkward factors in portable applications, and the need to control speed in recording can be avoided by recording a signal simultaneously with the dialogue.

There are two methods which achieve this by recording the synchronizing tone on the same track as the dialogue. One makes use of the fact that a magnetic pick-up head, arranged to reproduce the orthodox "linear" type of track, is relatively insensitive to magnetic modulation of the tape in the dimensions at right angles to it. The synchronizing signal therefore takes the form of a low-frequency tone (50-60 c/s) superimposed on the speech track and with a "lateral" instead of a "linear" type of modulation.[4]

The second of these methods makes use of a signal of very high frequency (14 kc/s) which is modulated at a low frequency (50-60 c/s). This modulated carrier is added to the speech signal in the recording head and recorded on the tape as a composite signal. In reproduction, the two signals are separated by suitable filters, and fed to separate amplifiers, the 14 kc/s carrier then being demodulated and the resultant signal used to control motor speed.[3, 5]

Both these systems have the desirable feature of a simple recording procedure, leaving the more complex work and apparatus involved in synchronizing entirely to the reproduction process, which, as far as film production is concerned, is usually carried out in a well-equipped professional studio.

5. Twin Track Method

The synchronizing system embodied in the recorder to be described makes use of a continuous reference signal on the same broad principles described above, but there are certain important differences in detail which simplify operation and make the machine very suitable for portable use.

The synchronizing signal itself is not mixed with the speech signal in any way, the two being recorded as separate tracks side by side on the tape. The tracks are both 0·100 in wide, spaced 0·025 in apart, and equidistant from the centre line of the tape. This means of course, that the speech input to the reproducing amplifier is lower than it would be for full width operation, but with careful head and amplifier design and adequate screening the overall effect on volume range is not significant, while high-frequency losses due to slight errors of azimuth are noticeably reduced. Also, separation of the two tracks in this way enables "cross talk" to be eliminated without undue difficulty. It is consequently not necessary to relegate the synchronizing signal to either extremity of the recording spectrum; its frequency may be chosen with due regard to the electrical and magnetic efficiency of the system.

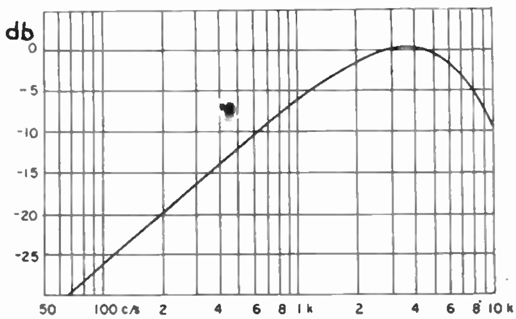


Fig. 2.—L.C. tape characteristic at 15 in per sec.

A typical response curve for magnetic tape (Fig. 2) shows that for constant modulation of the tape at the standard speed of 15 in/sec, the region of maximum voltage output from the reproducing head lies between 1,000 and 5,000 c/s. A carrier frequency of this order was therefore chosen.

The pulse system of modulation was chosen as being the most suitable for the display and control devices at present in use, the pulse frequency being governed by the camera design and type of motor employed.

Where it is required to synchronize to an a.c. supply, whether by the supply mains or the slip rings of a d.c. interlock motor, the pulse frequency is the same as the supply frequency (e.g. 50 or 60 c/s). Where it is required to synchronize to a camera driven by a battery motor, or even by clockwork, it is usually more convenient to pulse at picture frequency or a multiple thereof (e.g. 24 or 48 c/s).

When the 24 c/s frequency is used it will be realized that the pulses on the tape bear the same relationship to the sound as the frame lines to the picture.

The carrier source is an integral part of the recording machine, and the pulsing device is very simple and robust. For 24 or 48 c/s operation, it consists of a small cam-operated contact-breaker fitted to the "single turn" spindle or other convenient shaft on the camera or the motor (such as the "inching" knob). For a.c. sources, a simple bridge network of linear and non-linear elements is interposed, which passes one pulse of carrier for every cycle.

The synchronizing signal therefore consists of a series of pulses laid alongside the speech track. These pulses are an indication of the vital time relationship between the frame speeds of the picture and the sound recording to which they are attached. They do not necessarily indicate the linear tape speed, which is immaterial, and may in fact vary, due to slipping or stretch.

One point is important. Camera speed must be maintained at the standard speed of 24 frames/sec if differences in pitch are to be avoided in reproduction. An accurate tachometer, or better still, a governed type of motor should therefore be used on the picture camera, for with this system the camera speed, in effect, controls the sound speed as in the case of the newsreel type of camera.

6. Methods of Transcription

Having adopted a form of synchronizing signal which may be recorded by very simple, and therefore robust, apparatus, it might be expected that the ultimate transcription process would involve correspondingly elaborate equipment. This is not the case. Unless a large volume of work is being handled, manual control of tape speed is entirely satisfactory and the set-up is very simple.

A reference source is required, corresponding to the nominal pulse frequency, and which is interlocked to the photographic recorder. For a 24 c/s signal, this may be arranged by a shaft geared to a 1,500 r.p.m. synchronous motor through 25/24 reduction gearing. This 24 c/s shaft drives a contact-breaker which triggers the time base of a cathode-ray oscilloscope.

The recording machine itself may be used as a high-quality reproducer, and the output from the pulse head is connected to the "Y" plates of the tube, when the pulse wave-form will be seen. The motor speed control of the recording machine is then adjusted to maintain the pulse in a steady position on the C.R.T. screen, thus indicating synchronism with the original camera speed.

Although manual control as described above is by no means a difficult operation, it may become tiring or, at any rate, tedious on very long takes or if a considerable volume of work is handled. Under these circumstances automatic control should be used, and this may be arranged in several ways, based on different types of phase discriminator.

7. Portable Magnetic Recorder

From the foregoing survey, it is possible to appreciate many of the features which are important in a magnetic recorder for use in kinematography. The equipment now to be described is a professional instrument which incorporates many of these ideas in practical form, and comprises two units of equal size, containing the amplifier and recording machine respectively (Fig. 3). They are inter-connected by short flexible cables and power is derived from an accumulator carried separately. Total power consumption is 5 A at 12 V.

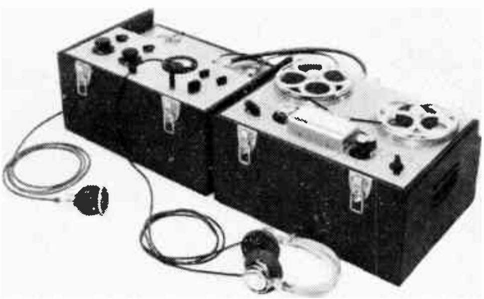


Fig. 3.—Leevers-Rich magnetic recorder, Model C.S.

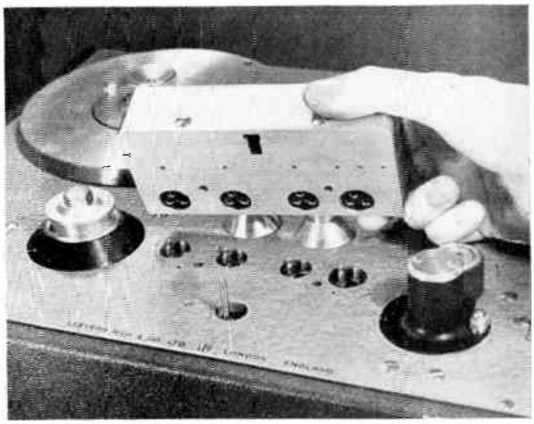


Fig. 4.—Multiple head unit.

The recording mechanism consists of the feed and take-up spools (each of which is driven by an inverse-torque motor), the spin-wheel, the multiple head assembly and the high-speed capstan. The 4-position rotary switch (bottom right) performs in correct sequence all the electrical and mechanical operations connected with the control of the recorder. The left-hand switch controls the power supplies to the amplifier unit.

The spools shown give a playing time of 15 minutes at the normal tape speed of 15 in/sec, and larger spools giving a playing time of 30 minutes can be accommodated.

The spinwheel carries stroboscopic markings which indicate the normal speed of 15 in/sec when illuminated from 50 c/s a.c. A portable 100 c/s stroboscopic viewer enables the speed to be set when operating away from a.c. mains.

The head assembly (Fig. 4) is removable as a unit and contains the four magnetic heads, with their screening and plug connections. The heads are (from left to right), "erase," "pulse," "record," and "play-back."

The underside view of the chassis (Fig. 5) shows the screened H.T. generator and oscillator chassis at the bottom, and one of the spool motors can be seen on the left. The triple skin screening conduit, carrying the play-off head lead, is visible passing beneath the head block and behind the spin-wheel to the plug termination at the rear.

The main drive motor and capstan assembly seen alongside the right-hand switch, may be removed as a complete unit. This unit carries the hardened steel capstan shaft and its flywheel which is driven direct from the motor shaft through a compliant coupling to ensure freedom from flutter. A rubber-tyred puck roller is also part of this assembly.

The amplifier unit is contained in a case to match that of the recorder and consists of two complete amplifiers, one for recording and the other for monitoring and play-back. These amplifiers can be used simultaneously, thus enabling the operator to "monitor off tape," i.e. to hear the sound he has recorded on the tape as it passes the play-off head a fraction of a second later. This is a valuable check on quality and leads to a very high standard of recording being achieved.

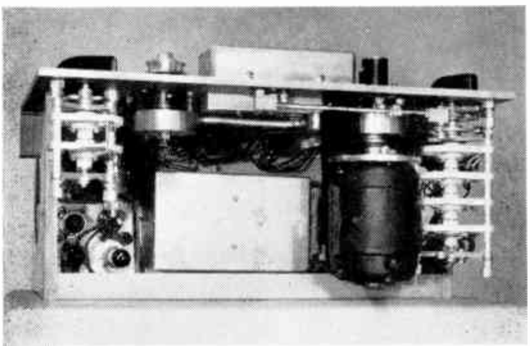


Fig. 5.—Recorder mechanism.

There are two input channels suitable for high-quality dynamic microphones of either the directional or the non-directional type. Each channel has a separate dialogue attenuator and gain control, and there is a reserve gain switch to give extra amplification for very distant pick-up. The meter can be switched to read battery voltage, modulation level, or R.F. bias voltage. The bias voltage is adjustable.

To avoid the possibility of acoustic feed-back, high-quality headphones are normally used for monitoring during recording, and they may be switched to monitor either the incoming signal, or the signal reproduced from the tape. For reproducing purposes, the amplifier contains an output stage capable of delivering over 4 W undistorted output and this may be switched

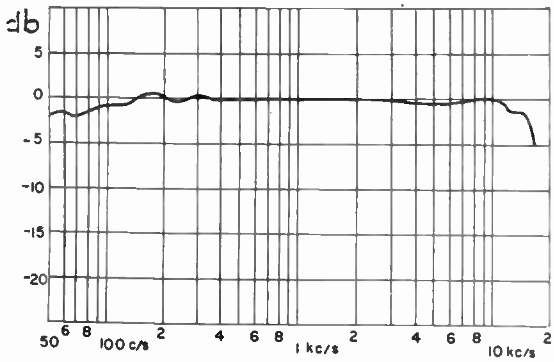


Fig. 6.—Overall frequency characteristic (L.C. tape).

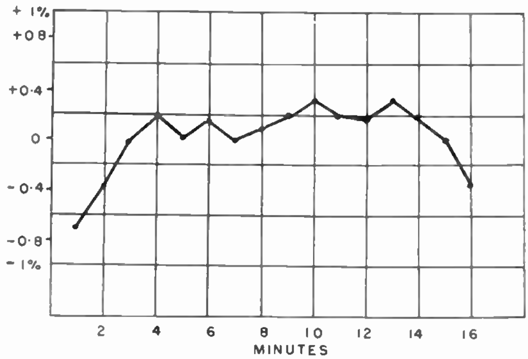


Fig. 7.—Time/speed characteristic.

over to either a small monitor speaker mounted in the case or to an external high-quality auditorium speaker.

The overall frequency response of the instrument is shown in Fig. 6. This is measured from microphone input plug to line output, using low coercivity tape. For a variation of ± 2 db, it extends well beyond 10,000 c/s, while the effective volume range of over 50 db is ample for normal applications.

Figure 7 shows the speed measured at 1 min intervals during a 16-min recording, no correction being applied to the speed regulator for the purposes of this test.

8. Conclusion

This paper has outlined methods and described apparatus whereby high-quality recordings may be made and synchronized with kinematograph films. By departing from orthodox methods of synchronizing which involve perforated film, the apparatus is made very compact, simple to use, and low in operating cost.

The equipment is arranged so that all the recording operations (except microphone positioning) are very simplified and are under the direct control of a single operator. Both the sound track and the synchronizing signal are stored on the tape to be dealt with later. The equipment is therefore a "sound storage machine."

When it is borne in mind that these machines have already carried out feature film recording with success, under conditions ranging from sun temperatures of over 110° F in Nigeria to air temperatures of 40° F below freezing in Norway, from humidity as high as 90 per cent on the Gold Coast to the recent hurricane in Jamaica, there is much to be said for this method whereby the exacting work of recording the photographic sound track is handled later by a specialist staff, working under the more ideal conditions of a fully equipped sound recording installation.

9. References

1. Ulner, M. "A German Magnetic Sound Recording System in Motion Pictures." *J. Soc. Mot. Pict. Tele. Engrs*, **56**, No. 4, April 1951, page 411.

2. Kolb, O. K. "Magnetic Sound and the Film." *British Kinematography*, **15**, No. 2, August 1949, page 37.

3. Hare, D. G. C. and Fling, W. D. "Picture-Synchronous Magnetic Tape Recording." *J. Soc. Mot. Pict. Tele. Engrs*, **54**, No. 5, May 1950, page 554.

4. Ranger, R. H. "Sprocketless Synchronous Magnetic Tape." *J. Soc. Mot. Pict. Tele. Engrs*, **54**, No. 3, March 1950, page 328.

5. Selsted, W. T. "Synchronous Recording on ¼ in Magnetic Tape." *J. Soc. Mot. Pict. Tele. Engrs*, **55**, No. 3, Sept. 1950, page 279.

"AUDIO FREQUENCY ENGINEERING"

Publication of the papers presented at Session 6 of the 1951 Radio Convention has been proceeding for the past few months and, in response to enquiries from members, the Programme and Papers Committee announces that the following papers will be published, in full, in the 1952 issues of the *Journal*.

"Objective Testing of Pick-ups and Loudspeakers" *by* K. R. McLachlan and R. Yorke, B.Sc., B.Eng.

"Speech Input Systems for Broadcast Transmitters" *by* S. Hill, M.Eng.

"Loudspeakers: Relations between Subjective and Objective Tests" *by* F. H. Brittain.

"Intermodulation Distortion: Its Significance and Measurement" *by* E. Berth-Jones, B.Sc.(Eng.).

"Loudspeaker Baffles and Cabinets" *by* J. A. Youngmark, M.A.

"Piezo-electric Crystal Pick-ups" *by* S. Kelly.

The following papers will not be published in full, but probably in condensed form:—

* "Electrophonic Organs" *by* L. E. A. Bourn.

* "The Loudspeaker in the Home" *by* P. J. Walker.

"The Royal Festival Hall: Acoustic Design and Testing" *by* P. H. Parkin, B.Sc.

"The Mechanism of Hearing" *by* T. S. Littler, M.Sc., Ph.D.

* Copies of these papers are available for reference in the Institution's Library, or may be purchased in preprint form, price 1s. each post free, so far as stocks permit.

Section Activities . . . .

NORTH-EASTERN SECTION —

The Annual General Meeting of the Section was held at the Institution of Engineers and Shipbuilders, Newcastle upon Tyne, on May 14th, when the main items of business were the presentation of the report on the session's activities and the election of officers and committee for the session 1952/53.

The retiring Chairman, Mr. L. G. Brough, reported that the programme of the past session had been well received and it had been found that papers dealing with television had attracted the largest attendances. The average attendance at meetings was well over 40 and had been as high as 80 members and visitors.

The 1952/53 committee was elected with the following officers:—

J. C. Martin, M.A. (Associate Member) (*Chairman*).

D. R. Parsons (Associate Member) (*Programme Secretary*).

J. I. Forster (Associate Member) (*Membership Secretary*).

L. G. Brough (Associate Member) (*Treasurer*).

At the conclusion of the formal proceedings, various films of technical and topical interest were shown, including the Television Newsreel of the Institution's 1951 Festival Convention Dinner and other Convention films.

BANGALORE —

The Bangalore Branch held its first technical meeting on February 21st at the Indian Institute of Science, when Mr. A. D. Collins (Associate) presented a paper on "An Electronic Time Schedule." The electronic system can measure the rate at which the difference between actual progress and the predetermined schedule is being made up or lost, and Mr. Collins described the application of the equipment to the movement of a train.

On April 1st, Mr. B. N. Prakash, M.Sc. (Associate Member), read a paper on "Progress of the Radio Industry in India and Problems relating to its Future Development." He first reviewed the expansion of radio factories from the initial stage of the production of receivers from sub-assemblies manufactured abroad, to the present stage where only a proportion of the components have to be imported. In the second part of his paper Mr. Prakash dealt in some detail with the manufacture of components, considering the possibilities of fabricating in India the individual items making up components, and the origins of the raw materials involved.

A second paper by Mr. A. D. Collins, on "An Electronic Training Aid for Radar Operations," was read at the meeting on May 6th. After stressing the need on economic grounds for such equipment, Mr. Collins gave a detailed description of the circuits used to simulate pulses reflected from a number of aircraft at continually varying distances from the ground radar station. He pointed out that equipment was completely electronic—a departure from other systems employing mechanical devices.

WEST MIDLAND —

On the evening of July 16th a party from the West Midland Section visited the electrical engineering dept. of Birmingham University. The party was welcomed by Mr. D. A. Bell, Reader in Electro-Magnetism,* who gave a short talk outlining the type of work carried on there.

Members were then taken through the laboratories of the "Summer School on Electronics" where a number of static and working exhibits were on view These covered such subjects as magnetic amplifiers, servomechanisms, timing devices and specialized valves and counting tubes.

The party then proceeded to another laboratory where investigations into noise in valves and semiconductors are being undertaken. Research was also being carried out on the nature of the transmitted television vision signal with the aim of reducing the necessary band width required for colour television.

Members then proceeded to the heavy electrical laboratory and were shown, amongst other things, an electronically-controlled motor generator set capable of maintaining any one of a wide choice of speeds from zero to maximum load, and a machine for sorting and counting canned goods by means of photoelectric devices.

* Mr. Bell was the author of the 1947 Convention paper on "Television Receiving Aerials," published in the *Journal* for January/February, 1948 (pp. 19-40).

NOTICES

Royal Garden Party

The President-elect (Mr. W. E. Miller) and Mr. G. D. Clifford (General Secretary) had the honour of invitations to the Royal Garden Party held at Buckingham Palace on July 10th last. This was the first Garden Party of Her Majesty's reign.

Increase in Examination Fees

The Council has recently approved the increase in examination fees to £1 1s. per part irrespective of the number of parts being taken at any one time. The fee for the entire examination at one sitting now becomes £5 5s.

This increase commences on October 1st and will include all entries for the May 1953 examination whilst those for the November 1952 examination will not be affected.

At the same time the reduced fee which was payable by student members of more than three years' standing has been abolished.

Course for Teachers of Radio and Television Servicing

A short course for Teachers of Radio and Television Servicing, organized jointly by the Ministry of Education and the Radio Industry Council, and directed by Mr. H. W. French, B.Sc. (Member), H.M. Inspector of Schools, will be held from September 8th to September 13th inclusive. The course, which will be residential, will be for full-time and part-time teachers of the subject in Technical Colleges. The lectures will take place at the Borough Polytechnic and visits will be made to set and component manufacturers, works, schools, B.B.C. studios, etc. Further details may be obtained from: The Ministry of Education, (Teachers Short Courses), 11 Bryanston Square, London, W.1.

R.I.C. Specifications

The following new specifications have recently been issued by the Radio Industry Council:

RIC/151—Switches, Dolly-Operated (Sections 1 and 2).

RIC/154—Switches, Wafer, Rotary (Sections 1 and 2).

RIC/251—Valve-holders, Electronic Receiver Types (Sections 1 and 2).

Further details may be obtained from the R.I.C., 59 Russell Square, London, W.C.1.

Lucknow Group

Members drawn from universities, All India Radio, Post and Telegraphs Department and the Police Wireless Department are considering the formation of a group in Lucknow for the purpose of holding regular meetings.

Any members interested in the group's activities should communicate with: C. P. Joshi, Esq., M.Sc., A.M.Brit.I.R.E., Communication Centre, Police Wireless Telegraphy Section, Dilkusha, Lucknow.

Conversazione of the Royal Society

Members will be interested to learn that Professor H. M. Barlow (Member) and Dr. A. L. Cullen, of University College, London, were responsible for presenting a novel microwave demonstration at the recent Royal Society Conversazione.

The possibility of the transmission of non-radiating surface waves along a wire was first described by Sommerfeld over fifty years ago, but it has only recently been realized by Goubau. The equipment shown by Professor Barlow and Dr. Cullen demonstrated how the wave is launched and received by concentric conical horns. The propagation along the wire can be increased by roughening or by coating with a dielectric since it depends on the surface reactance of the conductor. This effect enables the waves to negotiate bends; a bare polished wire radiates freely from sections showing change of direction and this phenomenon was also demonstrated.

Mr. A. F. Bulgin

Mr. A. F. Bulgin, whose biography was published in the June *Journal* (p. 367), is, it should have been added, a past chairman and a founder of the Radio and Electrical Component Manufacturers' Federation, of which he is now a Vice-President.

Mr. Bulgin is also a Freeman of the City of London, and a Liveryman of the Worshipful Companies of the Clockmakers, Farriers and Musicians.

Errata

In the article "The Work of the Radio Research Station," published in the July issue of the *Journal* (page 394) the phrase " . . . at right angles to the base line" (second paragraph, line 9) should be deleted.

APPLICANTS FOR MEMBERSHIP

New proposals were considered by the Membership Committee at a meeting held on July 30th, 1952, as follows: 32 proposals for direct election to Graduateship or higher grade of membership and 26 proposals for transfer to Graduateship or higher grade of membership. In addition 69 applications for Studentship registration were considered. This list also contains the name of 1 applicant who has subsequently agreed to accept a lower grade than that for which he originally applied.

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

Transfer from Associate Member to Full Member

BAZIN, Rene Eugene. *London, N.5.*
BRINKLEY, John Raymond. *Gt. Eversden, Cambridgeshire.*
CLAXTON, Maurice Ernest, Squadron Leader, B.Sc., M.Ed. *Debden, Essex.*

Direct Election to Associate Member

BLACKLAW, John, Flight Lieutenant. *Dundee.*
HUXTABLE, Thomas Albert. *Accra, Gold Coast.*
JAYAVEL, Chidambara, B.Sc. *Madras.*
MUNN, Leonard Charles. *Epsom, Surrey.*
PARRY, Charles Alchorne. *Sydney, New South Wales.*
*PENTON, William Arthur. *Wellington, New Zealand.*
PERRY, Sidney Harold. *Wallington, Surrey.*
SCRINE, Richard Claude. *West Harrow, Middlesex.*
SHAH, Sadiq, B.Sc. *Kohat, N.W.F.P., Pakistan.*
WELCH, Trevor William. *Birstall, Leicestershire.*

Transfer from Associate to Associate Member

BIRD, Henry George. *Manchester.*
BOLTON, Ronald. *Nairobi, Kenya.*
DAS, Daleep Bruce, Flight Lieutenant. *Kishenpur, India.*
DEAN, Kenneth John. *Croydon.*
GREGORY, Henry. *Rickmansworth.*
SWAIN, Eric. *London, N.4.*
WALE, Edward Frederick. *Slough, Buckinghamshire.*
WARD, Michael Marshall. *London, E.11*
WILLIAMS, Ivor James Stuart. *Bombay.*

Transfer from Graduate to Associate Member

PAWLUS, Jan. *Ilford, Essex.*

Direct Election to Associate

BUCKLAND, Ernest Clifford Norman. *Windsor, Berkshire.*
GRAY, John Lamont. *Tripoli, Lebanon.*
MYINT, Aung. *Rangoon, Burma.*
SHEPHERD, Adrien Walker. *London, W.2.*
TRENT, Mark Clifford. *Lyttleton, South Africa.*
WOOD, James. *Farnborough, Kent.*

Direct Election to Graduate

BOWLES, Eric. *Mitcham, Surrey.*
BRIGGS, Eric Harold. *Preston, Lancashire.*
FLAKE, Alfred John. *Felixstowe, Suffolk.*
HELLIWELL, Brian Stanley. *Southport, Lancashire.*
LE CAN, Claude Jan. *Paris.*
PATWARDHAN, P. Keshava. *Indore, India.*
PEAKIN, Kelvin Richard. *Thornton Heath, Surrey.*
SCRUBY, Joseph Mortlock. *Walmer, Kent.*
PUTHENPURAYIL, J. Varghese. *Dehra Dun, India.*
WILMOT, Alfred George. *Glamorgan.*

Transfer from Student to Graduate

LAVERICK, Charles, B.Sc. *Borehamwood, Hertfordshire.*
LAWTON, Samuel Derek. *Mottram, Cheshire.*
McILWRAITH, John W. B. *Portsmouth.*
SHORT, Harry. *Belfast.*
VENKATESWARAN, Gopalakrishnayyar. *Calicut, India.*

*Reinstatement.

Studentship Registrations

AHMAD, Muzaffar. *Karachi, Pakistan.*
AHMED, Jamul. *Fulaili, Hyderabad (Sind), Pakistan.*
ANAGNOSTOPOULOS, Aristides. *Athens.*
ASAMOAH, John Horace. *London, S.W.10.*
BARRY, Jugal Kishore, B.Sc. *Kanpur, India.*
BHATTACHARYA, Dilip Kumar. *Calcutta.*
BILLSON, Joseph Glen. *Boksburg, South Africa.*
CANDYLIS, Emmanuel. *Athens.*
CARLIS, Georges. *Athens.*
CHASTENEY, Peter. *Dagenham, Essex.*
CLARK, Dennis Henry. *London, N.W.10.*
COROBILIS, John. *Louridos, Greece.*
DE CASMAKER, Donald E. B. *Bristol.*
DOWSETT-MARSH, Julian Caryl. *Rayleigh, Essex.*
FARIA, Warren Arthur. *Rangoon, Burma.*
GARNER, William Vernon. *Salford, Lancashire.*
GAY, Lionel Stanley. *Durban, South Africa.*
GHOSH, Birendra Kumar. *Calcutta.*
GOLDSTEIN, Arie. *Haifa, Israel.*
HARGREAVES, James Bryce. *Queensland, Australia.*
HOSSAIN, Abu Jafar Mohd Hamed. *Dacca, East Pakistan.*
HUSSAIN, Nisar. *Mirpur, Pakistan.*
KHAN, Mohd Sarwar. *Punjab, Pakistan.*
KLAPPER, Kenneth Leonard. *Cheltenham, Gloucestershire.*
KORATKAR, Purushottam Vinayak, B.Sc. *Jambag, Hyderabad, India.*
KRISHNASWAMY, Venkitachalam. *Travancore, India.*
KYDONIEF, Stelios Nicholas. *Alexandria, Egypt.*
KYRTATOS, Georges. *Athens.*
LEE, Kenneth Pembroke. *Cookridge, Leeds.*
LOGIADIS, Minas. *Heraklion, Crete.*
MANOLARAKIS, Nicolas. *Athens.*
MARWAH, Sukhdev Singh. *Dehra Dun, India.*
MEHTANI, M. N. *Delhi, India.*
NICOLAIDES, Emmanuel. *Athens.*
NICOLS, John A. Daniel. *Ipswich, Suffolk.*
PAPATRIANTAPHYLOPOULOS, Kostantinos. *Athens.*
PAUL, Selvaraj Peter. *Madras.*
PINGLE, Sharadachandra Narayan. *Nasik City, India.*
PITSINIGOS, Peter. *Athens.*
RAMA, Jamnadas. *Transvaal, South Africa.*
REED, Malcolm Bruce. *Plymouth, Devon.*
ROBSON, Alan. *Newcastle-upon-Tyne.*
ROMVOS, Nicolas. *Athens.*
ROOK, William John. *Minehead, Somerset.*
SCHLOSS, Ralf. *Tel-Aviv, Israel.*
SEALE, Edward Gilbert. *Terlnure, Co. Dublin, Eire.*
SHORT, Thomas. *Dublin, Eire.*
SONI, Chittaranjan, Captain. *Cawnpore, India.*
SMITH, James. *Ludlow, Shropshire.*
SRINIVASAN, Krishnaswamy, B.A. *Mannargudi, Madras State.*
SYED, Mohd Mokurram. *Lahore, Pakistan.*
TALBOT, Leonard Oswald. *London, S.E.19.*
TATAKE, Vidyadhar Govind, B.Sc. *Poona, India.*
TAYLOR, Edwin Leslie. *Lincoln.*
TAYLOR, James William. *Co. Wicklow.*
THOMPSON, Allan Walton. *New South Wales.*
TSAUALOS, Ilias. *Athens.*
TSALTAS, Georges. *Athens.*
TSATSOMEROS, John. *Athens.*
UNDE, Madhav Anant. *Poona, India.*
VALLABH, Vrij, M.Sc. *Lucknow, India.*
VARADARAJAN, R. S. *Madras.*
VENKATESAN, A. R. *Palni, S. India.*
VISSER, Gideon Louwrens. *Johannesburg, South Africa.*
VISWINATHA, Rao C. *Bangalore, India.*
YAM YAU BAN. *Hong Kong.*
ZANNOS, Nicolas. *Athens, Greece.*

JOURNAL OF THE BRITISH INSTITUTION OF RADIO ENGINEERS

RECENT DEVELOPMENTS IN VIBRATORS AND VIBRATOR POWER PACKS*

by

J. H. Mitchell, B.Sc., Ph.D.†

A Paper presented at the Third Session of the 1951 *Radio Convention on July* 24*th at University College, Southampton*

SUMMARY

This paper deals only with the Grade I type of vibrator which is expected to give a life of at least the 1,000 hours necessary to meet Service requirements. It deals very fully with the different types of vibrators, and gives reasons for specializing in the main on synchronous split-reed, separately-driven types.

An outline is given of an extensive investigation into contact phenomena, the design of the vibrator itself and the circuits into which the vibrator is feeding, together with a short section on power pack performance.

An extensive range of vibrators is described covering outputs from a few milliwatts to over 200 watts, and extremely high conversion efficiencies have been obtained.

1. Introduction

The provision of power supplies for mobile radio equipment is an old issue for which a really satisfactory solution would appear never to have been found. The problem was dealt with as recently as February 1950 at a discussion meeting of the Radio Section of the Institution of Electrical Engineers.[1] This discussion brought out the relative advantages and disadvantages of vibrators and rotary convertors as were then known, and it was not possible to do more than hint at some of the vibrator developments then taking place. The past year has seen some of these developments nearer fruition, and it is the object of this paper to give some account of the first results of this work. It is perhaps desirable to present first of all the problems of conversion of d.c. to d.c. and the general requirements of a vibrator before proceeding to the various attempts to solve the problem.

2. Conversion of D.C. to D.C.

There are in general four principal methods of obtaining d.c. transformation: (1) electronic, (2) rotary convertors, (3) rotary interrupter followed by transformer and rectifier and (4) vibrator packs. In general the electronic method is not applicable below 24 V owing to the volt drop of the convertor tubes, and even here it is relatively inefficient. At, say, 100 V it can be considered as a possible method although even at this voltage efficiencies above 65 per cent. are very difficult to obtain. The third method is a compromise between the second and fourth and in general carries the weaknesses of both. Little attention has been paid to this system in this country although there have been attempts to develop it in Germany and America—in the latter country for very high powers at low voltages—with some success.

Where expense is not a major consideration, the rotary convertor has in the past held the field. The rotational speed has been increased to produce a relatively light-weight device giving an efficiency as high as 60-65 per cent. when upwards of 100 W is required. The shaft can be used for mechanical drives or with a fan to provide additional cooling. A major disadvantage is the reduction in life of the bearings at the higher rotational speeds—for example on aircraft work—where 1,000 hours between overhauls and three overhauls is the life of the device—and at altitudes the brush problems become very acute. It would appear that future progress with the rotary, either in efficiency or reduction of weight, must depend on higher rotational speeds or the development of new irons and the reduction in price of some of those already existing. Where development is continuing in the field of higher rotational speeds, quite high efficiencies have been obtained, but there seems little doubt at the moment that this advance will only be achieved at a much increased cost.

* Manuscript received May 9th, 1951.
† Head of Research, Ericsson Telephones, Ltd.
U.D.C. No. 621.314.621.

The vibrator has also made progress during the last 10 years but has tended to find application in the less expensive equipment. It is possibly this tendency towards price reduction that has restricted the advance of the vibrator. The radio set designer with a highly competitive market has tended to take the cheapest article that appeared to do his job and a general idea has resulted that vibrators are unreliable.

In the war years the Services laid down a specification for a Grade I vibrator and one firm in this country met that specification for one size of vibrator. Arising from the experience on this vibrator a scientist from one of the Ministries stated in the I.E.E. discussion[1] that "he disputed the widespread conception that they were unreliable devices. They were robust enough to be accepted for Service requirements and could be relied on for at least 1,000 hours. The conversion efficiency of a vibrator was higher than that of a rotary convertor. . . . One great advantage of the vibrator system was that several different outputs could be obtained from secondary windings on the static transformer. Moreover, if the need arose to change the outputs it was easier and cheaper to redesign the static transformer than to redesign a rotary transformer."

The work on this wartime vibrator, known as A.M. Type 14, has been accelerated during the past three years so that a range of Grade I vibrators have been produced up to 200 W at 24 V.

3. The Vibrator

It is worth while setting out the conditions of operation of vibrators and their associated circuits as at present understood. A list of the different types of vibrator is given below. (Table 1.)

In making a choice from these types the following points must be borne in mind. The synchronous or self-rectifying vibrator produces on one pair of contacts an a.c. from the d.c. source, and on a second pair of contacts rectifies this a.c. after it has been transformed, thereby eliminating the necessity of an external rectifying valve. The synchronous vibrator has advantages in commutation when dealing with large powers, giving an increased life to the interrupter contacts which, in general, are the first to wear.

The life of a contact is a function, among other factors, of the current it breaks. If, therefore, it can be arranged for the rectifying contacts to break before the primary contacts then, in general, a very low current is broken at a high voltage and the current has already begun to fall in the main contacts before they open.* This reason and the efficiency advantage of carrying the rectifying element in the vibrator have made us concentrate the major portion of our work on the synchronous type.

TABLE 1

Type	Reed and Contact Arrangements
(*a*) Non-synchronous, self-driven	Single changeover contact set, no driving contact.
(*b*) Non-synchronous, separately driven	Single changeover contact set. Drive contact fitted and electrically connected to the main contact set.
(*c*) Synchronous, self-driven	Two changeover sets of contacts fitted. The contacts are electrically connected via the reed. No drive contact fitted.
(*d*) Synchronous, separately driven	As (*c*) but driving contact fitted.
(*e*) Synchronous, split-reed, separately driven	Two changeover sets of contacts, no electrical connection between them. Drive contact fitted.

Much thought has been given to the question of self-driven versus separately-driven systems. For reliable operation the contact feeding the drive coil should not be affected by loading conditions since if this contact becomes appreciably worn or acquires a high resistance, or is otherwise affected by irregular local conditions, the mechanism may fail to start. This occurs more particularly with tungsten contacts which on standing tend to oxidize but which, after carrying a load for a few operations, tend by arcing and rubbing to clean up. This effect is further accentuated by the effect of wear on the load contact by use. A separate drive contact gets over these difficulties and in fact assists in the vibrator operation by permitting main contact cleaning in early working.

Tungsten would appear to be the best load contact material for voltages above about 2 V.

* This advantage is most marked with all quenched type circuits, but where commutating circuits are used (see below) the advantage is perhaps not so marked.

In the past there has been contradictory evidence for the best medium in which to operate the tungsten. Hydrogen was advocated in America and then rejected because of the cost of the sealing involved. Work on the Type 14 by a Service department indicated that dry air at one atmosphere was the best medium; the contacts working in hydrogen have only some 70 per cent. of their life in air.

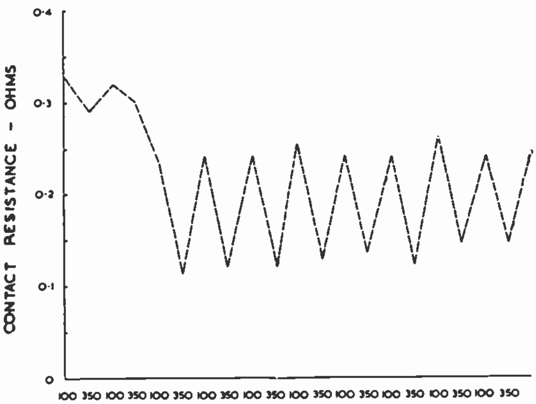


Fig. 1.—Relation between contact resistance and contact pressure.

In dealing with the failure of self-driven vibrators to start, the action of the load contacts will first be considered. An oxidized layer on the tungsten surface can give a contact resistance of many hundreds of ohms at low contact pressures; this resistance falls away as the pressure is increased. Fig. 1 shows a curve relating change in contact resistance of a thin oxide film on two tungsten contacts to variation of pressure; it will be noticed that the effect is cyclic. It is usual with tungsten contacts to apply a high contact pressure and, in general, this pressure is built up by the oscillatory motion of the vibrating reed. When starting, the drive coil impedance is only approximately equal to the drive coil resistance, and at low contact pressures contact resistances approaching infinity have been found. The drive coil is therefore deprived of the necessary impulsive current to start the oscillation which is to be built up to a sufficient amplitude. To increase the start contact pressure by mechanical bias demands a considerable working electromagnetic field, resulting in a subsequent undesirable amplitude of oscillation. It is with this type of failure in mind that the specification for a Grade I vibrator requires the vibrator to start at a voltage below its working voltage. There are other reasons for using separate drive, for example the electrical asymmetry which is placed across the contacts since the drive coil is across one half of the input transformer.

From the foregoing it will be appreciated that the author's criterion of a good vibrator requires conditions differing from those in vibrators usually found on the market. In the first place a comparatively high contact pressure is necessary to reduce contact resistance, a pressure rather higher than is generally employed, and, secondly, it is most desirable to have a separate drive contact as in no case was it found possible with tungsten contacts to obtain a satisfactory compromise in bias and starting conditions to permit the use of a self-drive vibrator.

All subsequent developments were therefore along the lines of an independently driven system and away from the more usual practice.

Considerable thought has been given to the relative merits of non-synchronous and synchronous vibrators and both have been developed for specific applications. In general, the Services have preferred the synchronous type on the score of efficiency and size reduction of the overall equipment. This matter will be referred to later in the paper, but first of all synchronous vibrators will be dealt with.

When dealing with synchronous vibrators there is a choice between using a split reed and commoned reed system. In Grade I vibrators, in which adjustment has to be carried out to within relatively narrow limits, the difference in production cost between the two is quite a small fraction of the total. Functionally the main difference between the split reed and the commoned reed lies in any requirement necessitating isolation of the output from the input, and also in the use of a voltage-doubling system on the output, which keeps the voltage across the rectifying contacts as low as possible and makes more efficient use of the transformer windings, resulting in a weight reduction. The splitting of the reed makes the mechanical design slightly more costly. A typical circuit diagram for a d.c.-to-d.c. split reed, separately-driven vibrator pack is given in Fig. 2, and the normal connection to the non-split reed is given in Fig. 3. In Fig. 2 the usual connection for the drive

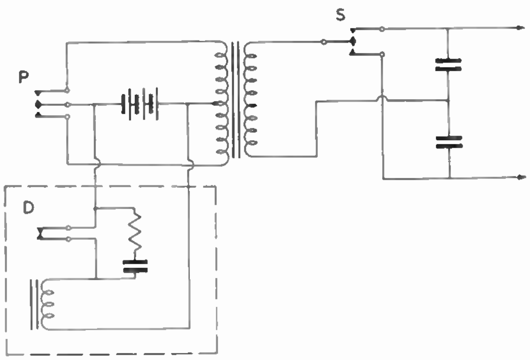


Fig. 2.—Split reed, separately-driven vibrator power pack.

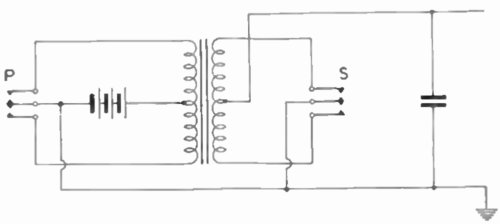


Fig. 3.—Non-split reed vibrator power pack.

contact with its resistor and capacitor to provide suppression is shown in the dotted brackets. For simplicity this drive circuit is omitted in the rest of the paper.

Where circuit conditions and the use of gas fillings sufficiently reduce the effect of surface resistance, tungsten has been found to be the best material for application at voltages greater than 2 V. A wide range of other materials has been tried out, including alloys and mixtures of platinum and tungsten, working under different contact pressures and different gaseous atmospheres.

In the A.M. Type 14 vibrator, which is the only Grade I vibrator at present marketed, the best results are obtained with a dry air filling at one atmosphere. The mechanism of electrical erosion, which in general causes the major contact wear, is due to the fact that the contacts meet at a very small area. This area becomes extremely hot with the passage of current, causing a local melting, and upon the separation of the contacts a bead of molten metal is drawn out between them. This bead does not break in the centre but near the cathode so that an indentation is left on one electrode and a small pip on the other. This phenomenon is attributed to the Thomson effect in which heat is carried in the direction of the electric current for the positive Thomson effect and against the current for the negative effect. In a reducing atmosphere this pip continues to build with repeated contact operation until it grows so large that either one contact becomes eaten through or the contacts weld together. When working in an oxidizing atmosphere the pip is found to be brittle and is rubbed away in the next operation of the contacts so that, in general, there is a wearing away of one electrode which becomes uniform over its surface, and the dust falls into the vibrator. It becomes necessary therefore to provide a rubbing action during the make of the contacts.

Interesting practical evidence of this theory is to be found in a Service Report dealing with the performance of A.M. Type 14 vibrators with air filling and with hydrogen filling working from a 14 V battery and to a load of 50 W at 300 V. With hydrogen filling the life of the vibrator was found to be less than 1,000 hours, whereas with air filling the life far exceeded 1,500 hours, and some vibrators were taken off test after periods of more than 2,000 hours.

Because of the nature of contact destruction it will be seen that bounce when current is carried is always undesirable as it consists of a number of breaks and results in excessive metallic transfer. The destructive effects can be minimized by commutation so that the current is a minimum at make and break.

4. Frequency

A number of conflicting factors of design and performance are involved, in the choice of operating frequency, for example, cost, general performance, efficiency, life, etc., and these result in an optimum frequency in the range of 80-180 c/s for existing power loads. A frequency of 110 c/s was decided on, and in the past has been widely adopted. At this frequency vibrators give a very useful life (in the case of Grade I of the order of 2,000 hours), the power packs become reasonably small and light, and the frequency and its second harmonic do not interfere with most mobile equipment in which there is appreciable audio cut-off below about 400 c/s. The drive power of the vibrator at this frequency is reasonable and there is no undue drive contact wear. However recent improvements in rotary transformers have increased their speed and efficiency, and now for a given power these are lighter than vibrator equipment operating at 110 c/s.

A vibrator, operating at 400 c/s, appeared in America some years ago but appears to have been withdrawn.

5. Contacts

The use of higher frequencies introduces essentially higher driving powers and quicker contact wear, resulting in a shorter life. To compete with the rotary in higher grade equipment it appears that the frequency of operation must be increased and ways and means must be found to reduce the driving power and increase contact life.

In order to deal with contact life, a large amount of work on contacts has been undertaken. In particular it was required to see if an alloy with a zero Thomson coefficient could be found, and early experiments were carried out on platinum. The method of determining material transfer or loss was twofold. A microbalance was used for weighing to the order of 10^{-5} to 10^{-6} gm, and a shadow technique for lower material transfer. This shadow technique is an extremely valuable tool. Replicas of the contacts are taken by pressing the contacts with warmed perspex. This replica is then shadowed by being put into a vacuum chamber and silver evaporated across it at a low angle of incidence. The prepared replica is then examined through a microscope, the shadows being measured and thereby the contour determined. This method has the advantage that the contacts need not be disturbed in their setting while taking the replica. Performance of the contact can thereby be taken at different stages of its life. Examples of this technique are shown in Fig. 4 which shows the cathode of a single break with platinum at 1·5 V carrying 28 A. In Fig. 5 is the anode of a contact that has broken 6 V at 1 A for 180,000 operations. This method will allow the estimation of material transfer to 10^{-8} gm.

In general, electrical wear tends to predominate over mechanical wear. The most troublesome form of electrical wear is the transport of material from the anode to the cathode. It has already been shown that this transport can be by formation of a bridge; it can also be caused

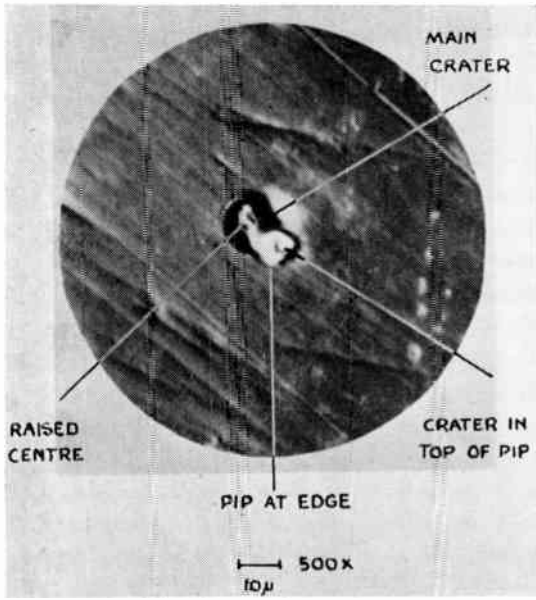


Fig. 4.—Shadow photograph of cathode contact after a single break at 1·5 V, 28 A.

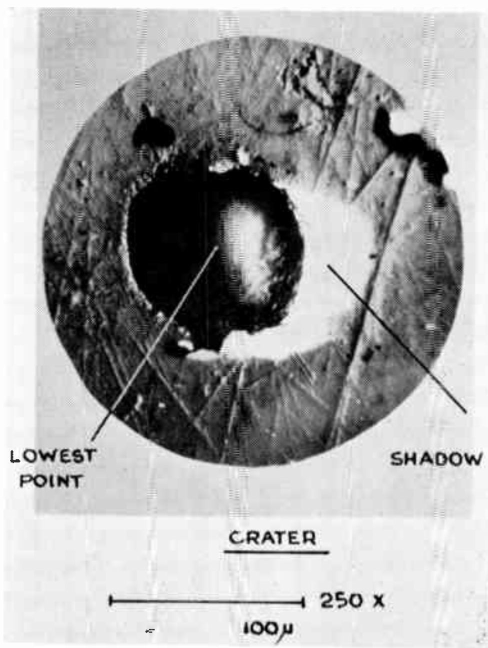


Fig. 5.—Shadow photograph of anode contact after 180,000 operations at 6 V, 1 A.

by highly-charged ions in an arc transfer. Broadly speaking it is possible in large measure to control arc transfer by external circuit conditions, but bridge transfer can only be controlled by rubbing away the material transferred or by some such expedient as the use of dissimilar metals.

Where similar materials are used for the contacts, bridge transfer is a function of (1) a high power of the current—in general a cubic law would appear to hold, (2) the melting point, (3) the electrical conductivity, and (4) the thermal conductivity.

The work in platinum showed a curious phenomenon. At less than 1·5 V anode build-up occurred, and at 4 V or more cathode build-up took place. From 1·5 to 2 V transfer was very small and could only be detected after lengthy operation. At about this voltage the metal in the contact boils at separation, and the physical explanation would appear to lie in the change in sign of the Thomson coefficient. Although other metals were examined the effect could only be found in platinum.

A search was made for an alloy having a zero Thomson coefficient. It was concluded that no such alloy could exist, and that the alloys generally combined the merits and demerits of the constituent elements. The choice of a particular alloy must therefore depend on the particular combination of the circumstances under which it is proposed to use the contact. Just as the radio designer uses a particular type of valve for a particular application, so must the user of contacts choose his material. As this work is now in preparation for publication it is unnecessary at this stage to compare the relative merits of the various alloys.

The major point that did come from this work was the apparent rapid decrease of material transfer if the current carried by the contact at make and break was insufficient to cause melting of the metal. This was particularly noticeable in the case of tungsten.

Work was carried out on the determination of the characteristics of tungsten contacts in various gases. Tungsten, clean and unoxidized, should theoretically give a maximum constriction resistance, with 15 gm pressure, of only 3 milliohms at a current of 1 A. With this contact pressure the resistance was found to be 5 Ω in wet air and 0·5 Ω in dry air. With inert gases the maximum resistance after a few hours operating was found not to exceed 0·15 Ω, but small traces of oxygen, as little as one part in 76,000, led to a pronounced increase of resistance. Some of the results obtained are as follows:—

Table 2

Contact Resistance of Tungsten in Gases

	Milliohms
High Vacuum	5
Pure Hydrogen	5-15
Pure Nitrogen	10-35
Hydrogen with 10^{-2}-10^{-1} mm Air	15-45
Nitrogen with 10^{-2}-10^{-1} mm Air	20-65
Nitrogen with 1 mm Air	40-80
Nitrogen with 20 mm Air	50-200

The presence of sulphur compounds was equally as damaging as oxygen.

There are thus two apparently contradictory possibilities. Firstly, to run tungsten in air, let the build-up due to the current be oxidized and then let the oxide be rubbed off. This will permit the breaking of heavy currents but with a steady loss of contact material. This technique demands a heavy contact pressure and rubbing action of the contacts. It has the disadvantage that the oxide can assist in the possible arcing of the contacts. The second is to run the tungsten in a reducing atmosphere where neither high pressure nor rubbing is necessary, but here build-up occurs unless the breaking current is kept low. If this breaking current is kept sufficiently low, build-up is negligible and contacts have extremely long life.

A certain amount of work was done on the use of dissimilar metals as contacts, in which the difference in the conductivity of the metals was used to give a differing effective contact temperature and thereby to balance out the tendency to transfer by the Thomson effect. This was found to be impractical for general application, although a pretty experiment in the laboratory!

An interesting effect was brought out on this work which might be called an "edge effect." When one contact is of larger diameter than the other, material lost from near the edge of the smaller tends to build up on the larger just outside the smaller one. In time the smaller contact tends to develop a chamfer. The effect is quite noticeable if the contacts are misaligned, for material builds up on a contact where it projects. The importance of uniform mating of contacts cannot therefore be overstressed.

In considering the material transferred, the questions of arc transfer and arc formation have been neglected. In general, the voltage producing the melting point and boiling point of the metal at the constriction is less than 2 V, whilst arcing can occur at about 15 V, so that 24 V circuits are more liable to arcing and flashover than 6 or 12 V circuits. It is necessary to modify the associated circuit so that the voltage is prevented from rising to a critical value until the gaps have separated sufficiently to prevent the arc from forming. Unfortunately the break is very rarely a clean one but consists of a sequence of "bounces" in which the contacts can remake with light contact pressures. The tendency to arc is accentuated as contacts begin to wear and become uneven or as they oxidize, and in some cases particles of contact material or the oxidized material dislodged in a previous make, can become trapped between the contacts. Dust has a similar effect. Care must therefore be taken that an adequate life test is carried out in the use of a material and that the operation of the system is not too near the arcing voltage.

In general the build-up of this voltage is a function of the load circuit and any arc quench circuit that may be employed. There is probably considerable scope for development of principles and components for arc quench circuits. It is now quite well known that a high frequency arc is set up by the small amount of inductance and capacitance in the leads connecting the device. With tungsten, arc quench circuits should permit a voltage of between 5 and 10 V at break—too low a voltage under these conditions tends to aggravate the tendency to arc at make. If a condition could be arrived at in which there was zero bounce at make and zero current at break, extremely heavy currents could be passed, without contact welding and without any undue contact build-up, by the introduction of a small inductance in the quench circuit.

Mechanical wear has not been dealt with, but there is little doubt that it tends to follow electrical wear. Electrical wear due to metal transfer roughens the surface and thereby accelerates mechanical wear by an appreciable factor.

A lengthy investigation into contacts thus showed that a new material of universal application was unlikely ever to be found, and that in choosing a contact, the operation of the device as a whole has to be considered—the contact, the mechanical design, and the electrical design. It is equally as dangerous to design a radio circuit and then look for a valve to use as it is to design a circuit and put in a vibrator, or for that matter any contact that is expected to give long life with hundreds of millions of operations.

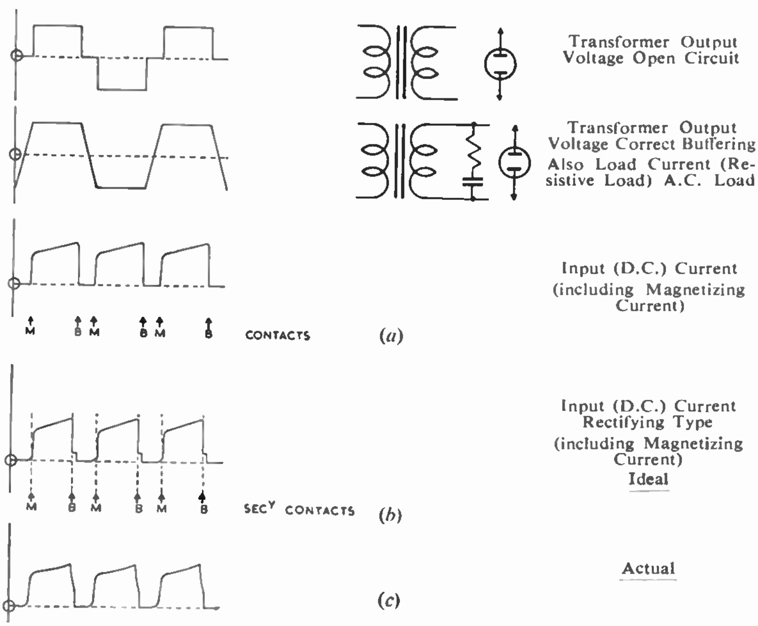


Fig. 6.—Voltage and current waveforms of vibrator, without and with commutation.

6. Circuit Technique

During the preceding paragraphs dealing with contacts, the desirability of making and breaking zero current has been brought out. The idea is not new: other electrical equipment has used similar ideas in Germany for convertor machines and in America for similar plants. In recent years it has found wider application in heavy a.c. engineering. Investigations were started on this method of commutating to try to obtain an improved output rating and life.

Early investigations were undertaken on the possibility of placing a saturable reactor in the secondary of the transformer circuit, although later this was not found to be necessary in all circuits.

In general, without commutation, the voltage waveform of the vibrator is given in Fig. 6. Assuming a perfect transformer, the current waveform will follow this.

Now let us consider the rectifying contacts closing after and opening before the main vibrator contacts. We get a current waveform somewhat more favourable, as in (*b*), assuming an idealized transformer. In point of fact the waveform is more nearly as in (*c*).

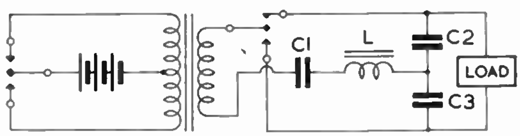


Fig. 7.—Vibrator incorporating a tuned circuit to provide commutation.

Now suppose we introduce a tuned circuit in the load as in Fig. 7 to increase the commutating effect.

The circuit involves the normal voltage doubling circuit produced in capacitors C2 and C3 connected to a suitable load shown diagrammatically. The capacitor C1 and the inductor L form a tuned circuit providing the commutation. During any one half cycle the capacitor under charge, the series inductance L and the capacitance C1 form an oscillatory circuit. The normal tuned frequency of this arrangement gives a half period rather shorter in duration than the make period of the vibrator. Thus in Fig. 8 if (*a*) is the normal period of the vibrator, then the tuned frequency would give a period as in (*b*), but across this circuit is a load damping it so that the output waveform is more nearly that shown in (*c*).

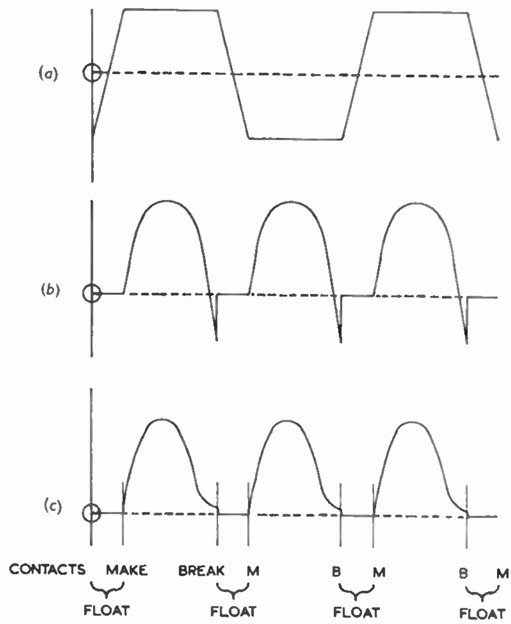


Fig. 8.—Voltage and current waveforms for circuit of Fig. 7. (a) Buffered transformer, output voltage waveform, (b) input (d.c.) current waveform, undamped output circuit, (c) input (d.c.) current waveform, damped output circuit.

The lines show the contact make and break points. A further modification is to adjust the values of the choke and the doubling capacitor so that the doubling capacitors are all that are necessary for the tuned circuit. For several reasons it is difficult to get zero current at break by this means although it can be reduced to a very low value. Difficulties are encountered with temperature shift of components and changes in battery voltage. As the power of the circuit becomes greater the impracticability of getting a zero break current also increases. This difficulty is eased by introducing a saturable reactor to assist, or take the place of, the inductor. This saturable reactor holds a high inductance when the contacts are first made and the current begins to flow. When the iron becomes saturated the inductance falls, the effective frequency is increased, and the current rises to a peak in accordance with the new oscillatory conditions. The current continuing in its oscillatory form then falls when the impedance of the reactor increases, thereby accelerating the current decline.

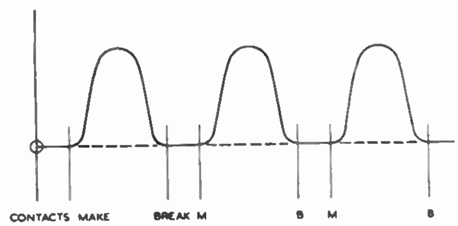


Fig. 9.—Input current. Commutated circuit with H.C.R.

A waveform as in Fig. 9 results which shows the delay before the current starts to rise after the contacts are made and the zero position reached well before the contacts open. Circuit reactors made of such materials as mu-metal can be made to produce this effect but the grain-oriented nickel-iron under the trade name of H.C.R. will be found more satisfactory.

With higher powered vibrators this method of commutating reduces the tendency to arc at voltages in excess of 300 V, but with lower powers commutation by tuning without a saturable reactor is quite satisfactory. In the case of higher powers using a series commutation, a disadvantage lies in the increased regulation of the system.

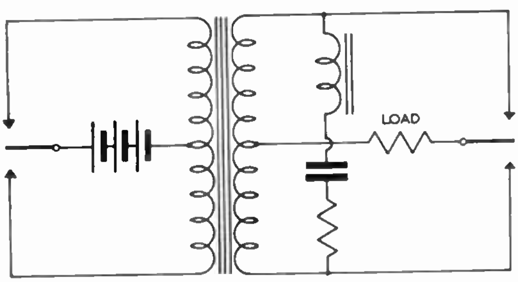


Fig. 10.—Parallel commutating circuit. Rectified load.

There are many other variants of this tuned circuit arrangement although in the author's opinion none so useful. For example, the circuit arrangement in Fig. 10 gives satisfactory results on a fixed load.

Early work suggested that on 24 V some 70 W output was the upper safe working power; with commutation and a reducing atmosphere it has been found possible to go to 100 W, but there is a fear of arcing beyond this figure. A pole changer connection has therefore been adopted.

Here tendency to arc formation is divided between the two rapidly opening contacts. By using the pole changer connection and commutation, powers greater than 250 W from a 24-V source at an efficiency of 80 per cent. are obtainable, as the current broken does not exceed 0·5 A on any contact, although the mean current carried by the primary is 13 A.

7. Regulation

One of the greatest problems in these packs is the regulation. In general, transformers are made as small as possible consistent with efficiency and heating, so that there is some degree of regulation introduced which in general is comparable with a rotary convertor. With high currents, regulation can also be adversely affected by the vibrator itself, for when it is remembered that the peak current is some three or four times the mean value, quite a small resistance can appreciably restrict the current. As previously pointed out, the oscillatory circuit also has an effective impedance which further impairs regulation.

Early work on regulation was concentrated on using a saturable reactor in the primary circuit which was fed from a rectified output voltage, as in Fig. 11. This circuit relies on the appropriate change in impedance of winding 3 in relation to battery voltage. It is obvious that the control circuit (ferro-resonant circuit LC, rectifier winding Z2) is fed by an alternating voltage varying

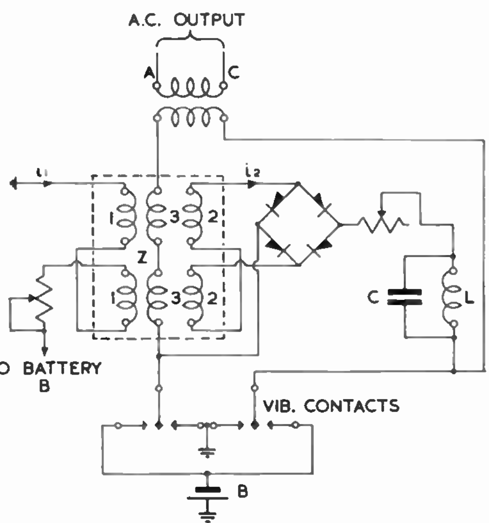


Fig. 11.—Power pack regulated by a saturable reactor in primary circuit.

directly as the battery voltage. When the latter is low, LC is tuned to approximate resonance, the opposing effect of winding 2 to d.c. control winding 1 is thus very low. Hence, owing to the lightly opposed saturating effect of winding 1, the impedance of winding 3 is low and consequently the voltage across the transformer primary is raised. Under high voltage conditions the reverse process occurs.

This system gave a much improved regulation but it does involve heavy inductors where weight is a primary consideration. Use has more recently been made of stepping the transformer secondary by a relay or series of relays. In the case where "humps" and slight delays in voltage correction can be tolerated, the system is simple, as in Fig. 12. Electronic methods are also possible. Thought is now being given to extending this technique, with the possibility of eventually using some form of tap changing motor.

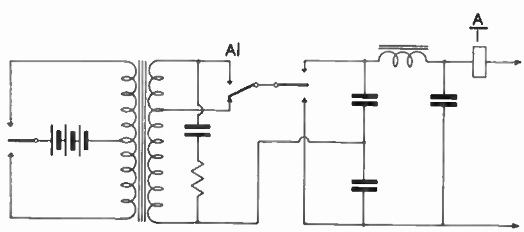


Fig. 12.—Power pack regulation by relay in transformer secondary circuit.

In many applications regulated voltage is required only for a limited number of purposes, in general, in the neighbourhood of 300 V. Work has been undertaken to produce a stable voltage diode at 300 V which eliminates the necessity of a series valve when lower voltage cold cathode diodes are used. Such a diode will shortly be marketed under the number GD296.

8. Considerations of Vibrator Design

Before going into the details of vibrator design it may be worth while giving some idea of the operational requirements of vibrators. The Services divide vibrators into two kinds, Grade I and Grade II. A summarized statement of these requirements is given in Table 3.

TABLE 3

	Grade I	Grade II
Seal	Hermetic	Watertight
Operating frequency	105-113*	98-122
Contact timing ratio	L.T. 36-42 H.T. 31-37	L.T. 35% min H.T. 32%
Contact bounce	5%	10%
Reduced starting voltage	75% of operating	75% of operating
Test voltage	750 V R.M.S.	600 V R.M.S.
Frequency variation	± 2 c/s (9-12 V)	± 3 c/s (10·8-13·2 V)
Acceleration	9*g* (now 12)	6*g*
Climatic testing	Full K.110 Now RCS/11	
Life	1,000 hours min.	

* New vibrators operate at different frequencies from these but this tolerance percentage is maintained.

Since this specification was issued an extension of the vibrator range has been undertaken both in frequency and power. The basic facts remain that a minimum life of 1,000 hours is required, that the vibrator should withstand an acceleration of 12*g* without damage and should be fully tropicalized.

When considering a range of vibrators the general problems in addition to the above are as follows. Firstly it is desirable to work at the highest possible frequency consistent with long life. This involves maintaining the correct balance between length and stiffness of reed and the stiffness of the contact springs, whilst keeping amplitude, contact opening, ratio and bounce within prescribed limits. The power needed to drive rises very rapidly with increase in frequency. For example on one vibrator the power for 50 c/s is 0·7 W, 110 c/s, 1·5 W, and 160 c/s 6 W. Great care has to be taken to ensure that the drive power does not become unwieldy since it can cause undue heating of the vibrator and at the same time reduce the efficiency.

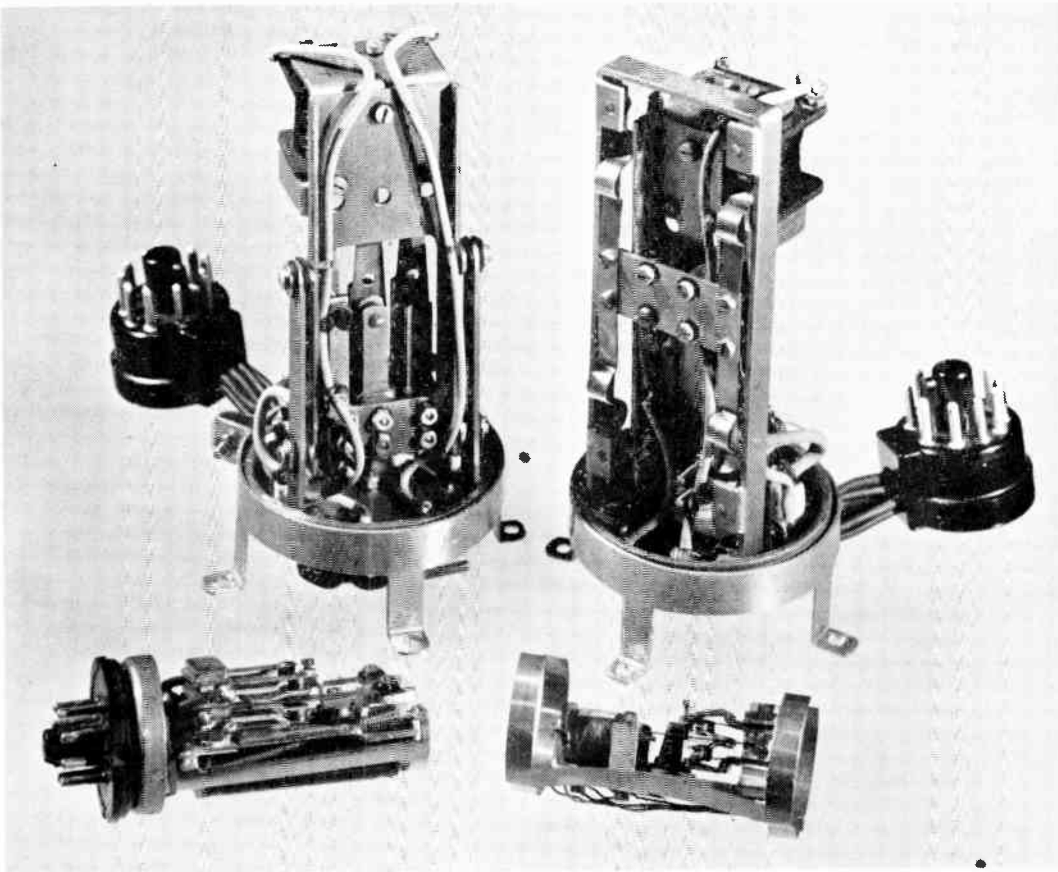


Fig. 13.—Methods of mounting vibrators.

Detailed consideration has been given to side and overhead drives, but there would appear to be little to choose between their relative efficiency. The side drive does allow some reduction in length at the expense of diameter, but as the vibrator must be held at the base the design is not so convenient to handle as the overhead drive.

One method of reducing the power necessary to drive the vibrator is by polarizing it, and this has been quite successfully carried out on two miniature vibrators. Consideration is now being given to carrying this technique further. The overhead drive lends itself more readily to polarization than the side drive.

In all cases it has been found preferable to provide a separate drive contact to give adequate life.

Another major problem of vibrator design is the method of suspension. In the work that has been undertaken the vibrators have been developed along the lines of Grade I in which quite heavy contact pressures are maintained, and this has resulted in an appreciable amount of energy going into mechanical vibration. As mentioned above, sulphur is more serious than oxygen in spoiling contact performance so that rubber in any quantity is not used. This leaves only mechanical methods of suspension. The suspension has to be such that the vibrator withstands 12*g*, does not make too much noise, and does not give rise to undue chassis disturbance.

This problem is a very difficult one and it is with very great regret that sponge rubber had to be discarded. Much of the chassis disturbance can be reduced by ensuring that the vibrator is connected to the base by the most flexible leads possible and is supported through a mounting which is flexible to the frequency of the vibrator and yet is rigid to the vibrator as a whole. Noise can be reduced by ensuring that the can does not resonate, either by spraying the outside, or by breaking up the sound waves inside. One method of doing this has been applied successfully by shot blasting the inside of the can and then inserting a lining of gauze.

In Fig. 13 are shown some of the methods of mounting that have been employed.

Considering the various vibrators under development, the lowest power vibrator is shown in Fig. 14. This vibrator takes only 30 mW to drive, consists of one changeover reed with separate drive, and will carry a current of up to ¼ A. Packs have been made which give an overall efficiency of 48 per cent. for a 5-V battery giving an output at 300 V at 100 μA. This vibrator is polarized and operates at a frequency of 150 c/s.

Its larger counterpart is also polarized, but operates at a frequency of 250 c/s and has two changeover springs. The drive power is ⅓ W. A power pack using this vibrator on 2 V input is capable of giving 4 to 6 W output at 100 V with an overall efficiency of some 70 per cent. This vibrator is shown in Fig. 15.

Passing now to heavier-duty vibrators, a miniature 250 c/s has been constructed—non-polarized, with two changeovers, which takes only 2/3 W to drive. When using resonant or commutating circuits and filled with a reducing atmosphere, this vibrator can handle 50 W d.c. output with a 24-V input. The efficiency is high, being up to 80 per cent., and the weight of the pack is less than the equivalent rotary convertor. The vibrator is shown in Fig. 16.

The vibrator shown in Fig. 17 is a cleaned-up version of the Type 14. The frequency is 110 c/s and the drive coil is at the side. The vibrator is mounted in a circular can and its overall size is reduced. By filling this vibrator with an inert gas it has been found to handle 100 W at 24 V quite well. In size of power pack it does not compete with the rotary convertor because of its frequency but its efficiency is higher.

A lot of thought has been given to a 400 c/s replacement for this vibrator, but so far this has proved too difficult to achieve practically. Drive power limitations, spring fatigue and contact wear have all combined to reduce the life to less than 1,000 hours. Work is, however, continuing but there will have to be a new approach to the problem.

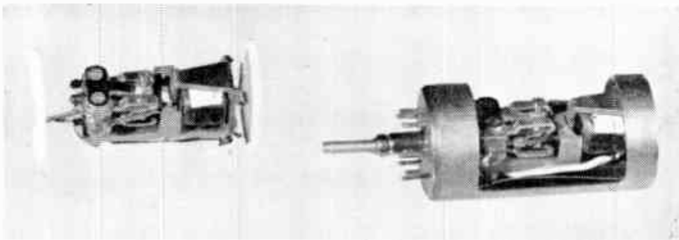
At the high power end of this range, two vibrators have been developed. The first, shown in Fig. 18, at 110 c/s is a simple pole changer without rectifying contacts. This vibrator gives an output of 250 W from a 24-V source. The second, not illustrated, is a three-reed vibrator operating at 150 c/s. The higher frequency was chosen as being the limit for this particular reed formation, and the third reed is to give rectification. At this frequency on a 200-W output the pack is slightly lighter than the equivalent rotary convertor.

The sealing of these vibrators has been rather a problem. For the smaller ones a rubber pressed seal has so far been used because these are to be placed in sealed equipment, whilst for the X.331 a neoprene seal has been developed. Neither of these seals is entirely satisfactory and much time has been spent on the problem. Work is in hand on a suitable glass and metal seal, on ceramic seals, and on a ceramic-araldite seal. This problem is still under active consideration and very interesting results have been obtained with a ceramic-araldite seal, which, however, does not withstand temperature variations as well as the glass.

9. The Power Pack

The power packs to combine all the advantages of the foregoing are not always as straightforward as this brief report indicates, when lightest weight and highest efficiency must be attained even if this entails some increase in manufacturing costs. In such circumstances, voltage doubling circuits in conjunction with "C" core transformers give a good weight and space factor.

For the lower-powered packs, sufficient commutation can be obtained by the doubling capacitors and the inductance of the transformer, or by the addition of a small choke. At higher powers H.C.R. gives beneficial results. The disadvantage in using the voltage doubling circuits lies in the heavy charging current of the capacitors when the pack is switched on, and in some packs we have found it desirable to insert a resistance in the circuit which is short-circuited by a relay after the vibrator has been operating for some 10 cycles.



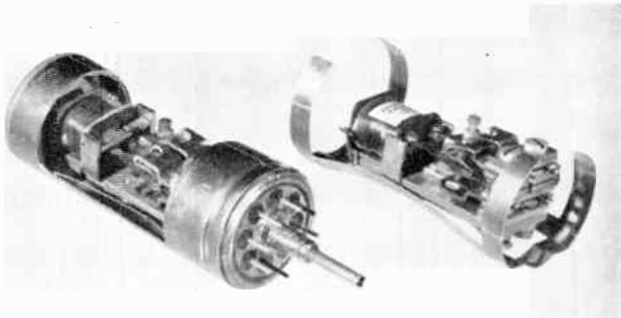


Fig. 14 (*above, left*).—*Low-power* (30 *mW*) *vibrator.*

Fig. 15 (*top, right*).—*Similar to Fig.* 14 *but larger and driven at* 250 *c/s.*

Fig. 16 (*middle, right*).—*Miniature heavy-duty vibrator.*

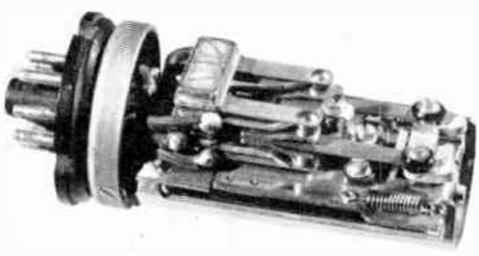


Fig. 17 (*left*).—*Cleaned-up version of A.M. Type* 14 *vibrator* (X331).

Fig. 18 (*bottom, right*).—*High-power* (250 *W*) *vibrator.*

The work so far undertaken permits the construction of efficient power packs in the range of a few milliwatts working from a 1·5-V battery to 250 W on a 24-V battery. In constructing a power pack it must be remembered that the vibrator is essentially a current device.

Work is in progress on extending the power and voltage range. In power, 500 W at 24 V is the target, and in voltage, work is proceeding at 36 V d.c., 110 V d.c., and 220 V d.c.

10. Commercial Types

A criticism which can be advanced against this work is that a Grade I vibrator has been constantly in mind without thought to the general user. This is largely true because the work was in large measure sponsored by the Services and the major competitor of the vibrator has been a rotary convertor or dry battery. The result is that the Grade I vibrator is many times more expensive than a Grade II. For commercial radio this may not be a serious factor, for the Grade I vibrator pack will still be much cheaper than a rotary convertor. In high-grade domestic radio, however, there is clearly a place for a vibrator falling midway between Grade I and Grade II. In time, such a vibrator may well become a possibility, but it is perhaps desirable to develop first the near-perfect, so that the necessary design consideration for good vibrators can be assessed, and subsequently to design for cost.

11. Conclusion

The difficulty of producing a satisfactory Grade I vibrator of high power has been overcome in principle at least and powers in excess of 250 W are a practical proposition. The weight and size of the existing rotary convertors can now be equalled or improved upon by vibrator packs over a power range of a few watts to many hundreds with an efficiency appreciably higher than the rotary transformer. Lives of vibrators can also be further extended. With the application of the experience gained on contacts it becomes increasingly clear that extremely long vibrator lives are possible. Reed failures and fatigues are found to be still less frequent than contact failures. As contacts remain operative over long periods owing to reduction in electrical wear, consideration will need to be given to mechanical design in order to reduce mechanical wear. Where this extension of life is likely to lead is by no means clear. Two conflicting requirements are likely to arise, the first a long-life high-reliability vibrator having a life of many thousands of hours, say at least 5,000, in which weight and size are of secondary importance; the second where 1,000 hours is perfectly satisfactory and weight, size, and efficiency are primary considerations. The first of these will require a low-frequency vibrator and the second a high-frequency system of at least 250 c/s. The upper limit of power is a very interesting speculation. Of course, if the input voltage is increased, increased power is possible. Thus with the highest power vibrator, with an input voltage of 100 V and a 500-V output, between 750 W–1 kW d.c. would be expected. The author sees no limitation up to 500 V input and has been giving serious consideration to a vibrator rectifier driven from the mains to give an output at 6 V of powers in the neighbourhood of 0·5 kW.

12. Acknowledgments

This work has been carried out by a group in the Ericsson Laboratories under the author's direction and much of this paper will appear later in greater detail, both theoretical and experimental, under the names of the individuals who have carried out the work.

Much of these investigations have been undertaken for the Ministry of Supply, and thanks are due to the Chief Scientist for permission to publish this work.

13. Reference

1. Discussion on "Mobile Radio Power Packs." *Proc. Instn Elec. Engrs*, **97**, Part III, Nov. 1950, pp. 458-9.

SEARCH RADAR FOR CIVIL AIRCRAFT *

by

P. L. Stride †

A Paper presented at the Fourth Session of the 1951 *Radio Convention on July* 27*th at University College, Southampton and read before the London Section on February* 20*th*, 1952

SUMMARY

The possible functions of airborne radar are briefly reviewed. Consideration of the basic design problems of a system intended primarily for (1) Detection of cumulo-nimbus clouds, (2) High ground avoidance, and (3) Map painting, indicates that a power of 10 kW at 3 cm with a 6-deg beam width is adequate. It is shown also that a roll and pitch stabilization of the scanning axis is essential.

A general description of a suitable equipment is followed by a summary of results of trials.

1. Introduction

The extensive use made of airborne radar during the late war suggested to many people that civil aviation would be able to benefit immediately from the equipment and techniques developed. It is significant that, although limited use has been made of secondary radar devices such as "Gee," beacons, etc., no airline has yet fitted primary radar for commercial operations.

It is believed that this delay is due, at least in part, to the potentially wide range of functions which this type of equipment can fulfil, and hence the difficulty of defining the characteristics of a system which will result in a real increase in safety and regularity of services without too great a penalty in terms of cost, weight and maintenance problems.

The possible functions may be divided conveniently into two classes—those that cannot be performed satisfactorily by any other method, and those that supplement existing facilities.

Examples of the first group are:—

(1) Detection of high ground in the flight path.

(2) Detection of dangerous storm centres, i.e. cumulo-nimbus clouds.

(3) Detection of other aircraft constituting a collision hazard.

The second group includes:—

(1) Navigation by "map-painting."

(2) Navigation in conjunction with suitable responder beacons.

(3) Measurement of ground speed and drift.

The relative importance placed on these various functions depends to a large extent on the sort of operations required, e.g. on those portions of overseas routes involving crossing mountain ranges or "let downs" in difficult country; then high ground warning and "map-painting" might prove a most valuable aid to navigation and the radar worth carrying for this reason alone. Similarly, for routes in tropical regions, detection of dangerous storm centres might be the primary need.

The equipment described in this paper arose out of a wartime requirement for the detection of dangerous cumulo-nimbus clouds by transport aircraft in Far Eastern theatres.

Early trials using an American AN/APS 15 set were carried out in 1945 and were followed by further trials in 1946-47 with a system built by the Telecommunications Research Establishment. The results of the early trials were sufficiently encouraging to warrant proceeding with the development of a fully engineered system suitable for civil aircraft.

Throughout this design, a satisfactory performance in respect of cloud warning, terrain clearance and, to a lesser extent, map-painting, has been the main consideration, and complications leading only to a limited increase in utility have been avoided.

2. Basic Design Considerations

2.1. *Frequency*

The theoretical aspects of radar echoes from meteorological phenomena have been dealt with by Ryde[1,2] and the results subsequently confirmed experimentally by Hooper and Kippax.[3]

* Manuscript received July, 1951.
† Electronics Division, E. K. Cole, Ltd.
U.D.C. No. 621.396.9 : 629.135.2.

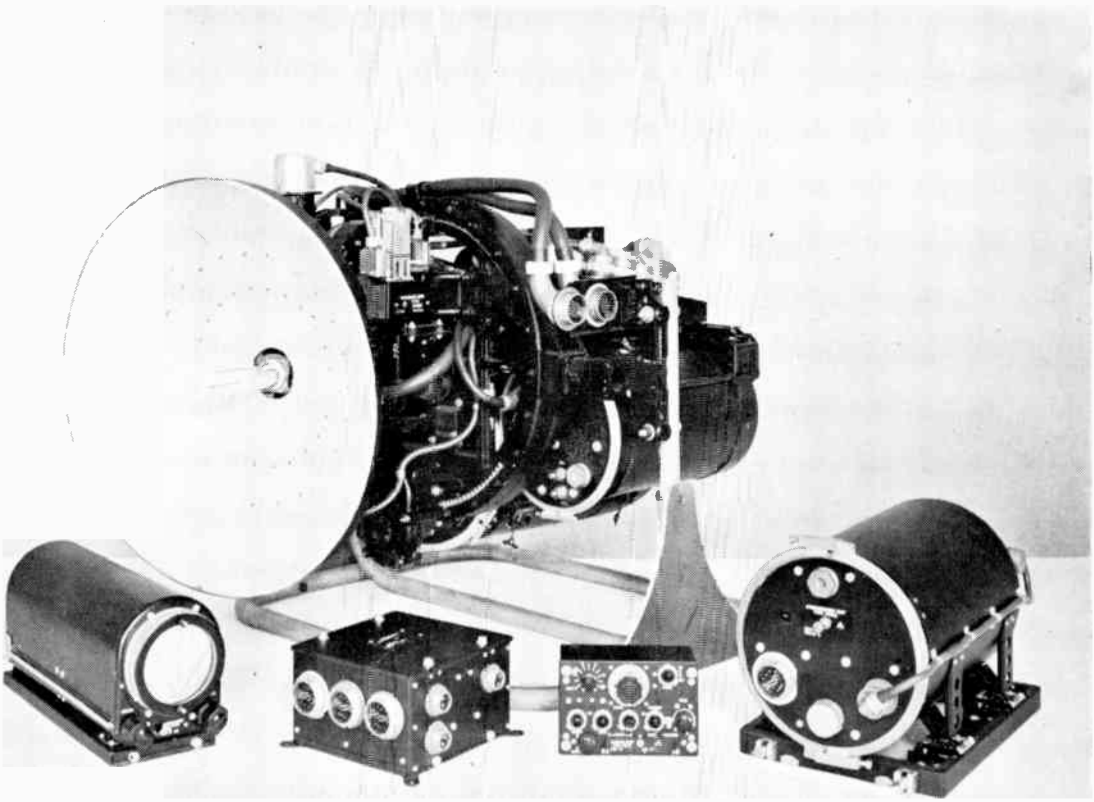


Fig. 1.—View of units making up the complete equipment.

It is shown that the equivalent echoing area A of a rainstorm is approximately given by

$$A = 0{\cdot}9\mu r^2\theta^2 NS \,.\, 10^8 \,.\, \phi \quad \ldots\ldots\ldots\ldots (1)$$

where A is the projected area of a perfect isotropic reflector, μ the pulse length in microseconds, r the range in kilometres, θ the divergence in degrees of the beam to half power, N the number of droplets per cm^3, and S the scattering function for one droplet. ϕ is the fraction of the beam area filled by the storm.

The scattering function S is complex and includes permittivity as a function of wavelength. However, it is approximately proportional to $\frac{D^6}{\lambda^4}$ where D is the droplet diameter and λ the wavelength, assuming that D is very much less than λ.

One purpose of the equipment is to detect turbulent cumulo-nimbus clouds as distinct from harmless rain-bearing types. Fortunately cumulo-nimbus clouds are characterized by large water droplets within the cloud and at a later stage in their development by a concentrated fall of such droplets. The theory indicates that scattering increases rapidly with drop size, hence the probability of differentiating between dangerous and non-dangerous cloud is good, providing that the wave-length chosen is long enough to preclude large echoes from fine droplet types. The path attenuation[1,2,3] is also important if the desired target is hidden in other heavy cloud and when it is desired to see the far edge of storm area. Taking all these factors into account leads to the conclusion that a wavelength in the region of 5-6 cm is the most favourable. In practice the choice is between either 10 cm or 3 cm because of the availability of components for these wavebands. For an aircraft installation where size and weight are important there are obvious advantages in using 3 cm since for a given beam width the mirror aperture is approximately one-third of that required at 10 cm.

2.2. *Beam Width*

The choice of beam width is influenced by several conflicting factors. A storm cloud may only be one or two miles wide so that at ranges in the region of 50 miles the angle subtended at the radar is only two or three degrees. It is also essential that the display is not confused and obscured by unwanted ground returns. Both of these factors indicate the desirability of a very narrow beam. However, for map painting a wider beam is required to give good horizontal coverage. A conical beam with an included angle of 6 deg., and capable of being tilted in elevation was used during early trials and found to be a satisfactory compromise. At 3 cm a beam of this width is given by an 18-in. paraboloid, a reasonably convenient size for an aircraft nose installation.

2.3. *Power*

The power required for a given detection range can be determined from the radar equation:—

$$r^4 = \frac{PAd^4\pi f^2}{64\lambda^2 S} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where P is transmitter power, A the equivalent echoing area for the target, d the mirror diameter, λ the wavelength, f the antenna illumination factor, S the minimum detectable signal, and r the range.

If the target is defined as a precipitation area with a mean rate of 25 mm/hr. and subtending angles of 2 deg. and 4 deg. in azimuth and elevation respectively, then the equivalent echoing area can be determined from equation (1) in conjunction with Ryde's tabulation[1,2,3] of $NS \times 10^8$ for various precipitation rates.

This area is found to be approximately 12,500 m^2 assuming that r is 80 km, μ 1 micro-sec, θ 3 deg., λ 3·25 cm and ϕ 0·3. It will be realized that this result is only useful as a guide to the magnitude of the quantities involved as it is profoundly affected by changes in precipitation rate. For example, at 12·5 mm/hr. the result is approximately 4,000 m^2, and at 50 mm/hr. it is 40,000 m^2.

Substituting the figure of 12,500 m^2 in equation (2) together with the other system parameters (d 46 cm, f 0·6 and S 1 $\times$ 10^{-12}W), gives a result for power of approximately 4·3 kW.

It should be noted that the figure taken for S will give a signal-to-noise ratio of only 2 to 1 assuming a receiver noise factor of about 18 db and a bandwidth of 2 Mc/s. A signal of this magnitude does not give a particularly well-defined "paint" on an intensity-modulated display.

However, the 2J42 magnetron with an output of about 7/8 kW gives a material improvement, and the early trials showed that this power was quite adequate, both for cloud detection and high ground warning. In fact, the signals received from some of the larger clouds suggested that their echoing area was nearer 50,000 m^2 than 12,500 m^2.

It is worthwhile considering the power necessary for detection of other aircraft constituting a collision hazard. A modest requirement would be two minutes warning at a closing speed of 450 knots. Assuming the echoing area of a medium sized aircraft to be 10 m^2 then the power necessary is about 80 kW. Since collisions between aircraft are comparatively rare, it was not considered worthwhile providing the higher power and the complex scanner for all-round coverage.

2.4. *Type of Scan and Display*

The cloud warning and terrain clearance applications of the equipment do not demand a large angle of scan, although something approaching 360 deg. is desirable for map painting. Wide angles of scan are difficult to provide without a ventral installation, a feature viewed with little enthusiasm by aircraft constructors. It must be remembered also that the scanner and radome projection would be quite large owing to the necessity for looking dead ahead for cloud warning. Accordingly, a nose installation using a scan angle of $\pm$ 75 deg. was adopted.

The choice of display for this type of scan lies between the B-scope and the sector P.P.I. Although the B-scope gives good angular discrimination at short ranges the picture is difficult to interpret for navigational purposes. Therefore, the sector P.P.I. was chosen with the centre of rotation near the bottom of the tube. In order to improve the angular discrimination at short ranges provision for making zero range correspond to a small arc rather than a point was also included.

Before considering scanner problems in more detail it is desirable to review the "safety circle" technique for clearance height prediction and high ground avoidance.

As the energy radiated by the aerial system is in the form of a cone, the terrain immediately below and for a certain distance ahead of the aircraft will not be illuminated by the beam. The radius of this blank sector will depend on the height of the aircraft above ground, the nature of the ground ahead of the aircraft, and the beam tilt angle. Measurement of the blank sector radius is the basis of the "safety circle" technique of high ground warning.

For a given future clearance height and a given beam tilt angle, the safety circle will have a certain range. Reduction of this range will indicate a reduction of this clearance height with possible risk of subsequent collision. It should be noted that clearance height is indicated at all bearings within ± 75 deg. of the aircraft heading, and safe avoidance routes over mountainous districts can be determined.

Figure 2 illustrates the method diagrammati-

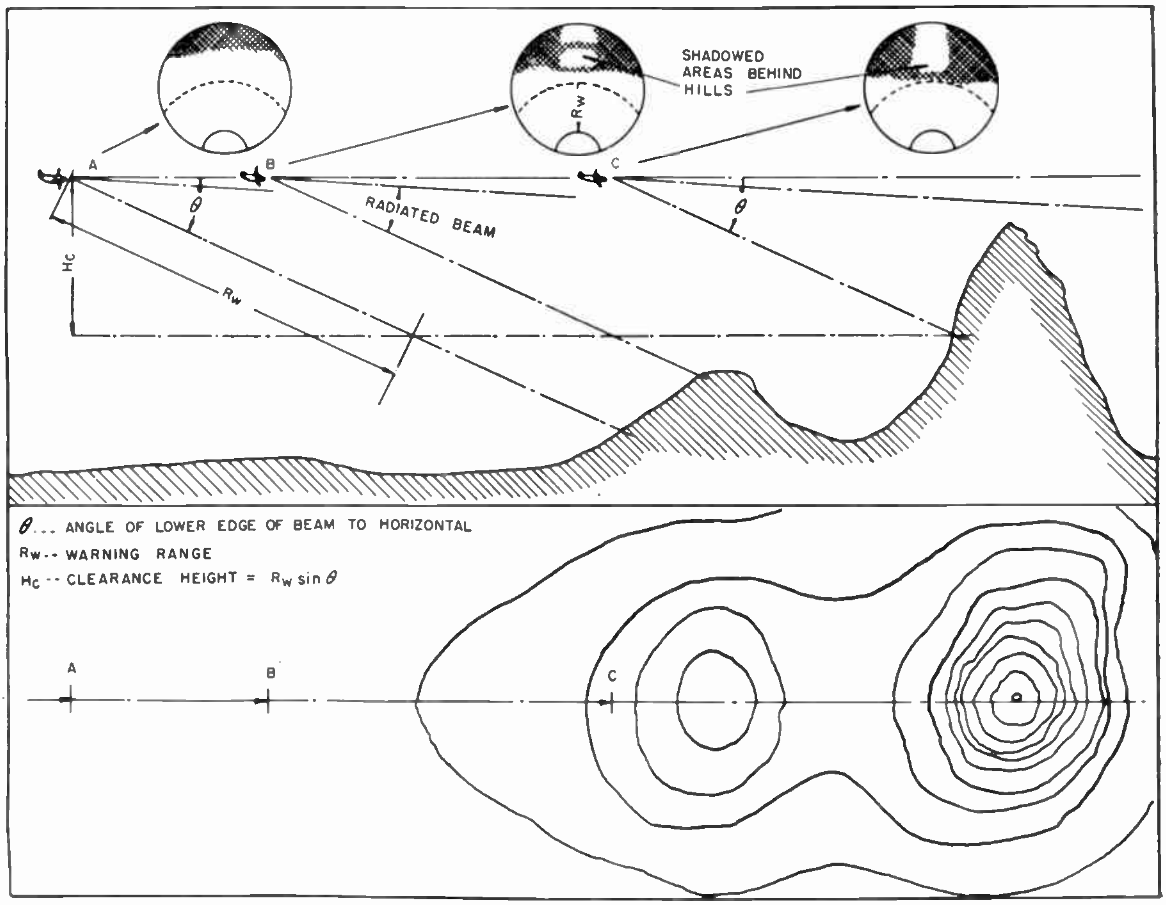


Fig. 2.—High ground warning by the safety circle technique.

cally. A tilt angle is selected so that the lower edge of the beam cuts the line of desired clearance height H_c at the required warning range R_w. As the aircraft proceeds, the radius of the blank sector varies according to the height of the terrain. This is shown in the diagram at A, B and C with appropriate indicator unit displays.

At A and B the radius of the blank sector is greater than that of the selected safety circle, indicating that the aircraft will have more than the minimum clearance height. At C, the responses are beginning to invade the safety circle, i.e. the arc of radius R_w. Therefore, while still R_w miles away from the high ground the pilot is given warning that either course must be altered or altitude increased to avoid it. In the case illustrated a 30-deg. turn to port or starboard will take the aircraft on to a safe course.

If the scanner is rigidly fixed to the aircraft structure it is clear that small changes in the aircraft attitude may result in large changes in the safety circle range. Also, ground returns are difficult to interpret when the angle of bank is appreciable. During the early trials, for which only an unstabilized equipment was available, attempts to check this high ground avoidance system were unsuccessful. Roll and pitch stabilization were, therefore, regarded as an essential requirement for the final equipment.

3. General Description

For convenience in installation, etc., the system is made up into the following units:—

1. Scanner and Stabilized Mounting.
2. Servo Amplifier.
3. Transmitter-Receiver.
4. Synchronizer.
5. Indicator.
6. Control Unit.
7. Junction Box.

In order to reduce the number of waveguide rotating joints and flexing cables to a minimum, the transmitter-receiver and servo units are normally carried on the stabilized mounting with the scanner. However, in some aircraft the space in the nose is very restricted and it has been found necessary to provide an alternative layout in which these units are separated.

The transmitter-receiver, synchronizer and servo amplifier are sealed and pressurized so that they may be mounted in the unpressurized compartments of an aircraft. Under these conditions they will operate up to at least 40,000 ft.; when unsealed the altitude limit is 25,000 ft. Although this type of construction introduces difficulties in cooling, the reduction in size is considerable as low pressure flash-over problems are removed. It is also much easier to meet tropical specifications and it is believed that the reliability in tropical service will be very much higher.

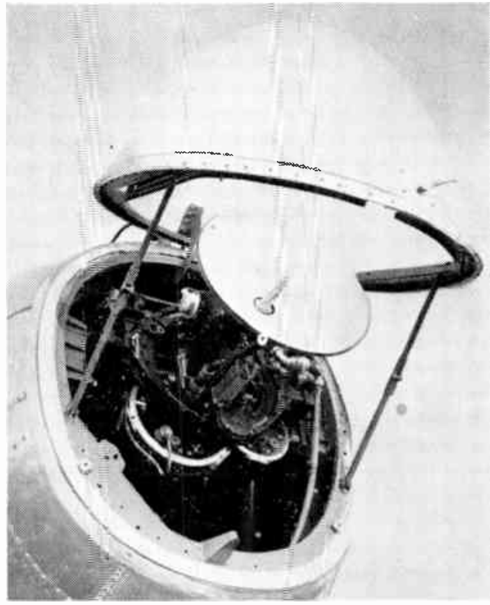


Fig. 3.—Scanner installed in nose of Viking with radome open.

The system is entirely a.c.-operated, except for a small amount of low voltage d.c. used for relay operation, etc. A 115-V 1,600 c/s single-phase supply is used for the main electronic units and 115 V 400 c/s three-phase for the servo system and blower motors.

A photograph of the complete equipment is shown in Fig. 1 and a block diagram in Fig. 4. In the description of the units that follows, no attempt is made to describe the detailed operation of well-known circuits already adequately covered in the literature of the subject.

3.1. *Stabilized Scanner*

The stabilized scanner may be conveniently split into two sections—the scanning aerial unit and the gyro stabilized platform.

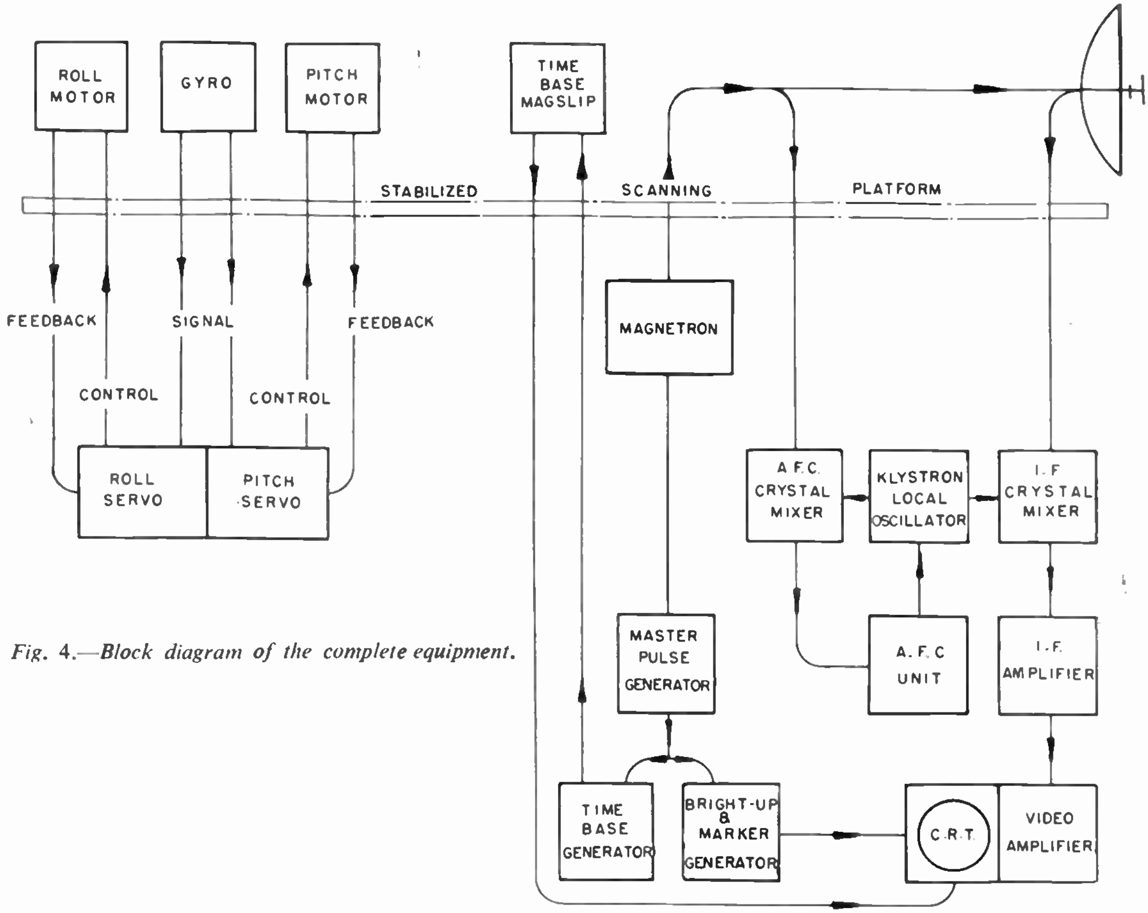


Fig. 4.—Block diagram of the complete equipment.

The complete assembly is shown in Fig. 3. The aerial assembly with its azimuth drive unit is bolted to a large ring bearing which provides the roll movement, the ring bearing being supported and pivoted on two side brackets which are bolted to the aircraft frame.

3.1.1. Scanning Aerial Unit

The antenna assembly consists of an 18-in. paraboloid with its focus in the aperture plane illuminated by dipole and reflector elements which are supported and energized by a waveguide passing through the vertex. The polar diagram horizontal plane is shown at Fig. 5. The assembly is swung in azimuth over an angle of 150 deg. through a spur gear train and crank mechanism from a 115-V 400-c/s motor. The time for a single sweep is one second. Provision is also made for moving the reflector relative to the dipole system through $\pm$ 7 deg. so that the beam can be tilted up or down with respect to the stabilized platform. Since the reflector only is moved, the beam deflection is greater than the mechanical movement by a factor of approximately 1·4. The vertical polar diagram at maximum tilt is shown at Fig. 6, and it will be noted that the side lobe structure is modified.

The reflector has a tilt movement of 2 deg/sec, which is obtained by a 115-V 400-c/s motor geared down through 2700 : 1 by a spur stage and worm drive and a further reduction of 15 : 1 by a lever and quadrant system.

Tilt control is provided by a simple relay-operated servo. The energizing coil of a polarized relay is connected between the moving contacts of two potentiometers—one clamped to the worm shaft of the tilt drive mechanism geared up 15 : 1 to the reflector and the other situated in the control unit. Direct current is supplied to these potentiometers. The contacts of the polarized relay are connected through energizing coils of two slave relays which control the direction of motion of the tilt motor by reversal of the phase connections. Any misalignment between the potentiometer wipers closes the contacts of the polarized relay in the appropriate direction. The selected slave relay controls the tilt motor in such a direction as to restore balance. At the balance point the slave relays are arranged to open circuit the 115-V a.c. and then apply d.c. to one winding of the motor. This d.c. provides braking and enables the "dead spot" to be reduced.

The stabilizing unit consists of a large ring bearing made up of 30 caged steel balls running in dural tracks which are a push fit in the inner and outer races. The scanning unit is bolted to the front of the inner ring and a sheet metal supporting structure at the back. This structure carries a junction box and a tray on vibration mountings, which provide a platform for the gyroscope unit and cradles with clamping bands for the transmitter-receiver unit and servo amplifier unit.

The roll movement is produced by a 115-V 400-c/s motor coupled to a drag cup velocity feedback generator and geared through 2,000 : 1. A reduction of 200 : 1 is obtained by three spur stages contained in the gearbox bolted to the inner ring, and a further external ratio of 10 : 1 obtained by the output pinion mating with a quadrant cut on the outer ring.

The main bearing is pivoted about the horizontal axis on the side brackets. The pitch movement is obtained by a similar motor assembly geared down through 5,900 : 1. A reduction of 590 : 1 is obtained by three spur stages contained in the pitch gearbox mounted on the outer ring and an external ratio of 10 : 1 by the output pinion mating with a quadrant on the port side bracket.

Should stabilization fail due to faults in the gyro or servo amplifier the system can be approximately centralized by limit switches. These switches are operated at the edges of narrow slots in bakelite tracks mounted on the roll and pitch bearings. When the platform moves so that the switch cam passes the edge of a slot the motor is energized and the system is driven back to the null position. Slipping flywheels are fitted to provide mechanical damping.

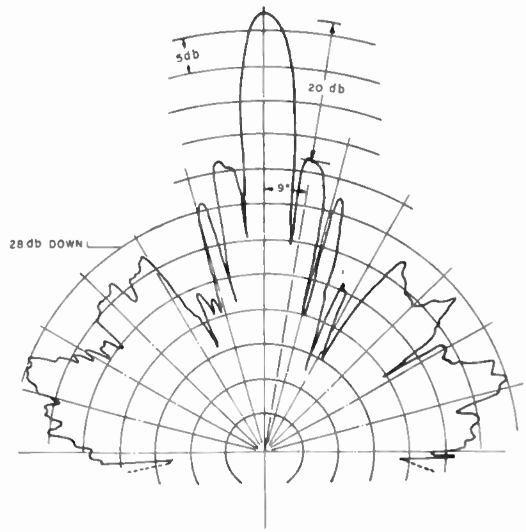


Fig. 5.—Horizontal polar diagram.

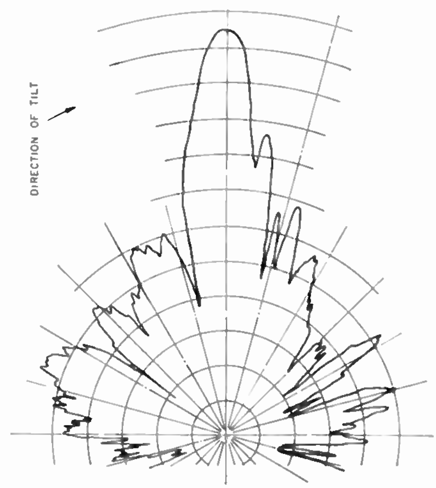


Fig. 6.—Vertical polar diagram with maximum tilt.

The stabilization accuracy is such that the platform remains horizontal within ± 2 deg. in roll or pitch for aircraft movements of up to 25 deg./sec and 10 deg/sec respectively. The error under level flight conditions is less than 1 deg.

Radio frequency energy is brought in through a short length of flexible wave guide and is fed to the antenna via a rotating joint on the axis of the final azimuth drive shaft. A magslip to provide angular deflection of the indicator time base is also mounted on the final shaft.

Electrical connections are through two 18-way cables, one to the transmitter receiver and one to the scanner junction box for distribution to the various sub-units. These main 18-way cables are flexible to cater for the roll and pitch movements.

As mentioned earlier, a variant of the scanner assembly has been designed in which the transmitter-receiver and servo units are remotely mounted. This necessitates two extra rotating joints on the roll and pitch axes, and modifies the cable system. In other respects the units are similar.

3.1.2. Control Gyroscope

The gyro unit, developed by Ferranti, consists of an electrically driven vertical rotor supported in gimbals with a long term gravity reference provided by a liquid switch and precession torque motors. The gravity reference is, of course, necessary to correct for random wander of the gyro as a result of unwanted precession forces such as bearing friction. The rate of correction is much slower than normal aircraft manœuvres, so that under these circumstances the gyro rotor is the reference. Inductive pick-offs associated with each gimbal produce a.c. error signals when the plane of the gyro mounting ceases to be at right-angles to the rotor axis. Over a small angle the magnitude of the error signal is proportional to the displacement and its phase relative to the supply indicates the sense.

The static error of the gyro rotor is less than ¼ deg. An aircraft in flight is usually subject to a small periodic motion of, say, ± 1 deg/min. The liquid switch system tries to correct this error with the result that the average error of the system in flight may be increased to about ½ deg.

The whole gyro system except the liquid switch is mounted in a hydrogen-filled sealed container.

3.2. *The Servo Amplifier*

The servo amplifier contains two similar circuits controlling the roll and pitch axes of the scanner.

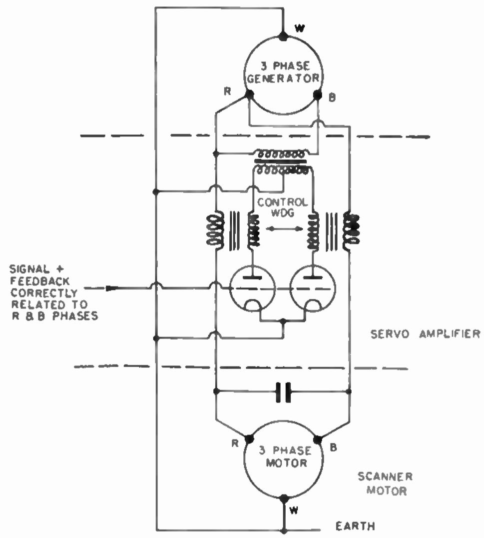


Fig. 7.—Simplifier servo amplifier unit.

It is desirable to consider first the method of controlling the correction motors. Fig. 7 shows a simplified circuit of this part of the system. It is well known that a three-phase induction motor can be run if two of its terminals are connected to two terminals of the generator and the third phase supplied through a phase advancing capacitor. The direction of rotation is determined by the phase connections. In Fig. 7, if the impedance of the left-hand reactor is high and the right hand low, then B phase on the motor is connected directly to R phase on the generator with R phase on the motor fed through the capacitor. If the reactor impedances are interchanged then the R and B connections on the motor are reversed, together with the direction of rotation. The actual impedance of the conducting reactor controls the motor torque.

In practice, each reactor power winding is split into two coils and rectifiers are inserted so that the motor current is divided into unidirectional pulses. The magnetic flux due to the d.c. components of these pulses provides positive feed back and increases the saturation of the core for a given current in the control winding. When this control current is zero, the minimum current in the motor is dependent on the reactance of the power windings at ripple frequency. In order to minimize the partial saturation due to the d.c. component of this small current, a fourth winding is energized by a separate d.c. source, so that the resultant flux is approaching zero. With the correct value of neutralizing current, the minimum motor current is about 50 mA, increasing to a full load of about 750 mA for a 7-mA control current. The time constant is approximately 20 m sec.

The common grids of the control valves are supplied with the a.c. error signals and their anodes from a centre-tapped transformer. The anode and the energizing winding of the pick-off system have the same phase reference so that the two valves constitute a phase-sensitive rectifier. The d.c. component of the anode current is smoothed by capacitors across the control windings.

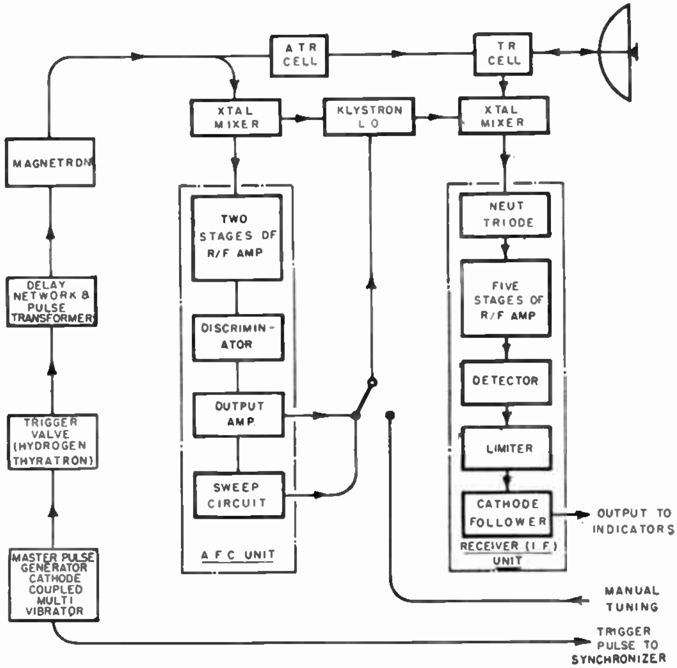


Fig. 9.—Transmitter-receiver—block diagram.

Figure 8 is a block diagram of the complete servo system for one axis. The stabilizing velocity feedback is produced by a drag cup generator, the energizing winding of which is correctly phased with respect to the signal. The proportion of signal to feedback is variable and is normally adjusted to suit the inertia of the scanner mechanism, so that the scanner executes one overshoot for a step function signal equal to about 5 deg. of misalignment. A feedback limiting circuit is provided so that a high initial correction speed is obtained for a large transient misalignment.

The remainder of the unit consists of a d.c. power supply for the early stages and the reactor neutralizing windings of the two complete servo chains. Although the unit is sealed and pressurized, no special cooling arrangements are necessary as the power dissipation is quite low.

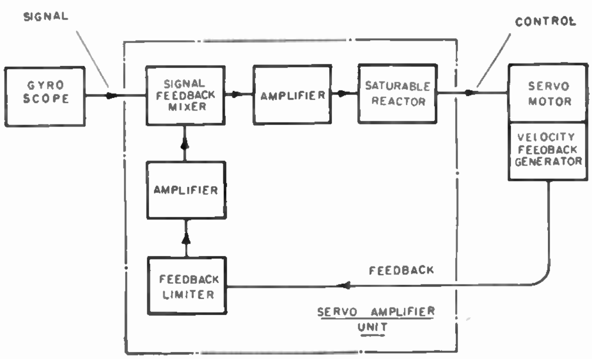


Fig. 8.—Servo system—block diagram.

3.3. *The Transmitter-Receiver Unit*

The transmitter-receiver unit contains all the R.F. circuits for the equipment, together with the master pulse generator, delay line modulator and the necessary power supplies. A block diagram is shown in Fig. 9.

The master pulse generator consists of a cathode-coupled multivibrator producing 50μsec pulses at a recurrence frequency of about 700 per sec. This output is taken from the cathode of the second valve to the synchronizer unit for time base triggering, etc. A ringing circuit in the anode of this valve provides the triggering voltage for the hydrogen thyratron used as the discharge device in a conventional 1 μsec delay network modulator. A pulse of 4·5 A at about 5·5 kV is delivered by the pulse transformer to the magnetron cathode.

The R.F. output is coupled to the waveguide duplexer and thence to a pressure seal and choke joint on front panel of the unit. The duplexer uses a 1B24 TR cell and a 1B35 broad band ATR cell. A subsidiary branch carries the 723 A/B local oscillator and the signal and A.F.C. crystals. Resistive strips across the guide between the local oscillator probe and the crystal cavities provide resistive loading for the local oscillator. The signal is fed to the crystal cavity through the TR cell and a section of cut-off waveguide carries the reference signal from the magnetron to the A.F.C. crystal.

The I.F. strip has a bandwidth of about 2 Mc/s centred on 45 Mc/s. The first stage is a 6AK5, triode-connected, and neutralized by a small trimmer from the anode circuit. The noise factor is about 2·5 db. The first stage is followed by five stages using single tuned circuits arranged as stagger-tuned pairs. The second detector, video limiter and output cathode follower complete the unit. A gain control range of 30 db is provided by a variable cathode resistor in two stages. Since minimum range is not critical no suppression is used.

The A.F.C. unit consists of two amplifier stages similar to those in the I.F. strip, followed by a discriminator and control circuit. Initially, the control circuit is oscillatory on a time constant of about 1 sec, so that the local oscillator reflector voltage and hence its frequency are swept over a small range. As the difference frequency sweeps through 45 Mc/s the discriminator output becomes positive and stops the sweep action. Thereafter the correct local oscillator frequency is maintained despite magnetron drift, etc., providing that the frequency variation required is within the 25 Mc/s electronic tuning range of the 723 A/B.

Structurally, the complete transmitter-receiver unit is split into four sections. A main deck carries the front panel, waveguide components and inter-unit wiring. The I.F. strip and A.F.C. system form two of the plug-in sub-units, while the third contains all the power supply and modulator components. The complete unit is pressurized and both internal and external blowing is necessary. Provision is made for monitoring crystal currents and the important supplies from a test plug on the front panel.

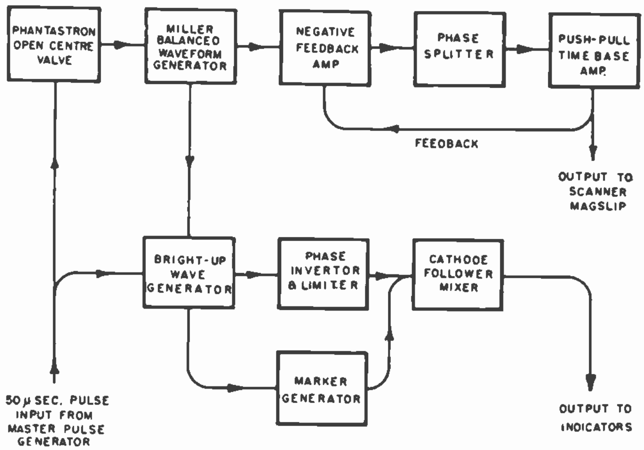


Fig. 10.—Synchronizer unit—block diagram.

3.4. *The Synchronizer Unit*

This unit contains all the time base, marker and bright-up circuits together with the necessary power supplies (Fig. 10).

Two time base ranges of 10 and 40 nautical miles are provided and are associated with two- and five-mile electronic markers. The open-centre facility on the 10-mile range is achieved by triggering the time base a pre-set amount after the leading edge of the master 50-μsec pulse, i.e. before the transmitter pulse. Since the marker and bright-up circuits are triggered coincidentally with the trailing edge of the master pulse with the transmitter pulse, range calibration is correct but zero range appears on the display as a small arc. The delay is achieved in a phantastron circuit.

The time base proper consists of five valves, generating a "balanced" Miller run-down.[4] The Miller valve has an inductive anode load formed by the primary of a transformer. The output from the secondary of the transformer feeds into a RC network, which compensates the time base waveform for distortion introduced by the magslip.

This circuit is followed by an amplifier, phase splitter and an output stage consisting of four valves in parallel push-pull with current negative feedback.

An output transformer couples this stage to the magslip and thence to the deflection yokes in the indicator. Voltage negative feedback is taken from the secondary of the output transformer to the cathode of the first amplifier.

Two indicator units can be operated in parallel if necessary.

A further six valves generate and mix the "bright-up" waveform and the marker "pips." Both these waveforms are initiated at the trailing edge of the master trigger pulse. The marker pips are produced by a valve-maintained oscillatory circuit which is allowed to operate for the duration of the bright-up waveform. The output for the oscillator is squared, then differentiated, and the positive going pips so produced are mixed with the "bright-up" waveform in a cathode follower and applied to the tube grid.

Since the complete unit is sealed and pressurized both internal and external blowing are necessary.

3.5. *Indicator Unit*

As the indicator unit is intended for cockpit mounting, it has been kept as small as possible and includes only the 3½-in. cathode ray tube with its deflection yoke, E.H.T. and L.T. supplies, d.c. restoring diodes and a single stage of video amplification. Focus and brightness controls are provided.

The video stage has a gain of about 8 with a bandwidth of 1·5 Mc/s to 3 db down.

It will be remembered that the display is a sector P.P.I. covering 150 deg. centred on the line of flight. In order to use as much as possible of the screen area the centre of rotation is near the bottom of the tube with a trace length of about 6 cm. This results in some of the picture being lost at extreme azimuth angles, but has not caused any difficulty in practical operations.

The most satisfactory screen material has proved to be the 2168 Fluoride powder giving a medium persistence orange "after-glow" with no visible "flash."

The unit is not pressurized as it will be installed in the pressure cabin of a high altitude aircraft. It is, however, satisfactory up to 25,000 ft. should pressurizing fail.

3.6. *The Control Unit*

This unit contains all the operational controls for the equipment and is intended for cockpit mounting on the S.B.A.C. console system.

These controls are:—

1. Scanner tilt angle.
2. Receiver gain.
3. Range switch—10 or 40 nautical miles.
4. Range marker on-off.
5. Manual tuning combined with manual/A.F.C. switch.
6. Stabilization on-off.
7. Main power on-off.
8. Tilt scale illumination.

In addition the following pre-set controls are provided:—

1. Tilt control sensitivity.
2. Indicator X and Y shifts.
3. "Open-centre" radius.

The controls most used during an actual operation are the scanner tilt angle, receiver gain and range switch.

4. Operational Trials

The operational trials of the equipment were carried out by the B.O.A.C. on behalf of the M.C.A. These trials were intended to assess the practical utility of the equipment for cloud detection and high ground avoidance, etc., rather than to provide any further scientific data on radar echoes from clouds. A number of other possible subsidiary uses of the equipment were also investigated. The first trials period was devoted primarily to cloud work[5] and was carried out in the Singapore-Hong Kong area using a flying boat, while the second period was used to investigate the high ground warning[6] application with a Viking aircraft. Since there was a certain amount of overlap in the work, the brief summary presented here does not differentiate between the two installations.

During all operations the aircraft was flown by the First Officer under directions from the Captain who observed the display only. Effectively, the aircraft was operating under blind flying conditions.

Provision was made for simultaneous photography of a second indicator display and the forward view from the aircraft, together with the readings of an accelerometer, altimeter, air speed indicator and clock.

4.1. *Cloud Detection*

Theoretical predictions and early trial results were amply confirmed by the detection of the

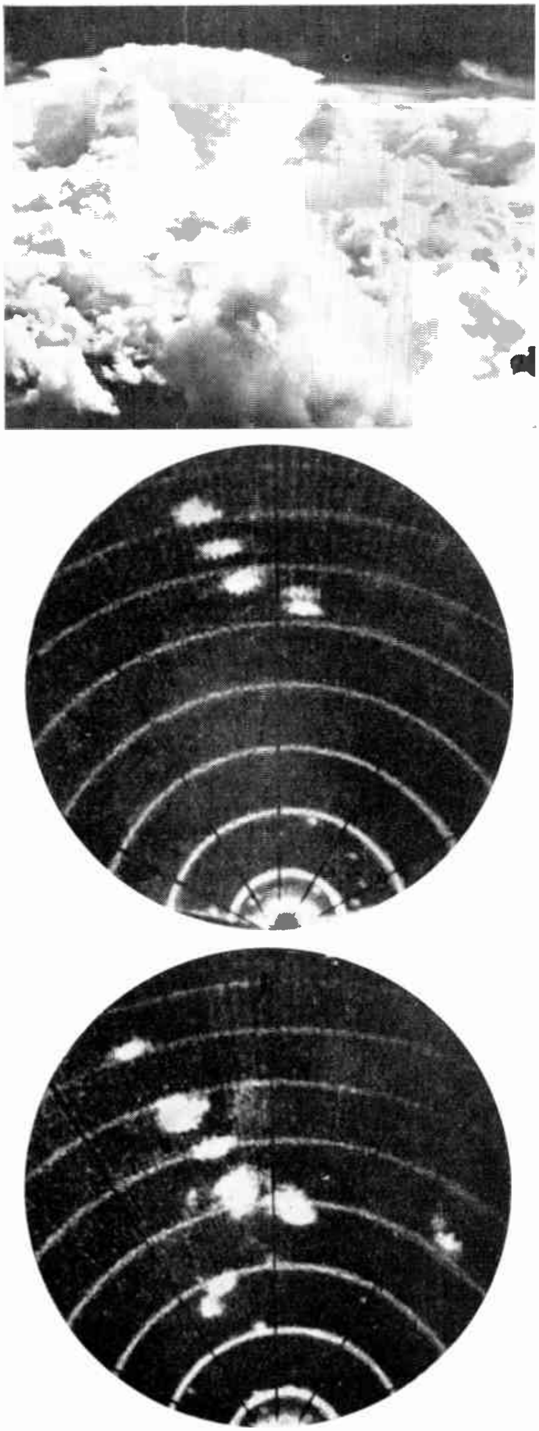
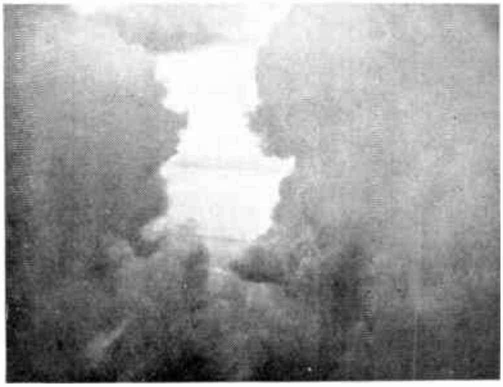


Fig. 11.—A group of growing cumulo-nimbus clouds photographed from a range of 20 miles. Aircraft altitude 10,000 ft. Cloud top, 28,000 ft., base 1,500 ft.

larger cumulo-nimbus clouds at the maximum range of 40 miles. In general the range of detection was dependent on the vertical depth of the cloud and most of those with depths exceeding 25,000 ft. gave responses at maximum range. The greatest vertical depth measured was about 40,000 ft. This result is to be expected since an increase in depth means that a greater portion of the beam area is filled by the target.

Figure 11 shows a group of growing cumulo-nimbus clouds together with the indicator display at different ranges. It is interesting to note that good returns are obtained from a number of cloud targets in line. It will be seen that the short-range display reveals a number of smaller responses at a range of 15-20 miles. These are from cumulus clouds to the left of the main cumulo-nimbus. Large cumulo-nimbus clouds showed two or three response areas within the main structure. Penetration through the radar-indicated gaps gave only slight turbulence. An example of such a gap is shown in Fig. 12.

Although a number of penetrations were made no reliable correlation was found between turbulence and range of detection or height of the cloud. However, it appears certain that if all radar response areas are regarded as potentially dangerous and avoided, then what would visually be classed as a forbidding cloud formation can be negotiated with safety and comfort. The lateral diversions involved are much smaller than would be necessary to completely avoid a large cloud bank. No responses were obtained from other types of cloud such as stratus or strato-cumulus. The echoes from cumulo-nimbus were always stronger from the lower regions of the cloud and usually disappeared around the freezing level. Unfortunately no observations were possible from above the freezing level owing to aircraft altitude limitations. Theory indicates that the echo intensity from ice crystals should be less than that from water droplets as the dielectric constant of ice is considerably lower than that of water and thus reduces the magnitude of S, the scattering function.



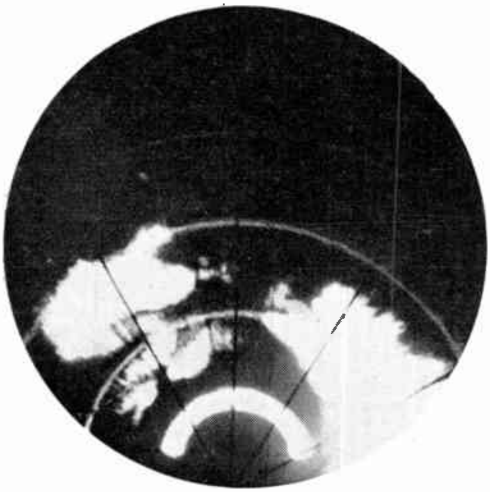


Fig. 12.—Example of a gap between two cumulo-nimbus clouds. This gap was observed on the indicator before it was seen visually. The aircraft was directed through by radar observations only.

4.2. *High Ground Warning*

A thorough investigation on the high ground warning and terrain clearance capabilities of the system showed that avoidance by the safety circle technique outlined earlier gave the most satisfactory results.

Tests of the method on a large number of different reflecting media such as level terrain, cliffs, mountains and ships, did not produce errors in indicated clearance height of greater than about 500 ft. providing that the inner cut-off range used was not greater than about 10 miles. These results were obtained at clearance heights in the region of 2,000-5,000 ft. At the lower clearance heights it was generally necessary to reduce the warning range in order to maintain a well-defined inner edge of the response. This effect was particularly pronounced over undulating ground.

In general a nominal clearance height of 3,000 ft. with the tilt adjusted to give a warning range of about 6 miles seemed to be the most useful compromise. This warning range provides for a factor of safety of about 3 to 1 on the turning circle of an aircraft executing a Rate 1 turn at 300 m.p.h., and this leaves adequate room for manœuvre should avoidance action be necessary.

Measurements in high ground areas using the 40-mile scale showed that the errors increased with range but still provided useful early warning information.

If a knowledge of future clearance height in a particular direction was not required it was always found possible to detect the presence of high ground and to take lateral avoidance action by observation of the shadow regions associated with high ground responses. Navigation through valleys was quite practicable by this method. Fig. 13 shows the response obtained while flying along a valley well below the mountain tops, while Figs. 14 and 15 show the indicator display in a high ground region.

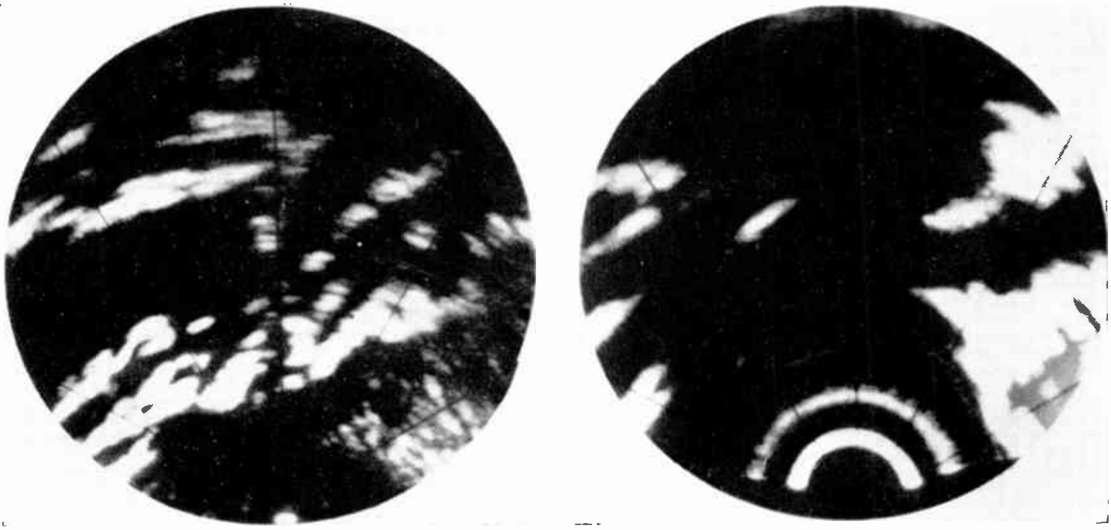
Fig. 13.—The display during passage along a valley below the mountains on either side.

Fig. 14.—Approaching a valley entrance from Grenoble.

The left-hand display shows the entrance at 13 miles.

The right-hand display (10-mile scale) shows the response during passage through the entrance.

Note the height ring at approximately 5,000 ft.



Tests with the pitch stabilization locked showed that small changes in aircraft attitude resulted in large changes in safety circle range and that a reasonably accurate measurement of clearance height could not be obtained.

A crude avoidance technique under these conditions was to put the aircraft in a stable climbing attitude whenever the safety circle approached the selected minimum. If the warning range increased then it could be assumed that the high ground was being avoided. It was found, however, that the clearance height achieved by this method could be dangerously small and was, of course, unknown to the operator.

4.3. *Map Painting*

During the course of trials a considerable amount of *en route* flying provided ample opportunities for assessing the utility of the map-painting facility. As would be expected from previous experience bold features, such as coastlines, large rivers and isolated regions of high ground, provided easily recognizable targets, and under these conditions it was possible to fix the position of the aircraft with greater accuracy and speed than by normal methods.

The range of detection of even flat, sandy coastlines was found to be in the region of 40 miles, while higher features such as small cliffs gave a well-defined display at that distance.

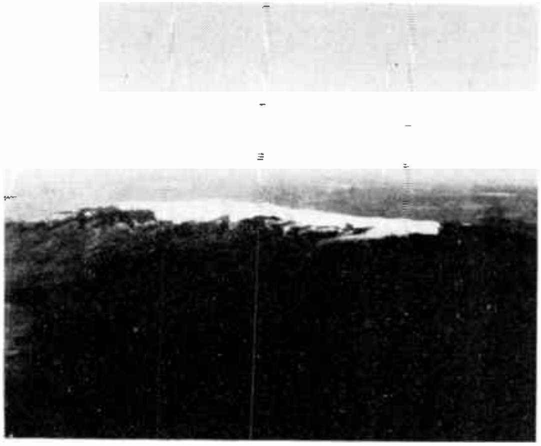
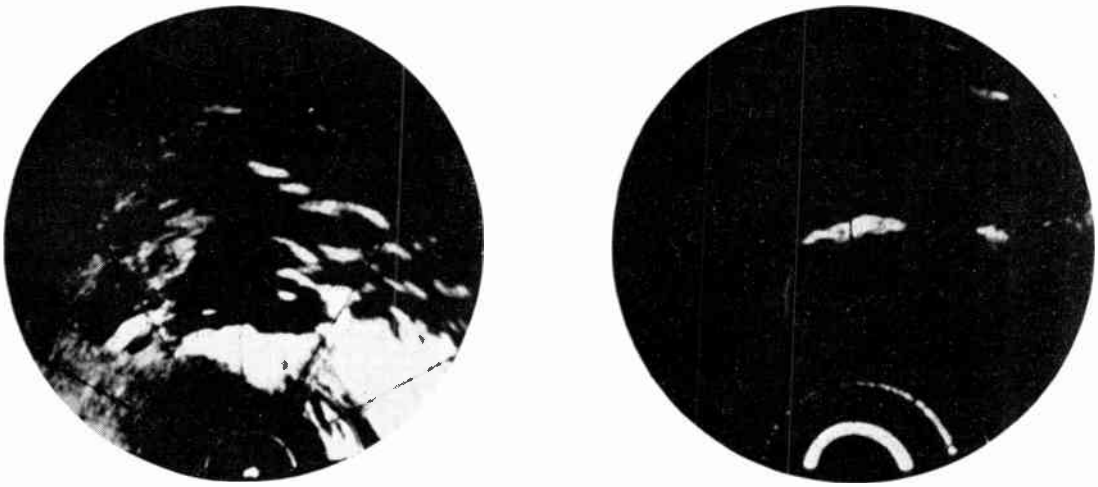


Fig. 15.—An approach to Mont Ventoux at a range of 12 *miles.*

The left-hand display (40-*mile scale*) *shows high ground behind the main target.*

The right-hand display shows the response disappearing at a "safety circle" of 4½ *miles.*

With −1½ *deg. tilt, the predicted clearance height was* 2,500 *ft. and the actual clearance* 2,750 *ft.*



Large sections of coastal routes such as Karachi-Bahrein were flown at night using the radar as the prime navigational aid, and approaches to marine airports were particularly easy. An example is shown in Fig. 16, where a breakwater (not shown on the map) together with responses from vessels in the harbour can be clearly distinguished.

A land-locked harbour surrounded by high ground, such as Hong Kong, provides a very difficult approach problem under bad weather conditions. Using the radar display it was found possible to negotiate the entrances and fly within the harbour area well below the surrounding high ground.

The equipment also provided a very useful method of position-fixing during approaches to aerodromes located in coastal regions. Over land regions a certain amount of experience was necessary, but once the display associated with a particular region had been identified it could be recognised again without great difficulty. Large rivers were detected up to about 25 miles, but the presence of shipping could block out large sections and be somewhat confusing. Large built-up areas provided reliable and easily recognizable targets.

5. Conclusions

It is considered that the results so far obtained with the equipment described indicate that airborne radar can be of great value in civil aircraft operations. Its use should lead to a material reduction in the number of flights

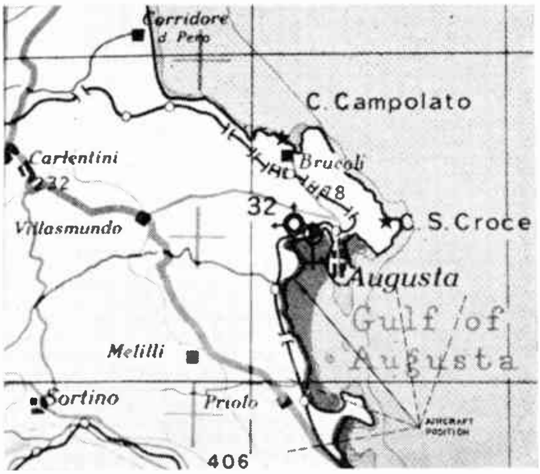


Fig. 16.—Augusta Harbour, Sicily. Responses in harbour area are from a large number of naval vessels. The breakwater seen on the display is not marked on the map.

cancelled or abandoned due to unfavourable weather conditions, particularly in tropical regions, and to the virtual elimination of collisions with high ground. Map painting is a useful *en route* navigational check, especially in coastal regions, and can be of great assistance in making bad weather approaches to marine airports or to airfields in close proximity to high ground. On regular routes the provision of special radar maps might assist considerably interpreting map painting displays.

Whether or not it is worth while complicating the equipment to improve the present functions or to provide for new ones will only become evident after operational experience is available over a variety of routes. Such experience is vital before any further useful development can be carried out.

6. Acknowledgments

The equipment described here is the culmination of the efforts of many people over a long period and it is probably invidious to mention names. However, special reference must be made to the author's colleagues, Messrs. Gard, Gibson and Cox, who were responsible for the design of various units of the system; to Messrs. Holland and Steer of T.R.E. for their invaluable assistance during the development; and finally, to Captain Field of B.O.A.C. for his conduct of the trials.

Acknowledgment is also made to the Ministry of Supply for permission to publish this paper and to the British Overseas Airways Corporation for the use of material from their reports.

7. References

1. J. W. Ryde. "The Attenuation and Radar Echoes produced at Centimetre Wavelengths by various Meteorological Phenomena." *Meteorological Factors in Radio Wave Propagation* (Physical Society Report, London, 1946).

2. J. W. Ryde. "The Attenuation of Centimetre Radio Waves and Echo Intensities resulting from Atmospheric Phenomena." *J. Instn Elec. Engrs*, **93**, 1946, Part IIIA, p. 101.

3. J. E. N. Hooper and A. A. Kippax. "Radar Echoes from Meteorological Precipitation." *J. Instn Elec. Engrs*, **91**, 1950, Part I, p. 89.

4. F. C. Williams, W. D. Howell and B. H. Briggs. "Plan Position Indicator Circuits." *J. Instn Elec. Engrs*, **93**, 1946, Part IIIA, p. 1219.

5. British Overseas Airways Corporation Report No. DF/R.17, Part I.

6. British Overseas Airways Corporation Report No. DF/R.17, Part II.