JOURNAL OF
The British Institution of Radio Engineers
(FOUNDED IN 1925 - INCORPORATED IN 1932)
"To promote the general advancement of and to facilitate the exchange of information and ideas on Radio Science."

Vol. X (New Series) No. 11 NOVEMBER 1950

REPORT OF THE TWENTY-FIFTH ANNUAL GENERAL MEETING

THE INSTITUTION'S TWENTY-FIFTH ANNUAL GENERAL MEETING (the seventeenth since Incorporation) was held at the London School of Hygiene and Tropical Medicine, Keppel Street, London, W.C.1, on September 27th, 1950.

Mr. L. H. Bedford (President) was supported by other officers of the Institution and members of the General Council. In addition, forty-eight other Corporate Members had signed the attendance book when the meeting opened.

1. To confirm the Minutes of the 24th Annual General Meeting held on September 22nd, 1949

A record of the last Annual General Meeting was published on pages 353-356 of the *Journal* for October, 1949. The President's proposal that these minutes of the proceedings be approved was carried unanimously.

2. To receive the Annual Report of the General Council

Mr. Bedford stated that, notwithstanding the difficulties of the printing industry, the Annual Report was published in the August-September *Journal*. The preparation of such a Report was in itself a considerable task, because every endeavour was made to reveal to the membership the diverse activities which engage the Council and Committees. Acceptance of the Report was, therefore, taken as a vote of confidence, but, as always, the officers and Council would be pleased to receive constructive suggestions.

Acknowledging the reference to himself in the Annual Report, Mr. Bedford said he felt that just as he was getting used to his many tasks as President his time had expired. He left his office with a great appreciation of the importance of the Institution and the value of its work. He had not been able to accomplish all that he had hoped, but in view of future plans he was pleased that his successor would be Mr. Paul Adorian. Mr. Bedford then expressed thanks to all his colleagues on Council and the Committees for their sterling support during his two years as President.

Mr. Bedford had been especially pleased to represent the Institution in a number of official discussions and one of the most important was with the Ministry of Labour and National Service. Such activity was primarily concerned with obtaining proper recognition of the Institution's status and value to the community. Under that heading, Mr. Bedford also mentioned the Institution's representation on the British Standards Institution and similar bodies. He urged that, in these matters, Council's work deserved the utmost support.

The President had been impressed with the tremendous amount of work which was undertaken by the Membership, Education and Papers Committees. In the past two years the total membership continued to show an increase. Particular pride could be taken in the fact that the Institution had been especially strengthened by an ever increasing total of transfers from junior to senior grades. This question was allied to our examination and educational work which ensured that membership increase was based on the very firm foundation of professional ability.

Regretting his inability to visit all Sections of the Institution, Mr. Bedford emphasized that the activities of the Sections in this country were essential to the corporate life of the membership.

The task of selecting suitable papers and arranging for their presentation was one which would be impossible without the loyal co-operation of the Section and Papers Committees. As President, he had taken a special interest in this work and he particularly advocated that all members should attend Section meetings and offer papers for reading.

Mr. Bedford then formally moved the adoption of the Annual Report of the General Council.

Mr. E. A. H. Bowsher (Member) in seconding the motion said that it might be a simple matter to raise questions of inteiest on the work and progress of the Institution. It was obvious from the Report, however, that the Council had accomplished a great deal during the past year and that there could be no complaint regarding the variety of subjects which were tackled on behalf of the membership.

The significant factors of a continued increase in membership and the very large increase in the number of candidates taking the examination were most gratifying. Members were entitled to presume that these would be very pertinent factors in obtaining further recognition of the profession.

The development of the membership overseas was of particular interest at the present time, and Mr. Bowsher felt sure that members would wish to send from the Annual General Meeting good wishes to the Sections in New Zealand and South Africa, and to support the proposal to establish further Sections in India and Australia.

On behalf of Corporate members, he thanked the members of Council for the work they had done during the year, and, in particular, expressed appreciation to the retiring President for his services to the Institution.

On a show of hands, the Annual Report of the Council was unanimously approved.

3. To elect the President

Mr. Bedford moved that Mr. Paul Adorian be elected as President of the Institution. The President-elect had always regarded his membership of the Institution as an opportunity for serving his profession, and to Mr. Bedford that quality was the first essential in anyone who accepted high office.

This proposal was carried with acclamation.

4. To elect the Vice-Presidents

The Council had already recommended the re-election of Mr. W. E. Miller as Mr. Adorian's principal Officer. Mr. Bedford said that it would be quite impossible to pay adequate tribute to Mr. Miller's very long service to the Institution. He was sure that every member would signify very hearty approval of the recommendation that Mr. Miller be re-elected a Vice-President.

Council had also recommended that Mr. Leslie Paddle and Mr. J. W. Ridgeway should be elected Vice-Presidents. Mr. Paddle was a Founder Member of the Institution, greatly deserving recognition for nearly twenty-five years of service on Council or one or more Committees. He was indeed a very old colleague of Mr. Miller and had contributed greatly towards bringing the Institution to its present status.

Mr. J. W. Ridgeway was especially well known in the industry for his work in the British Valve Manufacturers' Association and the Radio Industry Council. Although Chairman of both those industrial bodies, Mr. Ridgeway had always found time to give valued help and guidance on the Professional Purposes and Finance Committees of the Institution. In addition, he had served three terms as a member of the General Council.

Again, by a show of hands, unanimous approval was given to the Council's recommendations on the election of the Vice-Presidents.

5. To elect Ordinary members of the General Council

Mr. Bedford stated that the July *Journal* published the names of the retiring members of Council and it was, indeed, gratifying that the membership had supported the nominations made by Council. As a ballot had not been necessary, Mr. Bedford declared that the following had now been elected to the Council of the Institution :—

Professor E. E. Zepler (Member).

E. A. H. Bowsher (Member).

H. E. Drew (Member).

R. G. Kitchenn, B.Sc. (Associate Member).

Commander H. F. Short, M.B.E. (Associate Member).

H. A. Brooks (Associate Member) was re-elected for a second term, and

S. R. Chapman (Member), re-elected as Honorary Treasurer.

Mr. Bedford congratulated the above on their election to Council and expressed thanks to the retiring members for their services.

6. To receive the Auditors' Report, Accounts and Balance Sheet for the year ended March 31st, 1950

Although during the course of the year Mr. Bedford had made it his business to attend meetings of the Finance Committee, he welcomed the opportunity to call upon Mr. S. R. Chapman to deal with the report of the auditors and the accounts and balance sheet.

Recommending the adoption of the Accounts, Mr. Chapman urged all members to consider those Accounts in two ways : firstly, in relation to past years, especially in regard to income, and secondly, in relation to present costs and the increasing activities of the Institution.

Mr. Chapman remarked that no matter what accounts were considered to-day, whether they were of an institution, a corporation, or a manufacturing company, there was one common factor—that of increasing expenses. It was not his duty to make comment on the reason for the increasing burdens which were thrown upon the Institution in making purchases essential for its activities. Every endeavour was made to keep down expenses without impairing the essential functions of the Institution in serving its members.

Nearly every other professional body had been compelled to consider means of offsetting the present high costs of essential materials. Some of the older institutions, more fortunately placed in the matter of long-term investments, had fallen back upon their reserves. Even then, the majority of institutions had examined afresh the possibility of improving income by increasing subscriptions. The Membership and Finance Committees desired, however, to avoid penalizing still further those upon whom the burden of taxation and expenses was already high.

The Treasurer suggested that some encouragement might be taken from the fact that the Institution's revenue continued to rise, although not on such a steep level as present-day costs ! It was now exactly five years ago since he had first been honoured by being elected as the Institution's Treasurer. The gross revenue was then a little under £5,000. As the statement showed, the Institution had, in the last five years, more than doubled its income.

The Income and Expenditure Account needed no further explanation, and on the Balance Sheet Mr. Chapman pointed out that in the last five years the assets had also risen by over 100 per cent.

The Special Funds were also self-explanatory and, looking over the years, it would be seen that the permanent assets had been added to by increasing the existing funds and establishing further special funds.

Whilst the Finance Committee was mindful of the need to keep a careful watch on the matter of costs, which was often beyond their control, the accounts should give great satisfaction to the membership. Mr. Chapman had much pleasure in moving their adoption.

Mr. H. G. Henderson (Chairman of the Scottish Section) said that it was with some diffidence that he seconded the proposal that the Accounts and Auditors' Report be adopted. This was because he represented a Section which fully utilized the grant made from the General Fund, and his committee was, of course, anxious to extend its work by obtaining an increase of the grant !

However, members might well feel indebted to those who had been primarily concerned with the finances of the Institution for the way in which they had balanced the accounts in a very difficult year.

Bearing in mind that the income was increasing, members had reason to be pleased with the accounts and Mr. Henderson had much pleasure in seconding the proposal for their adoption.

The proposal was carried unanimously.

7. To appoint Auditors

Mr. Bedford had much pleasure in proposing the re-election of Messrs. Gladstone, Jenkins & Co., as the Institution's Auditors. As Gladstone, Titley & Co., they had, as in previous years, prepared the final accounts to the satisfaction of the membership.

The proposal was carried unanimously.

8. To appoint Solicitors

The retiring President stated that for many years the Institution had in legal matters been indebted to Mr. Charles Hill, of Braund & Hill, for skilled advice. His guidance and opinion was seldom immediately apparent, but his counsel was invaluable to the Institution in planning the future constitution. Mr. Bedford had pleasure in proposing that Messrs. Braund & Hill be re-appointed Solicitors to the Institution.

The proposal was carried unanimously.

9. Awards to Prize Winners

Mr. Bedford offered his congratulations to the candidates who had won prizes for meritorious effort in the Graduateship Examination and to authors who had been awarded Premiums for outstanding contributions to the *Journal*.

He then presented the awards to the various prizewinners. (Their names are given on pages 265 and 268 of the August-September *Journal*.)

Sir Louis Sterling personally presented the premium bearing his name.

10. Any other business

Before concluding the business of the meeting, the President expressed, on behalf of the Officers and Council, appreciation to the General Secretary and his staff for the work which had been done during the past. year to the considerable satisfaction of the entire membership.

There being no other business, Mr. Bedford again expressed his appreciation for the honour of having been President for the past two years. He had enjoyed the opportunity of assisting the Institution and assured members that the termination of his office did not mean the termination of his work ; whatever opportunity he might have to serve the Institution, he would most gladly accept.

REPORT OF THE ANNUAL GENERAL MEETING OF THE SUBSCRIBERS TO THE BENEVOLENT FUND

1. To receive the Annual Report of the Trustees

The retiring President referred to the Annual Report, which was published on pages 279-280 of the *Journal* for August-September 1950, and, as he considered it needed no further comment, he formally moved its adoption.

The proposal was carried unanimously.

2. To receive the Auditor's Report, Accounts and Balance Sheet for the year ended March 31st, 1950

The Statement of Accounts had been appended to the report and Mr. Bedford stated that these accounts were entirely satisfactory. A number of claims on the Fund had been made, and the Trustees were in the fortunate position of not having had to refuse some measure of assistance to any deserving case.

Bearing in mind the difficulties of getting the Fund launched less than 10 years ago, it was very encouraging to note that in the last five years over £2,000 in securities had been added to the fixed assets. Mr. Bedford formally moved the adoption of the Accounts.

The proposal was carried unanimously.

3. To elect the Trustees for the year 1950-51

Mr. Bedford first thanked, on behalf of the subscribers, the Trustees for the way in which they had handled this fund. He then formally moved that the Trustees for the year should be the following subscribers :—

Sir Ernest Fisk.

Sir Louis Sterling.

Mr. A. H. Whiteley.

The President of the Institution and the Chairman of the General Council would, as usual, serve as *ex-officio* trustees.

The motion was carried unanimously.

4. To elect Honorary Solicitor and Accountant to the Benevolent Fund

Mr. Bedford expressed the thanks of the subscribers to Mr. R. H. Jenkins, Fellow of the Institute of Chartered Accountants, and to Mr. Charles Hill, of Messrs. Braund & Hill, for their voluntary services and formally moved their re-election as Honorary Auditor and Solicitor.

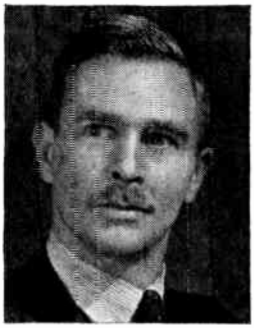
The motion was carried unanimously.

After the Annual General Meeting, Mr. Bedford introduced Mr. Paul Adorian, who delivered his Presidential Address. This will be published in the January, 1951, *Journal*.

GRADUATESHIP EXAMINATION PRIZE WINNERS, 1949

THE PRESIDENT'S PRIZE

The President's Prize for 1949 was awarded to Henry **Arnold Wolff**, who obtained first place in the Graduateship Examinations held during the year. Although born in England in 1914, Mr. Wolff received his general and technical education in Tasmania.



The whole of his career has been in the Australian radio industry and during the war he served as Radar Officer with the R.A.A.F. Since 1946 he had been in charge of the Installation and Service Department of a large Launceston firm of radio distributors.

Mr. Wolff was elected an Associate Member of the Institution in March of this year. He is also a Member of the Institution of Radio Engineers (Australia) and is the Chairman of the Launceston Division of that Institution.

AUDIO-FREQUENCY ENGINEERING PRIZE

K. S. S. Acharya, born in Mysore in 1921, studied at the University of Mysore, where he obtained a B.Sc.(Hons) in Physics in 1941, and M.Sc.(Wireless) in 1942.

After a period at the Bangalore Central College as a lecturer in Physics, Mr. Acharya secured his present position as a Technical Assistant at the Trichinopoly station of the All-India Radio in 1946.

Registered as a Student of the Institution in 1948, Mr. Acharya succeeded in the Graduateship examination in May, 1949, securing the highest number of marks awarded for the Audio Frequency Engineering paper; he transferred to Graduate membership shortly afterwards.

ELECTRONICS MEASUREMENTS PRIZE

John Francis Sayers was born in Erith, Kent, in 1924, and was educated at Bexleyheath Central School and the Northampton Polytechnic. He served in the R.E.M.E. from 1943 to 1947, and his first appointment in industry was with Marconi Instruments, Ltd.

After registering as a Student of the Institution in 1948 Mr. Sayers embarked upon full-time studies in preparation for the Institution's and City and Guilds examinations. He obtained his Final certificate in Telecommunications Engineering in May, 1949, and succeeded in the Graduateship examination in November of that year. In his optional subject of Electrical Measurements he obtained the highest marks awarded in the year.

Mr. Sayers now holds an appointment in the X-ray Laboratory of the Department of Applied Physics at the Northampton Polytechnic.

S. R. WALKER PRIZE

Alan David Phillips was born in London in 1925 and was educated at King Edward VI Grammar School, Retford. On leaving school he enlisted in the Royal Signals and became a Sergeant-Instructor.

After demobilization he took a full-time course in preparation for the Institution's Graduateship examination and for the City and Guilds certificate and he registered as a Student in March, 1949.

Soon after his success in the Graduateship examination Mr. Phillips obtained a commission as Sub-Lieutenant in the Electrical Branch of the Royal Navy.

He was awarded the S. R. Walker prize in recognition of obtaining the second highest marks in the 1949 examinations.

NOTICES

Obituaries

It is with the deepest regret that the Council records the death of James Gibson ATKINSON (Graduate). He was killed on October 17th, 1950, when the aircraft of which he was Radio Officer crashed in North London. He was 28 years of age and leaves a widow and two children.

Before joining British European Airways in 1947, Mr. Atkinson had served as Radio Officer in the Merchant Navy throughout the war years.

He became a Student Member of the Institution in 1947, and in February of this year he qualified by examination for transfer to Graduate.

* * *

Advice has just been received of the death, in April last, of Harold Thomas BURGESS (Associate Member).

After service in the Royal Navy (Wireless Branch) in the first world war, Mr. Burgess settled in Gravesend and qualified as an Associate Member in 1931. Only 55 years of age, Mr. Burgess leaves a widow, son and daughter, to whom the Council has expressed sympathy.

R.E.C.M.F. Exhibition, 1951

The Eighth Annual Private Exhibition of British Components, Valves and Test Gear for the Radio, Television, Electronic and Telecommunication Industries, will be held in the Great Hall, Grosvenor House, Park Lane, London, W.1, from Tuesday, April 10th, to Thursday, April 12th, 1951.

Admission will be by invitation only. Further details will be issued in due course by the organizers, the Radio and Electronic Component Manufacturers' Federation, 22 Surrey Street, Strand, London, W.C.2.

British Standards

The British Standards Institution has recently issued a revised British Standard: B.S. 1409: 1950 Letter Symbols for Electronic Valves.

This Standard was prepared under the supervision of the Electrical Industry Standards Committee by a sub-committee on which the Brit.I.R.E. was represented. It aims at standardizing the letter symbols used by valve manufacturers in their catalogues and in other technical literature.

Copies of the Standard may be obtained from the British Standards Institution, 24-28 Victoria Street, London, S.W.1, price 2s. post free.

The Trotter-Patterson Memorial Lecture

The Illuminating Engineering Society has founded a lecture in memory of two of its distinguished former members, A. P. Trotter and Sir Clifford Patterson, F.R.S. The Brit.I.R.E., in conjunction with other institutions, contributed to the fund raised to found the lectures.

The first Trotter-Patterson Memorial Lecture is to be given by Dr. J. W. T. Walsh, of the National Physical Laboratory, at 6 p.m. on January 17th next, at the Royal Institution. The title of his lecture will be "The Early Years of Illuminating Engineering in Great Britain."

Admission to this first lecture will be by ticket only. Members wishing to attend should apply to the Secretary for one of the tickets allocated to the Brit.I.R.E.

South-East London Technical College

Several courses of between 6 and 30 lectures devoted to various advanced radio and electrical engineering subjects are being given during the winter and spring terms at the South-East London Technical College.

These include Vector Analysis and Fundamental Electromagnetic Theory, Communication Networks, Operational Methods Applied to Electric Circuit Theory, Magnetic Amplifiers and their Applications, Servo-Mechanisms and Industrial Applications, Modulation, and High Voltage Engineering.

Further details may be obtained from the Head of the Department of Electrical Engineering and Applied Physics at the South-East London Technical College, Lewisham Way, S.E.4.

Amateur Television Transmissions

It was announced by the Postmaster General in the House of Commons on October 25th that arrangements were being made to license television transmission by amateurs in the bands 2,300 to 2,450 Mc/s, 5,650 to 5,850 Mc/s, and 10,000 to 10,500 M/cs. These are the internationally agreed amateur television bands.

THE INITIATION OF BREAKDOWN IN GASES SUBJECT TO HIGH FREQUENCY ELECTRIC FIELDS*

by

W. A. Prowse, B.Sc., Ph.D.†

A paper read before the North-Eastern Section on March 15th, 1950

SUMMARY

This paper discusses the literature dealing with the experimental data on the onset of electrical breakdown in gases covering the range from power frequencies to 9,000 Mc/s.

As the applied frequency is increased, various phenomena affect the circumstances of breakdown, particularly the stress at which this occurs. These phenomena begin at moderate radio frequencies, for gaps of the order 1 cm., with the non-removal of positive ions from the gap, and continue at much higher frequencies with the non-removal of electrons from the gap. Each of these effects, especially the persistence of electrons, lowers the breakdown voltage. The detailed shape of the curve relating breakdown voltage with *pd*, where *p* is the gas pressure and *d* the gap length, is much affected by the design of the electrode system and of the containing vessel. Extensive results are available on hydrogen.

Microwave breakdown has been studied in waveguides and in resonators: a considerable amount of theoretical work has been published based chiefly on the study of the balance between the growth of ionization by collision processes and the removal of electrons to the boundaries by diffusion. This work shows agreement with experiment for hydrogen over a wide range of frequencies and pressures, and for the monatomic gases where suitable data are available. Information on microwave breakdown at high values of *pd* is very limited: the breakdown is very abrupt and presents features not readily explained in terms of the diffusion theory.

1.0. Introduction

In broad outline, the onset of a gas discharge in steady fields necessitates two conditions: first, that an electron moving through the gas shall produce an avalanche of further electrons by collision processes and, second, that as a result of this avalanche further electrons shall be generated in the gas or at the cathode so that the transfer of charge may continue. Electrons are removed to the anode and positive ions to the cathode by the action of the field. The conditions in such an avalanche in an undistorted field are conveniently expressed in terms of the distance, x, of the electron from its starting point and Townsend's first coefficient α, which is the number of ion-pairs created by one electron per unit length of its path in the field direction. For one electron starting, n electrons appear x cm. nearer to the anode where

$$n = \varepsilon^{\alpha x} \qquad \text{(1)}$$

or, in a non-uniform field

$$n = \varepsilon^{\int \alpha \, dx} \qquad \text{(1a)}$$

At high enough frequencies, on the other hand, it is evidently possible that the movement of electrons, even at high stresses, may be too limited for their removal to the electrodes to constitute an important factor in breakdown. Multiplication of electrons and ions may then take place continuously within the body of the gas by localized collision processes and the second factor mentioned above is not necessary to breakdown. Although the existence of a high degree of ionization in a limited region may not result in ions actually crossing the gap, breakdown can occur in the sense that the energy supplied by the generator of oscillations is dissipated in the gap. This rate of dissipation is greatest when the velocity of the charge is in phase with the intensity of the electric field: a condition fully realized only when the frequency of the applied field is much below the frequency of collision between electrons and gas molecules.

* Manuscript received May 5th, 1950.
† Physics Department, University of Durham.
U.D.C. 621.315.618 : 621.3.015.5.

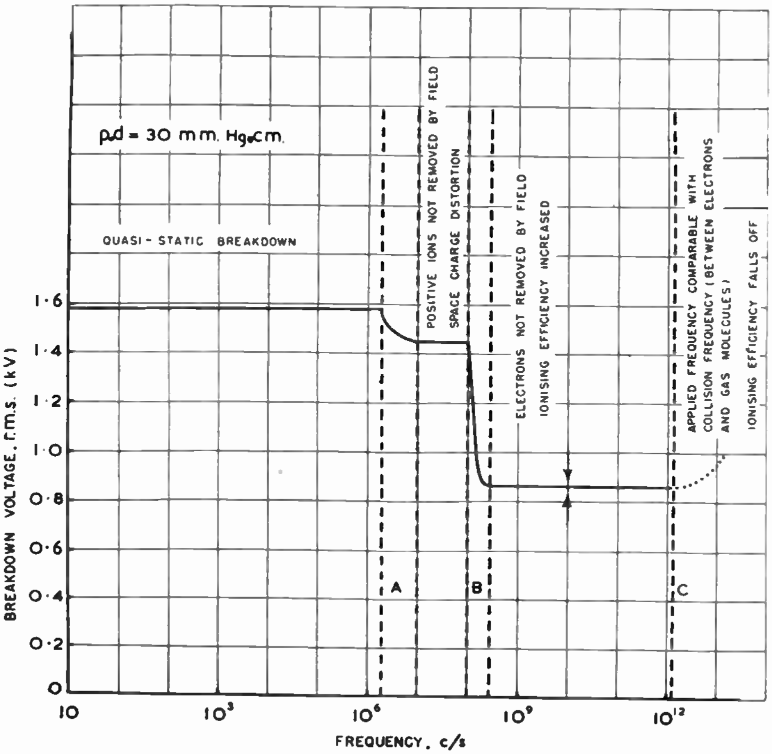


Fig. 1.—Breakdown voltage for a 0·4 mm gap in air at atmospheric pressure as a function of frequency (logarithmic scale). Based on Lassen (transition A). Pim (transition B), Labrum (transition C). The arrows indicate the upper frequency limit of experimental observations. Continuous observations over the whole frequency range do not exist: the diagram is intended to describe the main features only.

Between the two extreme cases of breakdown in steady fields and microwave breakdown a number of intermediate conditions occur, which at appropriate frequency ranges may influence breakdown. In the literature, experimental data are recorded covering a wide range of frequencies, gas pressures, electrode conditions and different gases. It is the purpose of this paper to discuss some of the more important contributions in this field, assigning what appear to be the most probable causes to the singularities observable in the results.

1.1. *Main Features*

The experimental techniques involved in work at various ranges of frequency vary so much that continuous observations on the breakdown of a given gap over the whole frequency range up to 10^{10} cycles per second do not exist. Moreover, not all of the transitions are determined by the usual parameter *pd*, where *p* represents the gas pressure and *d* the gap length. Nevertheless, the main transitions in mechanism are firmly enough established to justify a composite diagram (Fig. 1) illustrating features which will later be discussed in more detail.

Proceeding from the low-frequency end, and noting the use of a logarithmic frequency scale, the breakdown voltage retains the value appropriate to steady fields until the frequency range, 1 to 10 Mc/s, is reached, at which positive ions remain in the gap from cycle to cycle (A, Fig. 1), and the space charge thereby developed causes a lowering of breakdown potential. The next major change is an abrupt fall of breakdown potential which occurs about 100 Mc/s when electrons are no longer removed from the gap in each cycle (B, Fig. 1). Above this frequency gaseous conduction can set in within the body of the gas; i.e., the electrodes apply the stress and limit the extent of the discharge, but they do not necessarily take any other part. The last change shown, at C, is determined by the frequency of collision between an electron in the gap and the surrounding gas molecules, i.e., by the gas pressure independent of the length of the gap, and can only be observed at pressures low enough to give a collision frequency $<10^{10}$ per second. When the applied frequency approaches this collision frequency, the transfer of energy from the field to the gas, by the agency of the electron, becomes less efficient and the rate of ionization by collision falls off. In the microwave region, where this phenomenon has been observed, continuous frequency variation at the powers required is impracticable: the relevant experimental work is done by gas pressure variation, at values of the order of some millimetres of mercury.

2.0 Residual Positive Space Charge

At power frequencies, breakdown is similar in nature to breakdown in steady fields, inasmuch as both positive ions and electrons can be removed by the field between one voltage peak and the next. Each peak may be regarded as a fresh trial of whether the gas will break down under the peak stress: the observed peak breakdown voltages show sensible agreement with values measured for steady fields.[1]

At somewhat higher frequencies, beginning at about 10^5 cycles per second in air at atmospheric pressure for a 1-cm. gap, the removal of positive ions from the gap becomes incomplete. Owing to the finite mobility of the ions, a proportion of them will drift to and fro in the centre of the gap without reaching the electrodes. Here a dual influence may be exerted by these ions: they will cause a non-uniformity of the field in the gap, which in some regions will therefore exceed its nominal value as calculated from the geometry of the electrodes; in addition, they are available to stimulate further production of electrons in the gap—for example by photo-ionization as a result of recombination processes.

In formulating a general explanation of the effect of positive space charge on breakdown voltage, it is to be noted that the coefficient of differential ionization, Townsend's α, is extremely small until the intensity in the gap approaches the breakdown value for steady fields, when α begins to increase rapidly with the applied intensity. For the conditions represented by A (Fig. 2), electrons from the cathode will be crossing to the anode leaving behind a region of positive space charge which, in accordance with the distribution given by (1), will be concentrated towards the anode. These positive ions will move towards the right, as represented, until the condition B is realized, when their motion will be reversed. At the condition C the zone of positive charge will again lie against the left-hand plate, now the cathode, and thereafter will be captured by the cathode. About C, avalanches produced by electrons leaving the cathode will be affected by the new space charge distribution, which distorts the potential distribution as shown by the dotted line in *(d)*. It will be noted that, owing to the rapid increase of α with field intensity, $\int \alpha \, dx$ will be greater for C than for A, and, further, that the space charge in the new avalanches will be less concentrated towards the anode. Thus in successive cycles a positive space

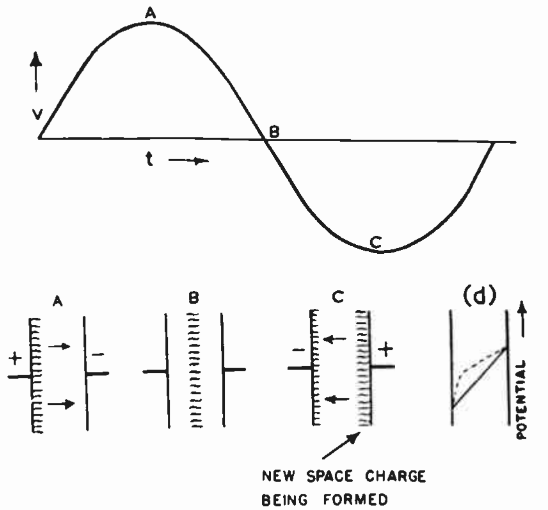


Fig. 2.—Movement of positive space-charge (shaded) during cycle. In (d) the field distortion corresponding to C is shown by the dotted line.

charge can be built up in the centre of the gap provided the time of one half cycle is too small to allow ions generated at the centre to be captured by the electrodes. It will further be observed that the build-up is a relatively slow process and that long statistical lags may be expected: these have been observed and commented on by Müller.[5]

Breakdown studies in this frequency region have been the subject of several papers.[2,3,4,5,6,7,8,9,10]

2.1. *Mobility of Positive Ions in a Spark Gap*

The amplitude, L, of movement of a particle having mobility k, in a field of peak intensity E_o and angular frequency ω is given by

$$L = 2E_o \frac{k}{\omega} \qquad \text{(2)}$$

This expression affords a useful criterion in deciding whether a peculiarity observed at a given frequency is attributable to a particular type of particle.

The departure from low-frequency values of breakdown stress is shown most clearly in the work of Lassen[3] (Fig. 3). In Table 1 the last column is the mobility of the positive ions in air calculated on the assumption that departure from low frequency values occurs when the positive ion can just cross the gap in one half cycle. Some interest attaches to the interpretation of these values. In dry air, at atmospheric pressure, the classical methods of measuring ionic mobility give a value of about 1·4 cm^2 sec^{-1}volt^{-1} but the ion is almost certainly a cluster of molecules, one carrying a positive charge. On the other hand, it is most unlikely that an ion formed in a field of about breakdown value will, while the field is maintained, attach neutral molecules. An estimate of the mobility appropriate to these monomolecular ions can be made as follows : the coefficient of diffusion for ions of mobility 1·4 cm.^{2} sec.$^{-1}$ volt^{-1} is 0·030 cm.^{2} sec.$^{-1}$, whereas the coefficient of diffusion for air through oxygen (which is nearly the same as that for oxygen through nitrogen) is 0·18 cm.^{2} sec.$^{-1}$. Although a charged molecule will have a slightly lower rate of diffusion than a neutral molecule, the effect is not likely to be large. Thus the mobility of the monomolecular ion is likely to be, approximately,

$$(0{\cdot}18/0{\cdot}03) \times 1{\cdot}4 = 8{\cdot}4 \text{ cm.}^2 \text{ sec.}^{-1} \text{ volt.}^{-1}$$

The increase of mobility in very strong fields is experimentally well established.[11]

Work on high-frequency breakdown before 1927 appears to have been confined to studies of breakdown voltages using damped oscillations[12, 13] and to work with sustained voltages at frequencies up to 120 kc/s.[10] Breakdown with damped oscillations is difficult to interpret but it seems likely that it resembles breakdown under impulsive d.c. conditions in that breakdown is probably initiated in the first surge or not at all. Goebeler[10] used frequencies in the quasi-static range and found no dependence on frequency up to his maximum frequency. In

TABLE I (see Fig. 3)

Breakdown between equal spheres in dry air at atmospheric pressure. (Lassen[3])

Gap length L cm.	Breakdown voltage V	Frequency n Cycle sec.$^{-1}$	Mobility of pos. ion k (calc.) cm^2 sec^{-1} volt^{-1}
0·34	1·26 × 10^4	1·43 × 10^5	4·1
0·22	0·83 × 10^4	3·1 × 10^5	5·7
0·11	0·48 × 10^4	8·8 × 10^5	7·0
0·05	0·30 × 10^4	24·5 × 10^5	6·4

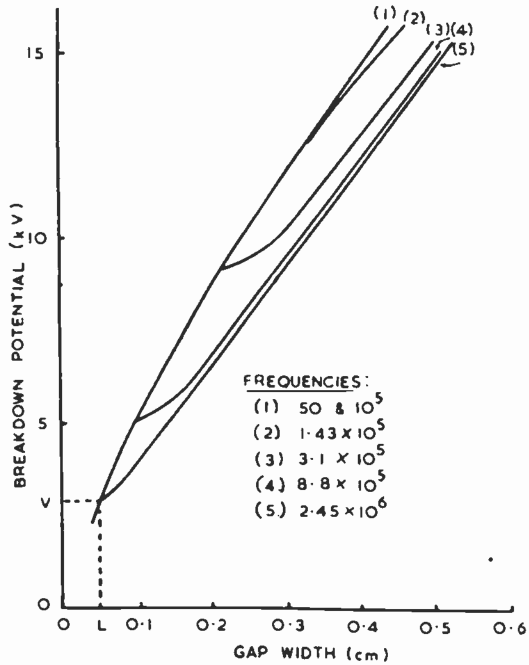


Fig. 3.—Sparking potential at various frequencies. Dry air, atmospheric pressure. (After Lassen).

1927 a paper was published[2] on breakdown in the range 60 c/s to 425 kc/s in air at atmospheric pressure, between 6·25 cm. spheres, for gaps up to 2·5 cm. A most useful review of work before 1933 was published by Darrow.[14] Later observations by Müller[5] and by Seward[6] show general agreement with the results obtained by Lassen[3] and by Reukema[2] where the conditions are sufficiently similar for direct comparison, and these authors all adopt explanations in terms of the effect of positive space charge. It should be noted that air at atmospheric pressure has almost alone been studied in this frequency range. Müller's observations extend to much higher frequencies, but in this upper range there is a fairly extensive later literature referring to work with electrode arrangements better adapted to the purpose.

Some work has been done in the frequency range up to 2 Mc/s, on breakdown in non-uniform fields, including the onset of corona between coaxial cylinders.[15] A fall in onset voltage and a change in form of the corona are observed at high frequencies, but any discussion of the mechanism at present would be unduly speculative.

3.0. Higher Frequencies, Possible Critical Conditions

Over the frequency ranges studied by the earlier workers, electrons were evidently removed to the electrodes in each cycle—electrons being enormously more mobile than positive ions. There is clearly an important range of frequencies in the neighbourhood of that at which electrons can just cross the gap in one half cycle. Before discussing experiments dealing with this range, however, it should be observed that other possible critical frequencies exist, notably collision frequencies in the gas and, possibly, frequencies of plasma oscillation. The interpretation of the frequency variation of breakdown voltage is based on a recognition, from other grounds, of the frequencies at which the various causes will operate.

3.1. *Non-removal of Electrons*

Although an electron in a gas does not possess a defined mobility, the greater part of its drift movement under the influence of a sinusoidal intensity takes place near the peak value of the field, and no considerable error is introduced by using for k (Eq. 2) the ratio of drift velocity to intensity corresponding to a steady field equal to the peak value.[16] The drift velocity is determined by the value of E/p, where E is the field intensity and p the gas pressure. Thus when the gap length d is just equal to the electron ambit L (Eq. 2) is conveniently put in the form

$$\frac{pd^2}{V\lambda} = \frac{kp}{(3 \times 10^{10}\pi)} \quad \ldots\ldots\ldots\ldots (3)$$

where λ is the free space wavelength for the applied oscillation and V is the peak value of the voltage applied to the gap of length d. The value of $\frac{\sqrt{2}\ kp}{(3 \times 10^{10}\pi)}$ calculated for hydrogen is $6{\cdot}0 \times 10^{-4}$: this is applicable where results are stated in terms of r.m.s. breakdown voltage (Table II).

The first investigation dealing explicitly with the non-removal of electrons from the field was made by Gill and Donaldson.[17] In these experiments the gas (air) was confined in a long tube which could be placed transverse to the large parallel plate electrodes (i.e., with the tube axis perpendicular to the axis of the electrodes) or alternatively it could be threaded through holes in the electrodes, to apply the field longitudinally. In the longitudinal arrangement electrons sweeping through a distance equal to the electrode spacing would not be trapped by the end walls of the vessel. The results showed clearly the effect of trapping the electrons on the wall and the electron velocities so calculated were shown to agree with previously known values.

In Fig. 4 the dotted curve relates to a wavelength of 86 metres: comparing this curve with the full line for the same wavelength, it is evident that the steps marked A . . A can represent the limiting circumstances, where electrons are just being trapped by the tube walls.

Extended experiments of a somewhat similar nature were reported by C. and H. Gutton[18] and more recently by Mlle. Chenot.[19] All of these workers studied, in addition, the nature of the sustained discharge which followed breakdown in the range of pressures they used. From

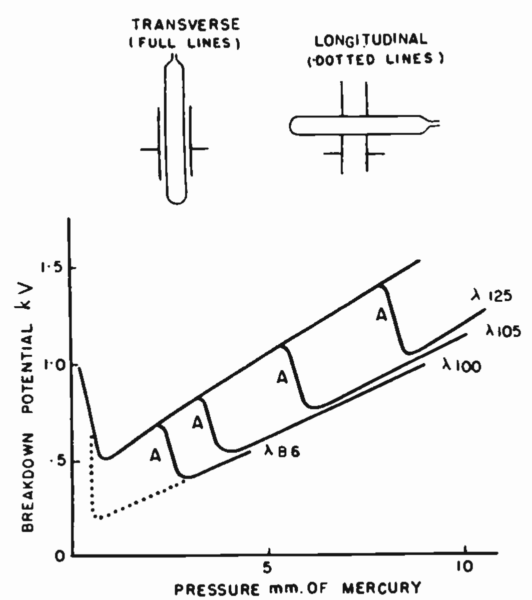


Fig. 4.—Breakdown voltage and pressure for two electrode arrangements. Wavelengths in metres. (After Gill and Donaldson.)

these observations they incline to the view that the abrupt variations of breakdown voltage are associated with resonance phenomena in the discharge tube. A considerable body of evidence has now accumulated, covering a wide range of frequencies, electrode systems, pressures and different gases, in all of which one potential jump can reasonably be interpreted in terms of the electron ambit. Discharge photographs provide clear evidence for resonance phenomena following breakdown, but no indication of conditions preceding breakdown. Some of Chenot's results are indicated in Fig. 5, which also shows the proportions of the discharge vessel: it will be noted that the electrodes are stuck on the ends of the tube. When narrower and longer tubes, or smaller electrodes, were used the steps in the curves were less abrupt. The criterion of Eq. 3 has been applied to a selection of these observations in Table II.

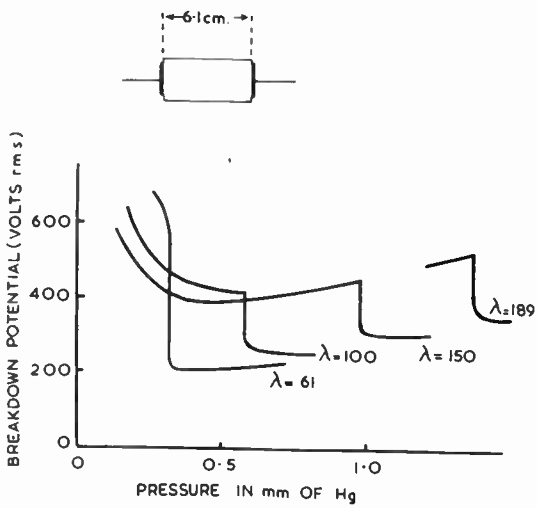


Fig. 5.—Breakdown voltage and pressure for hydrogen. Sketch shows proportions of tube and electrodes. Wavelength in metres. (After Chenot.)

TABLE II

Application of criterion of Eq. 3 to some of Chenot's results on the H.F. breakdown of hydrogen.

λ = wavelength of applied oscillation, in metres.

p = gas pressure in mm. of mercury.

V_e = r.m.s. value of breakdown voltage at which the sudden rise begins.

D = diameter of the electrodes.

λ	p	V_e	$\frac{pd^2}{V_e \lambda}$
D = 3·3 cm.			
232	1·31	500	$7{\cdot}2 \times 10^{-4}$
193	0·89	430	6·9
171	0·82	390	7·8
147	0·66	370	7·8
D = 4·0 cm.			
232	1·10	435	$7{\cdot}0 \times 10^{-4}$
192	0·84	370	7·5
148	0·60	300	8·6
D = 5·0 cm.			
232	1·01	380	$7{\cdot}4 \times 10^{-4}$
193	0·77	330	7·8
148	0·54	275	8·5

Length of tube, 8 cm.

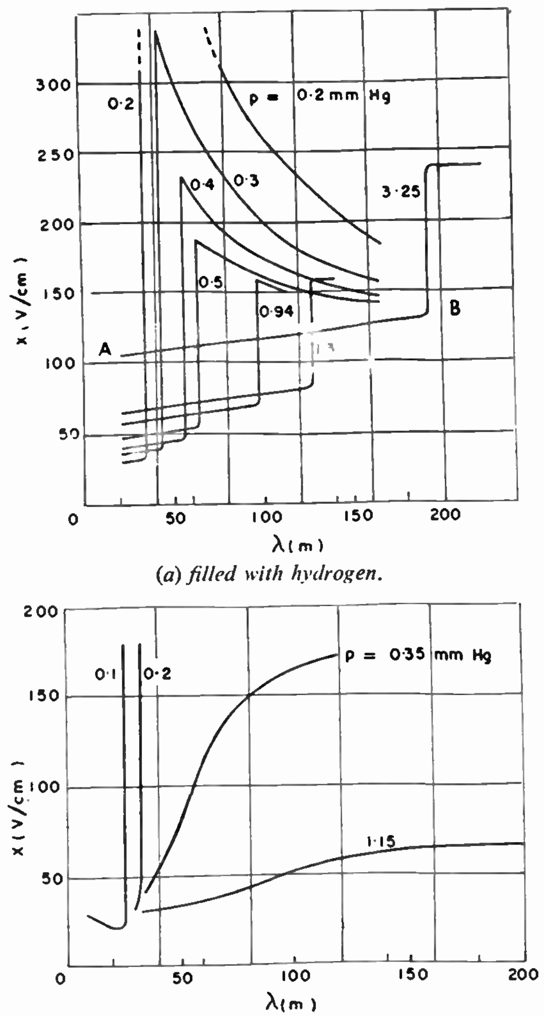
3.2. *Breakdown Mechanism*

Experiments of this type, of particular interest, have recently been recorded by Gill and von Engel[16] who establish firmly that the abrupt variation of potential occurs when electrons can just traverse the distance between the opposing walls of the containing vessel. Their results show clearly the different spread of electron velocities in various gases, and in addition afford interesting information on the maintenance mechanism which operates when electrons are absorbed by the end walls of the vessel.

Gill and von Engel's measurements are presented as curves relating the breakdown intensity and the wavelength of the applied oscillation: some of their results for hydrogen and for neon are shown in Fig. 6 (*a*) and (*b*) respectively. For the portion AB of a typical curve, a casual electron in the gas will oscillate without reaching the electrodes, its drift velocity, v, at any instant given by

$$v = kX_o \sin \omega t \quad \ldots\ldots\ldots\ldots (4)$$

where X_o is the peak intensity of the applied field and k a constant which is the ratio of the



(a) *filled with hydrogen.*

(b) *with neon.*

Fig. 6.—Field strength as a function of wavelength for a flat-ended cylindrical tube of 3·55 cm. internal length filled (a) with hydrogen (b) with neon. (Gill and von Engel.)

drift velocity of an electron to the field intensity for the condition X_0/p. If v exceeds a critical value, then the random velocity, which determines the ionising power of the electron, will attain the value requisite for ionization by collision : a cumulative and rapidly increasing growth of electron population will occur, leading to breakdown. The displacement amplitude associated with a given velocity is proportional to λ. The growing cloud of electrons therefore spreads more rapidly the greater λ and more losses to the ends occur, explaining the slow rise in breakdown stress as λ is increased. When the spread of velocities is greater, the cut-off becomes diffuse. Attention is drawn to the controlling effect of losses to the ends and also to the walls of the vessel used. Reference will later be made to this in connection with theories of breakdown at microwave frequencies.

At wavelengths above the cut-off, it is shown from the equation of motion for a particle of mass M and charge e in a field of intensity $X \cos \omega t$, namely :

$$M\left(\frac{d^2x}{dt^2}\right) = eX\cos\omega t - k'\left(\frac{dx}{dt}\right)$$

(where k' is a frictional constant) that

$$e^2X^2 = v^2(M^2\omega^2 + k'^2) \quad \ldots\ldots(5)$$

Here v is the maximum velocity of the particle. If the condition for breakdown be that a particular kind of particle shall attain a velocity v, then a linear relation between X^2 and ω^2 is to be expected ; this is indeed found for hydrogen. A further study of the curves enables the frictional constant k and hence the mobility of the particle to be deduced. By this means the particle is identified as the H_2^+ ion.

In the same range of experiments observations on the breakdown of neon are recorded. These show astonishingly low values for breakdown stress : 450 V cm.$^{-1}$ at atmospheric pressure.

Breakdown at extremely low pressures was studied by the same authors.[20] They showed that when the mean free path of an electron is long compared with the separation of the electrodes, conduction can be maintained by secondary electrons emitted from the ends of the vessel. The impinging electrons, carried by their momentum against the field, release secondary electrons in such phase as to be accelerated away from the ends. An electron in space would oscillate with its velocity in quadrature with the field, and so there is a range of conditions in which the action described is possible. When these conditions are not fulfilled the discharge stops completely.

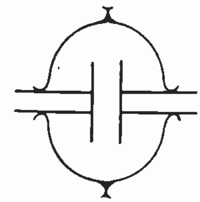
4.0. Transition Conditions in Open Gaps

In the experiments so far discussed, possible breakdown paths have been confined by the walls of the vessel containing the gas, except for the lower frequency experiments. It is well known, that for breakdown in steady fields at low pressures (i.e., below the minimum of the Paschen curve), when the breakdown voltage begins to rise with decreasing gap length, the discharge takes an alternative path unless deliberately confined. Thus the possibility arises that in the neighbourhood of the abrupt variations of potential, the discharge would choose a longer path if not prevented. Where positive ion transition times are concerned, the potential variations are so gentle that this question does not arise.

Experiments with open electrodes at high frequencies have been recorded by several workers,[21, 22, 23] all of whom have, in fact, observed regions in which the breakdown potential increases with a decrease in pd, where p is the gas pressure and d the length of the gap. Referring to Fig. 7 and Table III, based on J. Thomson's results for hydrogen, it will be seen that the steps marked A in curves 1, 2 and 3 satisfy the criterion already proposed in Eq. 3 and adequately satisfied by Chenot's observations. Thus these steps correspond with the transition condition for electrons just crossing the gap in one half cycle.

With the reduction in pd at the minima for curves 4 and 5, the assumption that electrons make a large number of collisions per half cycle begins to fail and it seems that the minima at the higher frequencies are to be considered in the light of the relation between collision frequency and the frequency of the applied oscillation (Section 1.1.) For the present, attention will be given to the electron ambit transition, which is also observed in the work of Githens and of Pim (A, Figs. 8 and 11). Among all of these observations, it seems that the only cases where breakdown has occurred along a path other than the shortest are those represented by the low pressure end of the Githens curves (B). Moreover, Githens finds that the curves only take this particular form for a system allowing plenty of space round the electrodes. The dotted lines show the general form of the curves for a confined discharge and the electrode systems are indicated in the sketches. There are theoretical grounds for suggesting that breakdown may take place either along the shortest track or by a path completely detached from the inner surfaces of the electrodes, but that it is unlikely to take place between the rounded edges of the electrodes.[46]

If enough space is available, there is clearly a



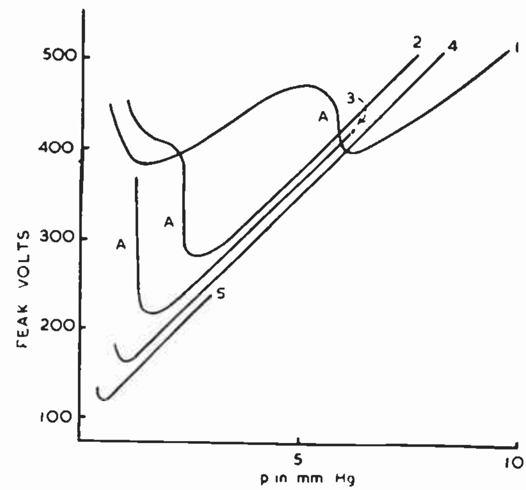


Fig. 7.—Field strength as a function of wave-length for a flat-ended cylindrical tube of 3·55 *cm. internal length, filled with pure neon at various pressures. (After J. Thomson.)*

TABLE III

Upper minima in breakdown curves for hydrogen (J. Thomson).

V_s, peak voltage for breakdown.

p, corresponding gas pressure.

n, frequency in Mc/s.

Curve No.	V_s	p (mm Hg)	n	$\frac{d^2p}{V_e\lambda}$ See Table II
1	372	5·92	1·80	9·0 × 10^{-4}
2	234	2·40	2·83	9·1 × 10^{-4}
3	185	1·32	3·73	8·4 × 10^{-4}
4	139	0·83	6·33	11·8 × 10^{-4}
5	107	0·36	15·6	16·5 × 10^{-4}

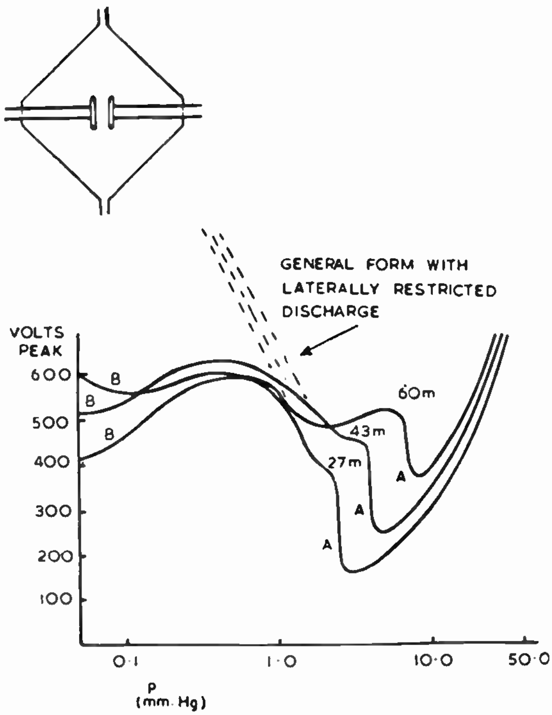


Fig. 8.—High-frequency breakdown in hydrogen (After S. Githens.) The upper sketch shows the electrode arrangement, gap 2·58 cm.

set of conditions in which the transition to the outer lines of force is accompanied by a large increase in track length (Fig. 9). Whether or not breakdown will occur in this outer region depends upon the height of the step in the curves relating to the confined discharge. If non-U.H.F. breakdown requires a very much greater stress than U.H.F. breakdown, then the discharge is likely to take a path remote from the centre of the system. Quantitative comparisons between the confined and unconfined discharges in this respect are likely to be misleading : Gill and von Engel have clearly shown the importance of the walls of the confining vessel in the mechanism of discharge when the electrons are trapped by the electrodes. Nevertheless, it may be remarked that the step is particularly large for hydrogen at a fraction of a millimetre pressure, the case in which Githens observes a detachment of the discharge path.

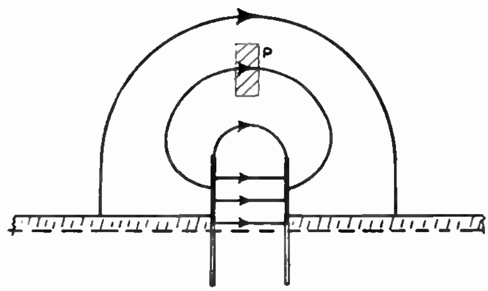


Fig. 9.—Sketch of half field of force, indicating at P the region where the path length shows rapid increase.

A point of particular interest emerges from Pim's measurements in air at atmospheric pressure : it appears that the breakdown stress for ultra high frequency conditions does not depend on the frequency. Its value, 28 kV/cm., agrees closely with that found by Cooper at microwave frequencies,[24, 25] and also corresponds closely enough with that observed for breakdown in steady fields for very long gaps.[26] No data are available for examining this last statement for gases other than air.

5.0. Breakdown at Microwave Frequencies

At microwave frequencies, at pressures of the order of one atmosphere, the amplitude of electron movement in air just breaking down is

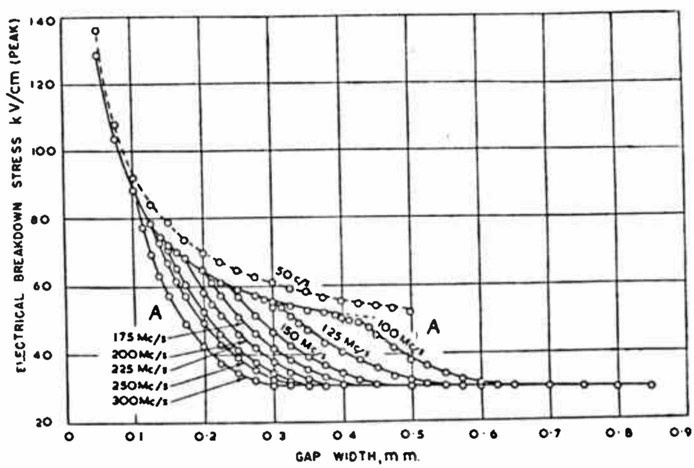


Fig. 10.—Variations of electrical breakdown stress with gap width at atmospheric pressure. (Pim.)

probably of the order $1 \cdot 5 \times 10^{-3}$ cm., so that the special condition is presented of electrons moving at high speeds over very limited distances. Breakdown at these frequencies was first investigated for technical purposes, because breakdown is one of the chief factors limiting the amount of power which can be transmitted by a given waveguide.

In outline, the method of experiment consists in measuring the rate of power flow through the section of guide or transmission line containing the gap, and measuring the standing wave ratio, for conditions just producing breakdown. The high voltages needed are produced by using pulsed magnetrons, and a knowledge of the pulse contour and duty cycle is needed before the voltage amplitude at the gap can be determined.

Measurements of this type were made by Cooper[24] at 10 cm. and at 3 cm. The outstanding result is that at atmospheric pressure the onset voltage (peak) for breakdown in dry air is 28 kV cm^{-1}—in close agreement with Pim's values for much lower frequencies. Somewhat similar experiments are also reported by Posin,[27] though these appear to be concerned more with the effect of variation of the various parameters than with establishing a precise value for the breakdown stress. Australian workers,[28, 29] similarly, have investigated breakdown in waveguides irradiated by short pulses: of these, the experiments of Labrum[29] on the breakdown of air and of helium are specially interesting.

Before going on to a discussion of experimental results, it may be noted that these divide into two main groups, dealing respectively with molecular gases at high pressures and with monatomic gases at low pressures. A very considerable body of theoretical work now exists, chiefly by American workers, applicable particularly to the onset of breakdown at relatively low pressures. This derives, in the first instance from the study, by Townsend and Gill[30] of high-frequency breakdown where diffusion is the chief mechanism restricting the growth of ionization.

5.1. *Diffusion Theory of Breakdown*

The probability that an electron will ionize by collision is zero, if its energy, in electron volts, is less than the ionization potential; above that value the ionization probability increases rapidly, eventually reaching a maximum and decreasing again, but for the range of electron energies concerned in breakdown theory it is usually sufficient to assume that above ionization voltage there is a rapid and linear increase of ionizing efficiency.

In the diffusion theory of breakdown, it is assumed that the other processes whereby an electron can be removed, namely, recombination and attachment, are negligible in their effect and that only diffusion to the walls of the vessel determines the rate of decay of ionization. This rate is calculable for electrodes of simple geometrical form.[41] The limits of application of this theory have recently been discussed by Brown and MacDonald,[31] who state that the field of application of this theory is limited by the conditions that

(i) the gap length must be small compared with the wave length of the applied oscillations;

(ii) the mean free path of the electron must not be comparable with the dimensions of the vessel;

(iii) the oscillation amplitude of the electron must be less than the electrode separation.

These authors find that the published data on hydrogen, where they fall within the prescribed conditions, form a self-consistent set of results covering a wavelength range from 10 cm. to 17,000 cm., and a range of about seven to one in the dimensions of the vessels employed. In a second paper[32] the same authors carry out a numerical calculation of breakdown voltages and obtain close agreement with observed values in hydrogen.

Holstein[33] considers that, when certain conditions are satisfied, the energy distribution of electrons subject to a high-frequency field is much the same as that of electrons in a steady field equal in magnitude to the r.m.s. value of the high-frequency field. Also Townsend and Gill[30] show that the mean energy should be that in such an equivalent field. In such a case it is to be expected that the growth of ionization may be computed on the assumption that Townsend's first coefficient α has the value appropriate to the r.m.s. value of the high-frequency field. Holstein's restricting condition is that the applied frequency must be greater than the frequency of inelastic collisions and less than the frequency of elastic collisions.

Krasik, D'Alpert and McCoubrey[34] have made experiments on the breakdown of argon at microwave frequencies, using sustained oscillations, with results in good accord with Holstein's theory. In experiments with the rare gases, particular care is necessary if uncertainties are not to be introduced by the transfer of energy through the action of metastable states. If an impurity is present for which the ionization potential is less than the excitation potential corresponding to a metastable state of the parent gas, then an atom of the parent gas in a metastable excited state can ionize an atom of the impurity by collision. Owing to the long lives of metastable states this is an efficient ionizing process. Thus an electron which, in the pure gas, would have made an inelastic, non-ionizing collision, in the presence of a suitable impurity would release an ion after some delay. This is sometimes known as the Penning effect.[35] Krasik, D'Alpert and McCoubrey took precautions to achieve the purity necessary to avoid this effect.

On the other hand, MacDonald and Brown[36] have made experiments deliberately employing the Penning effect. Their medium was helium with a mixture of mercury vapour. In this mixture, each inelastic collision in which the energy transfer was in excess of the excitation energy for the appropriate metastable state of helium, would result in producing a mercury ion by the eventual collision of the excited metastable helium atom with a mercury atom. The progress of ionization is then calculated from the energy distribution of the electrons, computing the fraction present whose energy exceeds that corresponding to the metastable state in question. Once again, diffusion is the operative removal mechanism. The results were in satisfactory agreement with theory.

Notwithstanding some divergencies among the methods of interpreting the growth of ionization, the foregoing studies have in common the removal of electrons by diffusion processes. An electron in the discharge vessel can be considered to have a mean life, which is the average time taken for it to achieve a Brownian motion drift to the electrodes, or out of the intense field region. If during this mean life it produces more than one new electron by collision, the ionisation will grow and eventually breakdown will occur. It follows that the time taken for an appreciable multiplication of the ionization should be long compared with the mean life of an electron, unless the applied intensity is much in excess of the minimum value for breakdown. In this connection the experiments of Labrum are of special interest.

These experiments are of the same general nature as those of Cooper already referred to, namely, determinations of breakdown voltages in wave guides energized by pulses of microwave radiation. Air and neon at low pressures are examined, for various pulse lengths and for various values of the pulse repetition frequency. During the pulse an exponential increase of ionization with time is assumed, so that if n_0 electrons are present at the beginning of the pulse the number, n, present at the end of a time t can be written

$$n = n_0 \varepsilon^{(G-L)t} \qquad (6)$$

where G = number of ion-pairs produced by one electron in unit time

and L = fraction of electrons present which disappear in unit time.

If the requirement for breakdown be the presence of at least n_D electrons in the gap, then $(G-L)$ must exceed $\frac{1}{T}\,\mathrm{Log}_\varepsilon \frac{n_D}{n_0}$ for breakdown, where T is the pulse duration. The logarithmic form indicates that, provided n_D is large, no great precision is needed in its specification. A likely value for n_D is about 10^{13}. G is clearly of the same nature as Townsend's α and can be expected to vary in the same way with the applied intensity. In a non-attaching gas, where diffusion is the chief agent in removing electrons, L is small and it is assumed that no removal of electrons occurs during the first few microseconds : in fact, there is not enough time for an electron to drift an appreciable distance. Thus, the observed breakdown potential is determined by the pulse duration : the breakdown stress is that which gives a value of G equal to $\frac{1}{T}\,\mathrm{Log}_\varepsilon \frac{n_D}{n_0}$. Fig. 11 (*a*) shows the variation of breakdown stress in neon with pressure for two pulse lengths and for two values of the pulse repetition frequency. The effect of pulse repetition frequency is explained on the basis of ionization remaining in the gap from pulse to pulse. The original paper offers a quantitative explanation for the results on neon, but not for those on air (Fig. 11 (*b*). It may well be suggested that the attachment of electrons to oxygen atoms in air is a sufficient explanation of the differences between air and neon, but until experimental data are forthcoming to show that there are material differences in the effect of pulse length as between attaching and non-attaching molecular gases, any such suggestion must be treated with reserve. It will also be noticed that if G shows an abrupt increase from zero at a certain stress then breakdown can be expected just above this stress, whereas if the increase of G from zero is gentle a greater dependence on pulse duration is to be expected.

In explanation of the minima of the curves, attention is drawn to the expression of Gill and Townsend[37] for the average energy gained, V_e in electron volts, per mean free path, by an electron in a field of intensity X and angular frequency ω, namely,

$$V_e = \frac{e}{2m} \frac{1}{\nu^2 + \omega^2} X_o^2 \quad \ldots\ldots\ldots\ldots (7)$$

where ν represents the collision frequency for an electron with gas molecules. It is next assumed that the electron accumulates this energy at the rate V_e per collision until it possesses more than V_i electron volts, where V_i is the ionization potential of the gas. Thereafter it loses all of its energy in one ionising collision and the process starts again. This definite picture of the ionising mechanism leads to an expression for G and thence, for the breakdown field X_o, to the inequality

$$X_o^2 > \frac{4V_i}{\frac{e}{m}} \frac{\omega^2 + \frac{1}{3}\nu^2}{\nu} \cdot \frac{1}{T} \operatorname{Log} \varepsilon \frac{n_D}{n_o} \ldots (8)$$

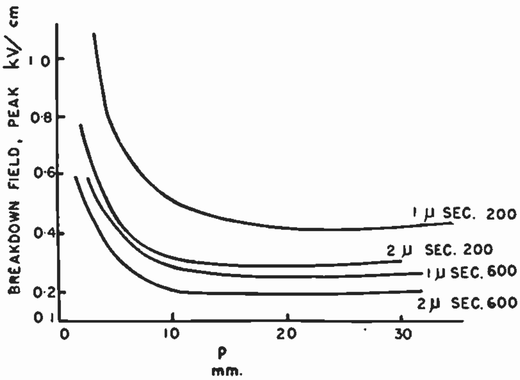
This satisfactorily accounts for the minimum in the breakdown curve.

The special conditions which arise when the applied frequency is of the same order as the collision frequency have also been considered by Margenau[38] who introduces an effective field for energy transfer, X_e, related to the r.m.s. field by the expression

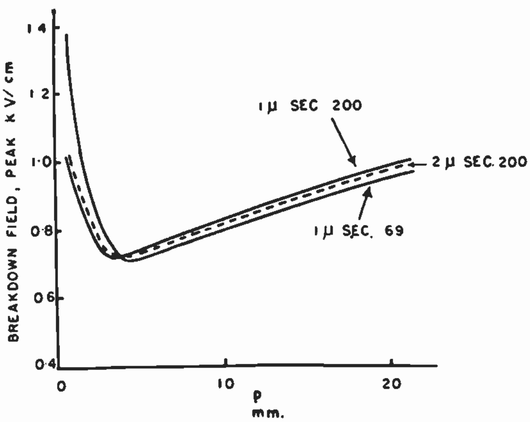
$$X_e^2 = X^2 \frac{\nu^2}{\nu^2 + \omega^2} \quad \ldots\ldots\ldots\ldots (9)$$

X_e is the steady field which would produce the same energy transfer to the gas as the applied high-frequency field X.

This relation expresses the physical condition that, when collisions are rare enough, the electron can oscillate with its velocity in quadrature with the field, thereby absorbing no energy for an appreciable part of its existence. Full transfer of energy from the field to the gas can only take place if several collisions occur per cycle. When the number of collisions per cycle is large, then in molecular gases energy is likely to be dissipated in inelastic, non-ionising collisions, so that the random velocity of the electron fails to attain ionising magnitude unless the field is much increased. Molecular gases admit of the transfer of small amounts of energy, e.g. to rotational movement of the molecule.[39]



(*a*) *Neon* ; $\lambda = 3{\cdot}2$ *cm.*



(*b*) *Air* ; $\lambda = 3{\cdot}2$ *cm.*

Fig. 11.—Labrum's observations on the breakdown of (a) neon, and (b) air. The figures on the curves indicate pulse duration, and pulse repetition frequency (*sec.*$^{-1}$).

In monatomic gases, inelastic collisions are only possible for energies in excess of the atomic excitation potential values : the transfer of small amounts of energy, of the order of two or three electron volts, does not occur as it may readily do in polyatomic gases. Thus, in monatomic gases the energy of an electron can build up over a series of elastic collisions in the manner envisaged by Labrum, producing ions directly or storing energy usefully in metastable states. At sufficiently low stress, even the small energy loss occurring in elastic collisions will suffice to balance the energy gain from the field and breakdown will not occur ; it is characteristic of the monatomic gases that in these circumstances the electrons constitute a much "hotter" population than the atoms of the gas.

A theory of high-frequency breakdown has been proposed by Hale,[40] based on the assumption that the electron must reach ionising energy at the end of one mean free path. This is in decided contrast with the views discussed above, except for the region of frequency and gas pressure in which an electron makes only one or two collisions per half cycle. Hale calculated the values of breakdown fields in argon and in xenon as functions of the applied frequency and of gas pressure, and obtained good agreement with experimental results in the range of low pressures for frequencies exceeding 10 Mc/s.

5.2 *Discharge in Resonators at Higher Pressures*

One of the striking features of gas breakdown in steady fields has been the wide difference in interpretation of discharges according to whether these are on the low-pressure side or the high-pressure side of the minimum of the Paschen curve (relating breakdown voltage with *pd* where *p* is the gas pressure and *d* the gap length). On the low-pressure side, Townsend's interpretation is based on the question whether a small ion current in the gas will decay, or grow, at the given stress, i.e. the breakdown is envisaged as the failure of a possible equilibrium, for which the current once started would remain constant. On the high-pressure side, experiments on the rate of breakdown indicate that the onset of conduction is too rapid to be explained in terms of quasi-equilibrium processes : Meek's streamer theory has had considerable success in explaining these phenomena.[43]

Microwave experiments at high values of *pd* present considerable difficulty in the build-up and control of the high voltages, but preliminary accounts have been published dealing with the initial stages of sparks in resonators at atmospheric pressure.[44,45]

Quite apart from the more formal observations the appearance of the discharge in a relatively long gap presents points of interest. It has already been remarked (Section 1.0) that it may not be necessary for a conducting filament to cross the whole of the gap in order to effect the discharge of a high-frequency resonant system ; also the theoretical work has been concerned rather with the growth of the electron population than with the probable form of the discharge. On the whole, the theories propounded would suggest a relatively slow spread of the discharge by processes of a diffusive type.

In the experiments the resonator was of the nosed-in cavity type (Fig. 12), which produces a reasonably uniform intensity over most of the region between the re-entrant surfaces and which can be tuned over a limited frequency range. The resonant qualities of such a cavity are good enough to allow a high voltage to build up between the electrodes when a pulsed magnetron is used as the source of power. Visual and photographic observations on the discharge produced by single pulses of one microsecond duration showed that this usually took the form of a bright spot on one of the electrodes, with a luminous tail extending into the gap (Fig. 13). It was also observed that the bright spot emits the line spectrum of the electrode material and the tail, in air, a nitrogen band spectrum. A radium capsule was used to provide casual electrons.

In later experiments an auxiliary spark was employed to irradiate the gas in the resonator. The resulting photoelectrons caused the dis-

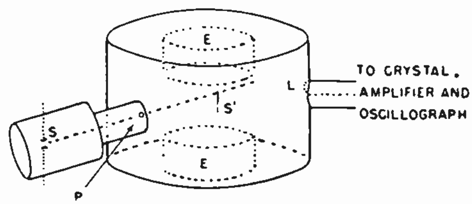


Fig. 12.—Sketch of resonator showing electrodes (E), auxiliary spark gap (S), and pinhole (P), pick-up loop (L), and a mid-gap streamer (S). Arrangements for energizing resonator are not shown. The spark gap fires about 0·3 μ sec. before the resonator is energized.

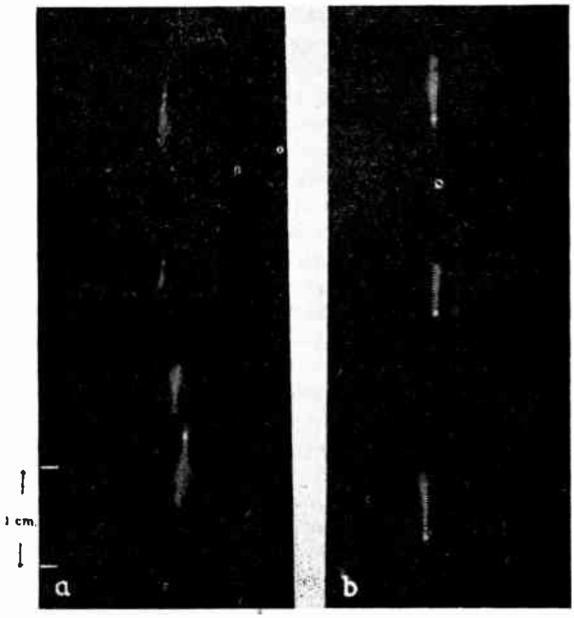


Fig. 13.—Photographs of discharges in a resonator, (a) without irradiation, (b) with one electrode irradiated with ultra-violet light. The film was moved between successive discharges. Note that in (b) the discharge always starts from the same electrode and that subsidiary streamers are present. Electrode separation 1·44 cm.

charge to begin in mid-gap, on the track of the irradiating beam, so that electrode effects were avoided. The mid-gap streamers so produced developed at a high speed and for moderate over-voltages could almost cross the gap (1·4 cm.) in one microsecond. Oscillographic observations on the breakdown in these conditions were also made, recording the envelope of the pulse in the resonator. The limited results available showed that the breakdown takes place remarkably quickly: in hydrogen the field probably collapsed in less than the response time of the instruments, about 1/25 microsecond, with no evidence of a voltage overshoot when discharge took place on the initial slope of the pulse.

So far the information presented is primarily an indication of a promising line of approach in the study of breakdown mechanisms, but, as for steady fields, the abruptness of the breakdown imposes a restriction on speculation, and suggests that, in the high-pressure range, breakdown is not likely to be interpreted on a quasi-equilibrium basis.

6.0 Conclusion

The main features distinguishing ultra high-frequency breakdown from breakdown in steady fields are susceptible of explanation in terms of reasonable hypotheses, based on the non-removal of ions and electrons from the test gap when the frequency is high enough; these hypotheses have been tested by comparison with data on mobilities obtained by very different methods. At microwave frequencies, a simple criterion for breakdown can be stated—that the mean life of an electron in the test gap must be long enough to permit of the generation of a new electron by collision ionization. One view, expressed in the diffusion theory of breakdown, interprets the mean life of an electron as the time taken for it to drift out of the applied field and many results have been interpreted on this basis. But numerous physical processes may contribute to breakdown and the central problem is to determine how, and to what extent, they do so.

For example, the difference in behaviour between neon and air subjected to pulses of microwave radiation might be attributable to electron attachment in oxygen, if that does occur during the application of the field. But it might also arise from the ability of polyatomic molecules to absorb small amounts of energy by inelastic collisions. As in work on spark breakdown in steady fields, the abruptness of the discharge at atmospheric pressure is difficult to explain and imposes a valuable limitation on theoretical speculations.

A promising field of investigation lies in comparative studies of the breakdown of various pure gases over the frequency range from the abrupt transition (corresponding to the non-removal of electrons) up to microwave frequencies. Experiments on the time factors accompanying breakdown are likely to be as illuminating as actual stress measurements. Oxygen and nitrogen, in particular, afford interesting possibilities, since the mean life of an electron in oxygen, at least in the absence of a field, is so much shorter than in nitrogen.

There is always the likelihood that observable breakdown is preceded by events not observable in themselves, particularly the gradual growth from a few casual electrons to a population large enough to effect a discharge. Unless this growth is extraordinarily rapid, it will give rise to a variation of breakdown potential with pulse length, for short pulses of high-frequency energy, and further work in this field would be of great interest.

8.0 Acknowledgments

The study of this literature has been made in connection with a programme of work supported by the British Electrical and Allied Industries Research Association. Grateful acknowledgment is made of this support and of permission to publish this paper.

9.0 References

1. Peek. "Dielectric Phenomena in High Voltage Engineering" (McGraw-Hill. 3rd Ed. 1929), p. 140.
2. Reukema. *J.Am.I.E.E.*, 1937. Sept. p. 38.
2a. Hulburt. *Phys. Rev.*, **20**, 1922, p. 127.
3. Lassen. *Arch. f. Elek.*, **25**, 1931, p. 322.
4. Kampschulte. *Arch. f. Elek.*, **24**, 1930, p. 525.
5. Müller. *Arch. f. Elek.*, **28**, 1934, p. 341.
6. Seward. *J.I.E.E.*, **84**, 1939, p. 288.
7. Clark and Ryan. *Proc. Am. I.E.E.*, **33**, 1914, II, p. 937.
7a. Jacottet. *E.T.Z.*, **92**, 1939, p. 60.
8. Luft. *Arch. f. Elek.*, **31**, 1937, p. 93.
9. Fucks. *Z. f. Phys.*, **103**, 1936, p. 709.
10. Goebeler. *Arch. f. Elek.*, **14**, 1925, p. 491.
11. Cobine. "Gaseous Conductors" (McGraw-Hill, 1941), p. 41.
12. Algermissen. *Ann. der Phys.*, **19**, 1906, p. 1,007.
13. Leontiewa. *Phys. Zeits.*, **23**, 1922, p. 33.
14. Darrow. *Bell Syst. Tech. J.*, **11**, 1932, p. 576, and **12**, 1933, p. 91.
15. Miseré. *Arch. f. Elek.*, **28**, 1934, p. 411.
16. Gill and von Engel. *Proc. Roy. Soc.* A. **197**, 1949, p. 112.
17. Gill and Donaldson. *Phil. Mag.*, **12**, 1931, p. 719.
18. C. and H. Gutton. *Comptes Rendus.* **186**, 1928, p. 303.
18a. H. Gutton. *Ann. de Phys.*, **13**, 1930, p. 62.
19. Chenot. 1re Thèse, Paris, 1947.
20. Gill and von Engel. *Proc. Roy. Soc.* A. **192**, 1948, p. 446.
21. J. Thomson. *Phil. Mag.*, **23**, 1937, p. 1.
22. Githens. *Phys. Rev.*, **57**, 1940, p. 822.
23. Pim. *Nature*, **161**, 1948, p. 683. and *Proc.I.E.E.* III, **96**, 1949, p. 117.
24. Cooper. *J.I.E.E.*, **94**, III, 1947, p. 315.
25. Cooper and Prowse. *J.I.E.E.*, **95**, III, 1948, p. 342.
26. Bowdler. *J.I.E.E.*, **95**, III, 1948, p. 344.
27. Posin. *Phys. Rev.*, **73**, 1948, p. 496.
28. Freeman. C.S.I.R. Australia. RPR **50**, Nov. 1946.
29. Labrum. C.S.I.R. Australia. RPR. **85**, Dec. 1947.
30. Townsend and Gill. *Phil. Mag.*, **26**, 1938, p. 290.
31. Brown and McDonald. *Phys. Rev.*, **76**, 1949, p. 1,629.
32. McDonald and Brown. *Phys. Rev.*, **76**, 1949, p. 1,634.
33. Holstein. *Phys. Rev.*, **70**, 1946, p. 367.
34. Krasik, D'Alpert and McCoubrey. *Phys. Rev.*, **76**, 1949, p. 722.
35. Penning. *Naturwiss.* **15**, 1927, p. 818.
36. McDonald and Brown. *Phys. Rev.*, **75**, 1949, p. 411.
37. Townsend and Gill. *Loc.cit.*
38. Margenau. *Phys. Rev.*, **69**, 1946, p. 508.
39. See, e.g. Loeb, "Atomic Structure" (Chapman and Hall, 1938), p. 307.
40. Hale. *Phys. Rev.*, **73**, 1948, p. 1,046.
41. Herlin and Brown. *Phys. Rev.*, **74**, 1948, p. 291.
42. McDonald and Brown. *Phys. Rev.*, **75**, 1949, p. 411.
43. Loeb and Meek. "Mechanism of the Electric Spark" (Stanford Univ. Press, 1940).
44. Prowse and Cooper. *Nature*, **161**, 1948, p. 310.
45. Prowse and Jasinski. *Nature*, **163**, 1949, p. 103
46. Prowse. *Proc.I.E.E.*, **97**, III, 1950, p. 253

A TELEVISION SYNCHRONIZING-SIGNAL GENERATOR*

by

J. E. Benson,† B.Sc., M.E., H. J. Oyston,‡ B.Sc. (Eng.) and B. R. Johnson‡

SUMMARY

A brief description is given of the British and American television synchronizing-signal waveforms. The essential features of these waveforms and the technical requirements of the generating equipment are indicated. An outline is then given of a selection of typical circuit techniques employed in synchronizing generators. This is followed by a description of an experimental 525-line 25-picture synchronizing-signal generator unit employing equalizing pulses and suitable for negative modulation. Apart from a comparison of the two systems, the paper is based on the American system, and the terminology used is American.

1.0 Introduction

The synchronizing-signal generator has been aptly called the heart of the television transmitter. Its output waveform may even more aptly be regarded as the *backbone* of the television signal, providing, in effect, the framework into which the picture modulation fits, the whole complex wave being then modulated on to the R.F. carrier.

The main purpose of the synchronizing-signal generator is to provide a series of accurately timed pulses to synchronize the horizontally and vertically deflecting sawtooth wave generators both in the camera and the receiver, together with a series of blanking pulses for deleting the flyback stroke of the cathode-ray beam in each case.

Before discussing details of the synchronizing-signal waveform and of the equipment necessary to produce it, the essential features of the signal in relation to the television picture are outlined, and some of the basic principles and typical circuit techniques employed in the process of generating the various pulses and of combining them to form the complete synchronizing-signal waveform are described.

2.0 The Television Synchronizing Signal

In the English system, each set of lines is called a "frame," there being two frames per complete picture of 405 lines, and 50 frames or 25 complete pictures per second, whereas in the American system, each set of lines is called a "field." The complete picture comprising two fields is called a "frame" and contains 525 lines. There are 60 fields and 30 frames or pictures per second.

In the present paper, in order to avoid confusion, the unambiguous terms "field" and "picture" will be used, there being two fields per picture in interlaced scanning.

2.1. *The B.B.C. Synchronizing Signal*

A diagram of the synchronizing-signal wave used in the Marconi-E.M.I. system of the British Broadcasting Corporation is shown in Fig. 1. The system of positive modulation is employed whereby white corresponds to maximum carrier amplitude and black to 30 per cent. of this amplitude. The synchronizing pulses occupy the ultra-black region between 30 per cent. and zero carrier level.

The beginning of each field is marked by a series of eight vertical (or field) synchronizing pulses which recur at half-line intervals within the series. Further, there is an interval of exactly 202½ lines between the beginning of the two series of vertical synchronizing pulses. This ensures that the successive fields occur at intervals of an odd number of half-lines apart so that the two sets of lines are correctly interlaced.

The scanning beam is blanked out for a period of at least 10 lines from the beginning of each vertical synchronizing pulse to allow time for the vertical flyback or retrace stroke to take place. The horizontal (or line) flyback occurs during the period of the horizontal pedestals which occupy a short period extending from slightly before to

* Reprinted from the *Proc.I.R.E. (Aust.)*, May 1949.
† Development Engineer, Research Laboratories, A.W.A., Ltd., Ashfield, N.S.W.
‡ Assistant Engineer, A.W.A. Research Laboratories, Ashfield, N.S.W.
U.D.C. No. 621.397.335:621.396.61.

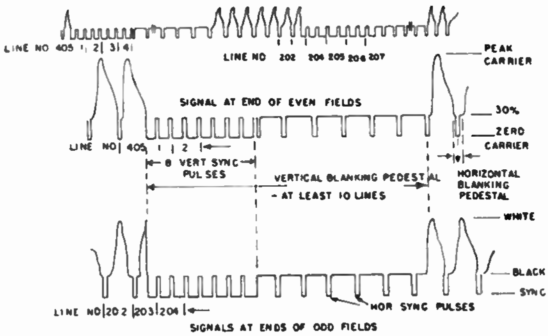


Fig. 1.—Diagram of the B.B.C. television waveform.

slightly after the period of the horizontal synchronizing pulses. These periods on either side of the synchronizing pulses are called the front and back porches. They serve as guard periods to prevent the picture modulation from interfering with the synchronizing pulses.

2.2. *Synchronizing-Pulse Separation*

Simple methods of separating the horizontal and vertical synchronizing signals from the composite wave are shown in Fig. 2.

A differentiating circuit comprising a series capacitance, C, and shunt resistance, R, is employed to select the horizontal synchronizing pulses. When CR is small, the voltage across R is proportional to the rate of change of the input voltage and thus takes the form of a series of sharp pulses or pips corresponding to each abrupt change in the amplitude of the synchronizing waveform. There are two positive pips

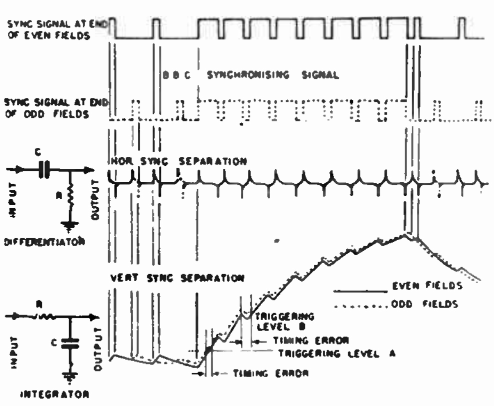


Fig. 2.—Typical R-C sync. separation circuits.

per line during the vertical synchronizing period and one per line for the remainder of the series. It will be noted that a regular continuity of spacing is maintained between horizontal synchronizing pulses during the entire series so that the horizontal scanning oscillator remains in synchronism uninterrupted by the occurrence of the vertical synchronizing pulses. The natural frequency of the horizontal scanning oscillator is such that the occurrence of synchronizing pips of twice line frequency does not affect its operation, thus permitting it to remain synchronized to the line frequency.

The vertical synchronizing pulses are separated by means of an integrating circuit comprising a series resistance, R, and a shunt capacitance, C. The output voltage across C undergoes a

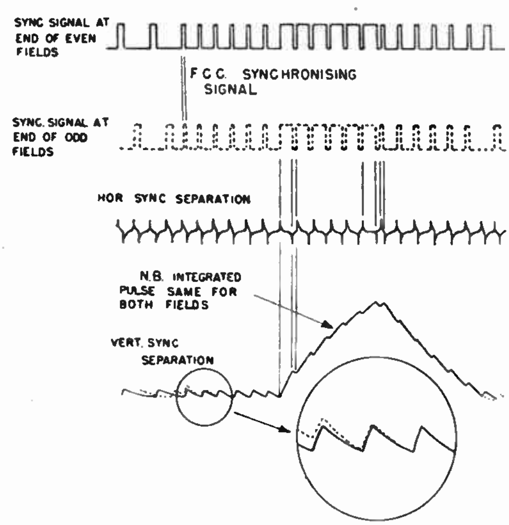


Fig. 3.—Diagram showing the effect of equalizing pulses on vertical sync. separation using an integrator circuit.

substantial rise during the period of the vertical synchronizing pulse but not during the periods of the horizontal synchronizing pulses.

It will be noted that the period between the beginning of the vertical synchronizing pulse and the preceding horizontal synchronizing pulse is different for the two successive fields. This means that the voltage across the shunt capacitor C at the beginning of a vertical synchronizing pulse differs from one field to the other due to the different residual charges on C in each case. Consequently the time between the

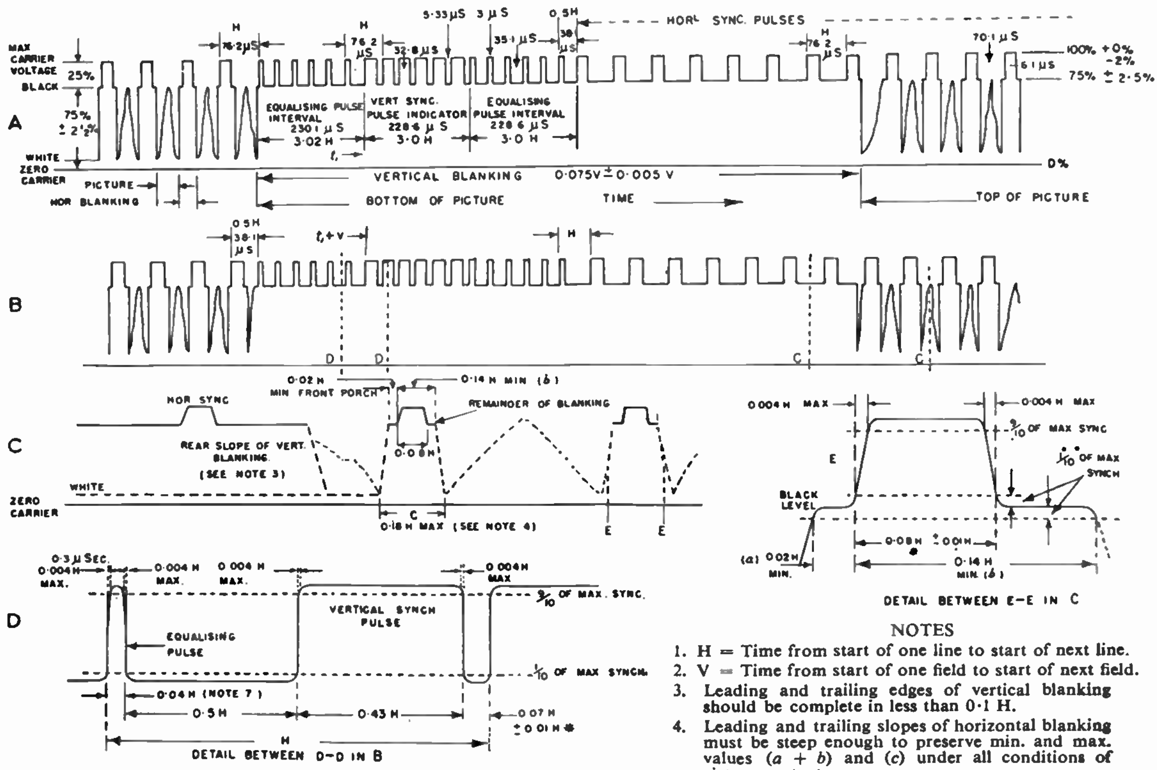


Fig. 4.—Diagram of the modified F.C.C. television waveform used in the synchronizing-signal generator.

Times in μ Secs. are for V = 0·02 Sec. (i.e. Picture frequency = 25 per sec.) 2 interlaced fields and 525 lines per picture.

NOTES

1. H = Time from start of one line to start of next line.
2. V = Time from start of one field to start of next field.
3. Leading and trailing edges of vertical blanking should be complete in less than 0·1 H.
4. Leading and trailing slopes of horizontal blanking must be steep enough to preserve min. and max. values ($a + b$) and (c) under all conditions of picture content.
5. Dimensions marked with an asterisk* indicate that tolerances given are permitted only for long-time va riations, and not for successive cycles.
6. For receiver design, vertical retrace shall be complete in 0·07 V.
7. Equalising pulse area shall be between 0·45 and 0·5 of the area of a horizontal synch. pulse.
8. Horizontal dimensions not to scale in A, B, and C.

beginning of the vertical synchronizing pulse and the instant of firing of the vertical sweep oscillator will be different, resulting in a slight error in alignment of the two sets of scanning lines. The error is small, however, provided the triggering of the vertical sweep oscillator occurs during the period of corresponding vertical synchronizing pulses in each alternate field.

In the American system, the defect is eliminated by the precaution of providing a series of six short pulses at half-line intervals before and after the vertical synchronizing pulses. The effect of these "equalizing" pulses is to equalize the conditions preceding each vertical synchronizing pulse, thus rendering the intregrated outputs from the vertical sync. separator identical for the two successive fields as shown in Fig. 3.

2.3. *The F.C.C. Synchronizing Signal*

The synchronizing waveform specified by the American Federal Communications Commission is similar to that shown in Fig. 4. Reference should be made to the text of the F.C.C. "Standards of Good Engineering Practice Concerning Television Broadcast Stations"[1] (See also R.M.A. Standards[2]). Negative modulation is employed in which increasing luminous intensity corresponds to decreasing carrier amplitude. The *white* level corresponds to almost zero carrier amplitude and the *black* level to 75 per cent. of the maximum carrier amplitude, while the synchronizing pulses extend on into the ultra-black region to full carrier amplitude.

There are two significant advantages of

negative modulation worthy of note. One is that there is a possible increase in power over an otherwise similar positive modulation system of approximately 30 per cent.[3] The other is that noise interference peaks appear as black rather than white spots on the screen and are consequently less obtrusive.

It will be seen from Fig. 4 that each of the two vertical synchronizing pulse intervals is preceded and followed by equal intervals of 3 lines duration containing 6 equalizing pulses. The beginning of the first series of equalizing pulses corresponds to the bottom of the picture. The retrace of the scanning spot back to the top of the picture for the start of the next field occurs during the period of the blanking interval which occupies a period of approximately 20 lines duration, i.e. 11 lines beyond the last equalizing pulse.

2.4. *Basic Essentials of a Synchronizing-Signal Generator*

The essential elements in a synchronizing-signal generator are indicated in the simplified functional diagram of Fig. 5.

The basic unit of the generator is the frequency-control unit which comprises a master oscillator, divider chain, and an A.F.C. discriminator. The purpose of this unit is to establish an integral relationship between twice the line frequency and the field frequency and to provide means of locking the latter to the frequency of the a.c. mains supply.

The reason for locking the field frequency to the a.c. mains is that interference effects in the form of intensity modulation or non-linear distortion at mains frequency due to inadequate filtering or shielding are far less noticeable when stationary than when moving across the picture. If great care is taken to eliminate such interference both at the transmitter and receiver, the field frequency need not be synchronized to that of the a.c. mains and in fact may differ arbitrarily from it. In such cases it is convenient to employ independent crystal control of the master frequency generator.[4]

Frequency division instead of multiplication is employed to relate the half-line and field frequencies because it is the only method which will establish an exact instantaneous integral relationship between the two frequencies. In the

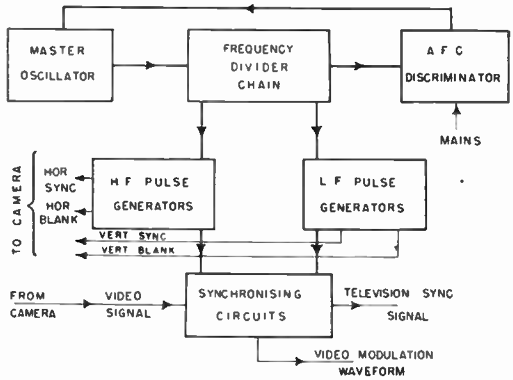


Fig. 5.—Simplified block schematic showing the essentials of a synchronizing-signal generator.

case of frequency multiplication, it is only the average output frequency that is integrally related to the input, the instantaneous or cycle to-cycle frequency being dependent upon the adjustment of the tuned circuit. This point has been discussed by Bedford and Smith.[5]

From the divider chain are derived the low- and high-frequency signals required for driving the various pulse generators which supply the basic pulse waves required to synthesize the final synchronizing signal, as well as the horizontal and vertical synchronizing and blanking signals for the camera tube. The final section of the generator contains the synthesizing or mixing circuits in which these component pulses are added and clipped to form the synchronizing-signal wave. Finally the blanking and video signals are added to form the video modulation waveform.

3.0 Pulse Circuit Techniques

3.1. *Mains Locking Circuit*

The principle of operation of a typical mains locking circuit is shown in Fig. 6. The circuit has been described in some detail by Bedford and Smith.[5]

The field-frequency output from the divider chain, having the form of short pulses (a) is fed into a phase discriminator along with a sinusoidal wave of mains frequency (b). The wave (a) operates as a series of gating-pulses which sample a portion of the mains wave once per cycle and charge a capacitor to the voltage of the

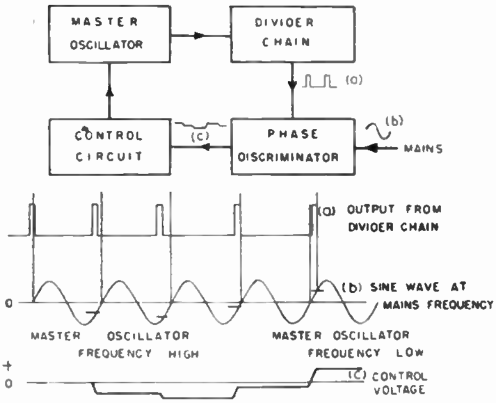


Fig. 6.—Diagram showing the principle of a typical mains locking circuit.

sample. The output voltage taken across this capacitor is fed as a control bias to correct the frequency of the master oscillator or multivibrator driving the chain. The circuit reaches a state of stable equilibrium when the two frequencies are equal. Suppose now, that the relative phases are such that when this condition is reached the centre of the gating pulse coincides with the zero-axis point of the sine wave so that the net charge added to the capacitor each cycle is zero. If, for any reason, the relative frequencies change, the gating pulse will sample either a negative or positive portion of the sine wave and add the corresponding charge to the capacitor. The change in direct voltage across this capacitor operates to change the frequency of the master oscillator until equilibrium is restored and synchronism of the divider output with the main frequency maintained.

3.2. *Divider Circuits*

The divider circuits most commonly employed for television work are either the locked oscillator or pulse counter type. The more conservative regenerative type used extensively for frequency standards do not appear to have been used in this application.

Applegarth[6] employs blocking oscillators with selective synchronization by means of a tuned circuit.

Bedford and Smith[5] describe a step counter in which a trigger circuit is fired by the voltage across a capacitor which is charged in a series of steps from rectangular input pulses. The trigger circuit discharges the capacitor and produces a signal output pulse after n input pulses. A detailed analysis of this type of circuit is given by Easton and Odessy,[7] who use a blocking oscillator for discharging the capacitor.

More recently, the cascade binary counters of the type described by Grosdoff[8] have been proposed for use in synchronizing signal generators by Schoenfeld, Brown and Milwitt.[4] The principal advantage of this type of divider is that the division ratio depends on the circuit connections rather than the circuit constants resulting in excellent long period stability without need for trimmer adjustments.

The circuit employed in the present equipment is a simplified step counter due to Schlesinger[9] and described in some detail by Benson and Dash[10]. A simplified circuit diagram of this divider is given in Fig. 7. The wavefoıms (a), (b) and (c) are typical of those applying to a division ratio of 5 : 1.

3.3. *Time-Delay Circuits*

In the process of building up the synchronizing signal wave, it is sometimes necessary to introduce definite phase shifts or time delays between the various component waveforms. Delay circuits may be passive such as the artificial line of Fig. 8 (A) or active such as the electronic circuits of Fig. 8 (B) and (C).

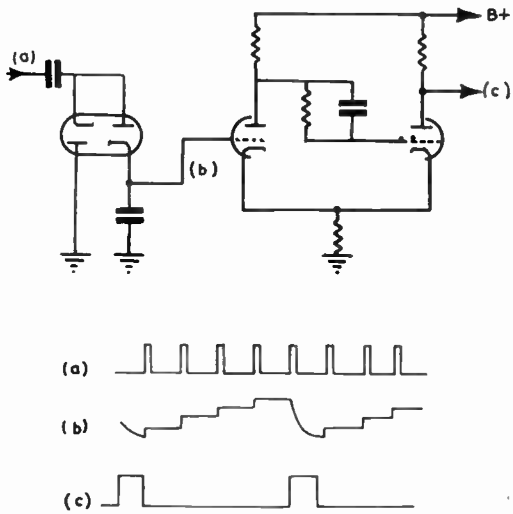


Fig. 7.—Circuit diagram and waveforms of a typical 5:1 *counter stage.*

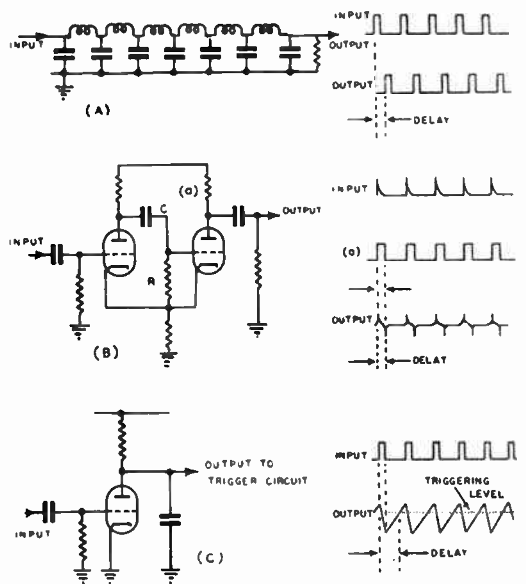


Fig. 8.—Circuit and waveforms of three typical time delay systems.

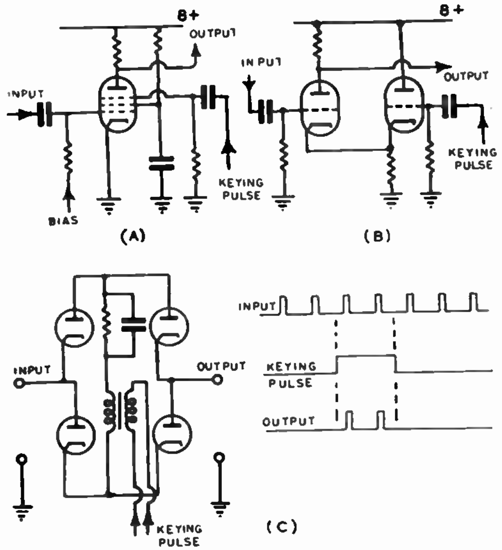


Fig. 9.—Typical keying or gating circuits.

Delay lines provide an extremely accurate and reliable means of achieving small time delays and are used in the most conservative designs of synchronizing signal generators.

The object of a good delay line is to achieve the desired time delay with a minimum of distortion of the pulse shape. It is particularly important that the sharpness of the leading or reference edge of the pulse should not be lost.

Typical electronic delay circuits are shown in Fig. 8 (B) and (C). The former is a flip-flop or driven multivibrator type of pulse generator followed by a differentiator circuit. The time delay between input and output is determined by the duration of the pulse (a) which is a function of the product RC. In the other circuit, Fig. 8 (C), the input pulse is amplified and integrated to produce a sawtooth wave which is fed on to a trigger circuit whose triggering level is stably fixed. The instant of triggering, defined by the intersection of the sawtooth wave with the triggering line, thus establishes the delay relative to the leading edge of the initial pulse.

3.4. *Typical Keying or Gating Circuits*

Fig. 9 shows three typical keying or gating circuits together with an illustration of typical waveforms. The general principle underlying these circuits is that the transconductance of the circuit with respect to the input signal is controlled by the keying or gating wave, being finite for the duration of the keying pulse and zero at all other times. In circuit Fig. 9 (A) the valve is normally cut off by the negative potential developed across the suppressor grid resistor, a positive pulse on the suppressor causing the valve to conduct. In circuit (B) a negative gating pulse is required on the grid of the keying valve to cancel the cut-off bias developed across the common cathode resistor and applied to the grid of the input valve. In circuit (C) the polarity is such that the keying pulse applies a positive potential across each pair of tandem diodes from cathode to anode, providing two parallel conducting paths from input to output.

3.5. *Pulse-Forming Circuits*

Several typical pulse-forming circuits are shown in Fig. 10. Two of these, viz., the Abraham-Bloch multivibrator (A) and the blocking oscillator (C), are of the self-oscillatory type which may be synchronized if desired to an external signal. The Schmitt flip-flop circuit (B), on the other hand, is non-oscillatory and requires

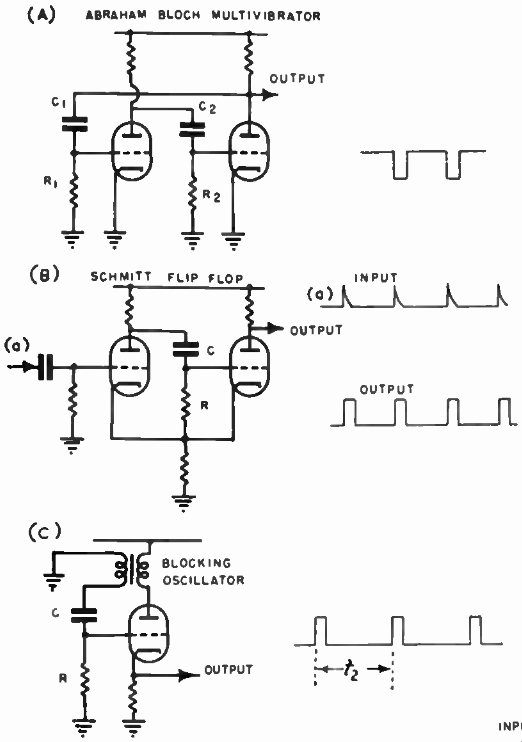


Fig. 10.—Typical pulse-forming circuits.

to be triggered once per cycle. It has the advantage common to all driven-type circuits that it either operates in exact synchronism with the driving signal or not at all. The circuit is a development from the Eccles-Jordan trigger circuit having only one instead of two stable states per cycle of operation. The application of a short triggering pulse renders the circuit momentarily unstable and an output pulse is then emitted, the length of which is determined by the time constant of the coupling circuit C.R.

3.6. *Mixing Circuits*

Four examples of mixing or synthesizing circuits are shown in Fig. 11. In all cases the circuits function as simple linear combining amplifiers with some degree of isolation between the various input circuits. It is sometimes convenient to combine clipping or limiting operations with mixing by suitable adjustment of the bias and load resistance of the valves.

3.7. *Pulse-Selecting Circuits*

In Fig. 12 are shown two examples of pulse-selecting circuits with examples of typical waveforms. Circuit (A) is a passive network into which a series of timing pulses (a) is fed together with a selecting pulse (b). Wave (c) is formed by differentiation of wave (b), while wave (d) is the linear sum of (a) and (c). It will be seen that one pulse in wave (d) attains a greater height than any of the others : this pulse is used to trigger off another pulse-generating circuit. In circuit (B) a portion of a damped oscillatory train is used as the pedestal for accentuating one of the pulses for the subsequent triggering action.

3.8. *Clamp Circuits*

The circuits of Fig. 13 illustrate methods of clamping or fixing the potential of a given portion of a pulse wave relative to a reference level such as earth. Circuits of this type are used to restore the d.c. component of the television signal at the receiver after it has become lost during transmission and so re-establish the

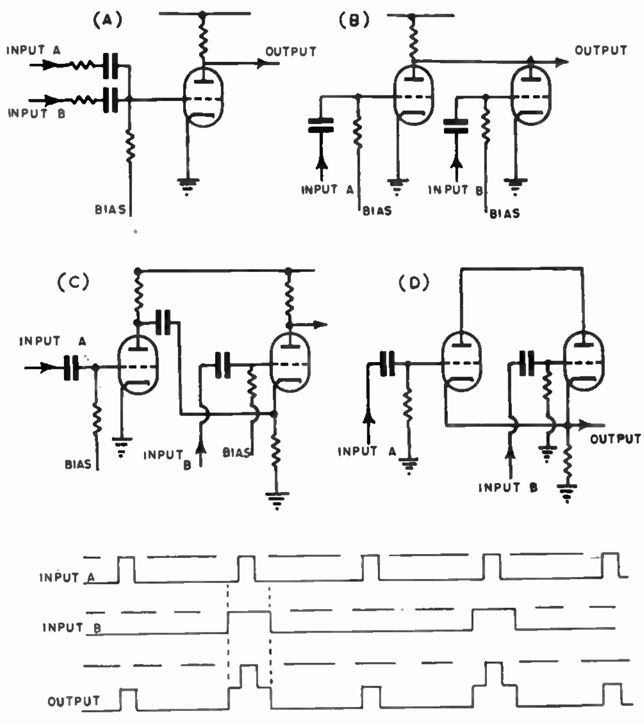


Fig. 11.—Typical mixing circuits.

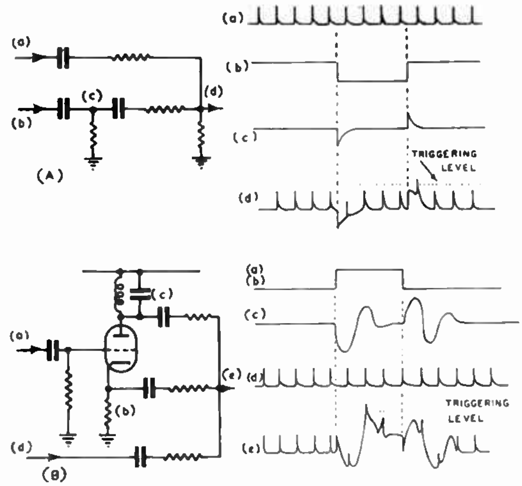


Fig. 12.—Typical pulse-selecting circuits.

correct degree of average brightness applying to each individual picture.

Referring to circuit (A), upon application of a periodic signal potential the diode conducts and short-circuits the output, i.e., clamps it, to earth during the period of the positive portion of the cycle and remains open circuited during the remainder of the cycle.

Circuits (B) and (C) require separate gating pulses to determine the instant of clamping but they enable more complex clamping arrangements to be made. For instance, it is possible with these circuits to clamp a television waveform on the front or back porch of the horizontal blanking pedestal which corresponds in the American system to the black level. Both these circuits provide a clamping level independently of the signal input voltage since the diode current is provided by the gating pulses instead of by the input signal as in case (A). Circuit (C) is an improvement on (B) in that a pair of low-impedance diodes replace the bias resistors R1 and R2 which set a lower limit to the short-circuit impedance in the clamping condition.

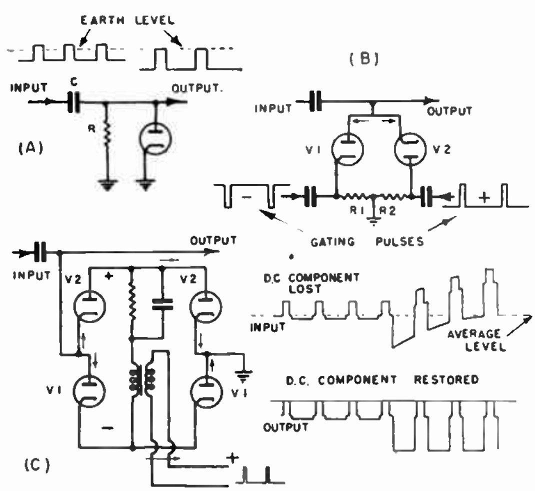


Fig. 13.—Typical d.c. restorer or clamp circuits.

3.9. *Limiting or Clipping Circuits*

Fig. 14 illustrates three typical limiting or clipping circuits in common use. The diode circuits are useful for single-ended clipping. The shunt diode circuit (A) requires a high impedance input and consequently is not well suited to high-frequency operation. The series diode (B) on the other hand may be operated between relatively low impedances.

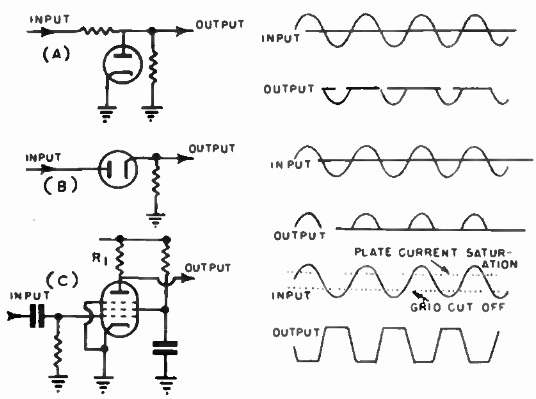


Fig. 14.—Typical limiting or clipping circuits.

The pentode clipper (C) provides clipping on either or both halves of the input wave, which, in the latter case swings the valve from plate current cut-off to grid current. Sharp plate-current cut-off is achieved by operating the valve into a low load resistance.

4.0 Pulse Wave Synthesis

The technique adopted in the present design of building up the complete synchronizing signal from its component pulse waves will not be considered. The most important principle universally adopted in synchronizing-signal generator design is that the leading edge of all synchronizing pulses shall be precisely determined in time, and in fact preferably be actually derived from a common source. A convenient choice for this common source is the equalizing pulse series of twice line frequency. After suitable delay and selection, the various pulses are added so that the leading edge of the equalizing pulses actually become the leading edge of the horizontal and vertical synchronizing pulses.

4.1. *Horizontal Line Synchronizing Pulse Circuit*

Fig. 15 shows how alternate equalizing pulses are selected and used to trigger the horizontal synchronizing pulse generator. The horizontal pedestal pulses whose width is somewhat greater than that of the horizontal synchronizing pulses are used as gating pulses to key in alternate equalizing pulses. These are then fed into the triggering terminals of a flip-flop circuit which generates the horizontal synchronizing pulses. Since the horizontal pulse flip-flop is triggered by the leading edge of the equalizing pulses, it is clear that the leading edge of the resulting output pulses must lag, or at least cannot lead, the leading edge of the equalizing pulses. Subsequent addition of these pulses therefore results in the leading edges of the equalizing pulses becoming the leading edges of the horizontal synchronizing pulses. In some designs[5] a delay line is incorporated to ensure a definite lag between the two series of pulses. When a delay line is employed it is usually made to determine the relative phases of all high-frequency pulses required to build up the final wave. By tapping off at various points along the line, and taking some intermediate point as a reference, pulses occurring either before or after the reference pulse may be taken off as required. Satisfactory results, however, have been achieved in the present design without the use of a delay line.

4.2. *Horizontal Pedestal Circuit*

The leading edge of the horizontal pedestal is required to precede that of the horizontal synchronizing pulse by a small interval called the " front porch." This interval is not very critical, serving only as a guard interval to avoid interference from the picture modulation. It is therefore not necessary to use a delay line specifically for this purpose when one is not used for the other pulses in the system.

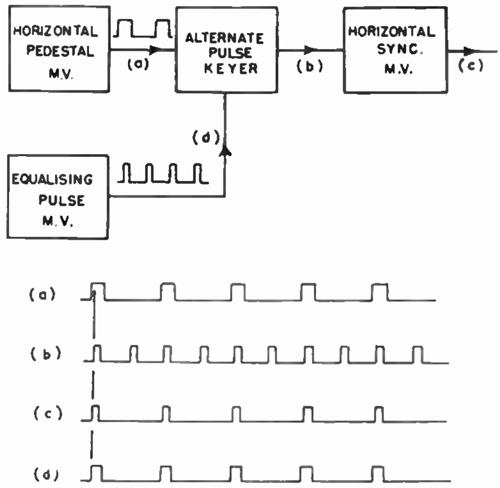


Fig. 15.—Block diagram and waveforms of horizontal sync. pulse generator.

Applegarth[6] employs an electronic delay circuit to establish the front porch interval and his technique has been followed in the present design. The circuit arrangement used in the present design is indicated in Fig. 16. Pulses of line frequency (b) are derived from the equalizing pulses (a) coming from the master multivibrator by means of a 2 : 1 counter divider and used to operate a sawtooth generator to produce the wave (c), which is then fed to a biased trigger circuit as previously discussed in connection with Fig. 8. The firing instant is thus made to precede the pulse (b) by the period

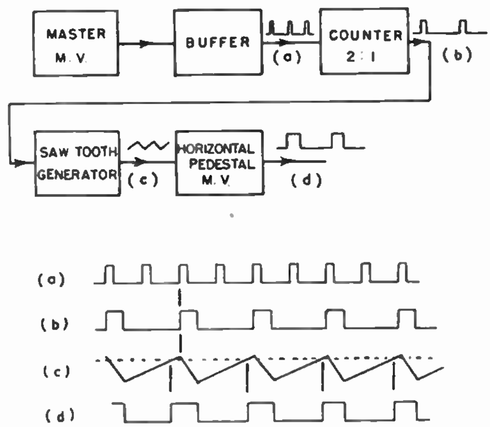


Fig. 16.—Block diagram and waveforms of a horizontal pedestal generator.

required for the front porch. The width of the horizontal pedestal and hence the duration of the back porch is determined by the internal time constants of the trigger circuit.

4.3. *Horizontal Synchronizing Pulse Keyer*

Referring to Fig. 17, the alternate equalizing pulses (a) and horizontal synchronizing pulses (b) are fed additively into a keying or gating circuit A. A gating pulse of 9 lines duration repeated at field frequency is fed in with such polarity that the gate circuit is blocked for the 9-line period. The resulting wave, after clipping to remove the portion of the equalizing pulses having common duration with the horizontal synchronizing pulses, is shown in fig. 17 (d).

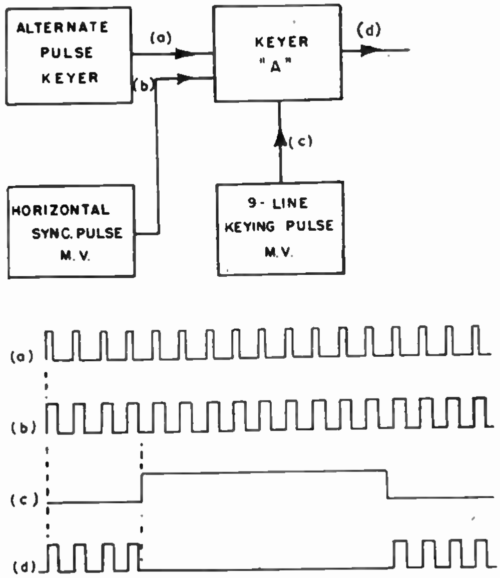


Fig. 17.—Block diagram and waveforms of a horizontal sync. keyer system.

4.4. *Vertical Frame Synchronizing Block Circuit*

The method of generating the vertical synchronizing blocks is shown in Fig. 18, following again the methods of Applegarth.[6] A sawtooth wave (b) derived from equalizing pulses is fed into an inverter and clipper which passes only the triangular tops of the waves above the clipping level shown in (b). The resulting wave (c) is further clipped and amplified to yield the vertical synchronizing blocks shown in (d). The leading edge of these blocks is later established by keyed equalizing pulses as discussed previously.

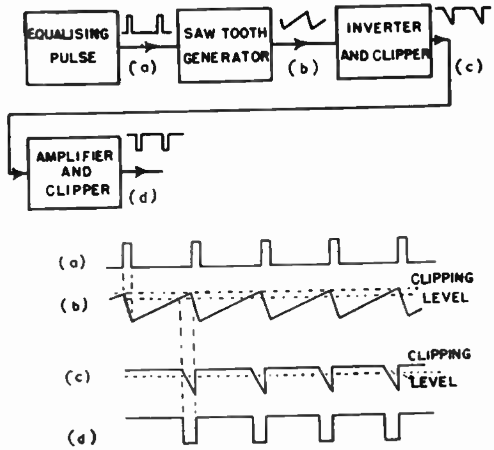


Fig. 18.—Block diagram and waveforms of a vertical sync. block generator.

4.5. 3-*Line Keying Circuit*

The purpose of the 3-line keying pulse is to select a group of six vertical synchronizing blocks beginning after an interval of six equalizing pulses from the commencement of the 9-line keying pulse. It will be apparent that the leading edge of the 3-line pulse must be made to fall within the space between the two vertical synchronizing blocks at an interval of 3 lines from the leading edge of the 9-line pulse. The method of doing this is shown in Fig. 19. The leading edge of the 9-line pulse (a) triggers a 3-line pulse

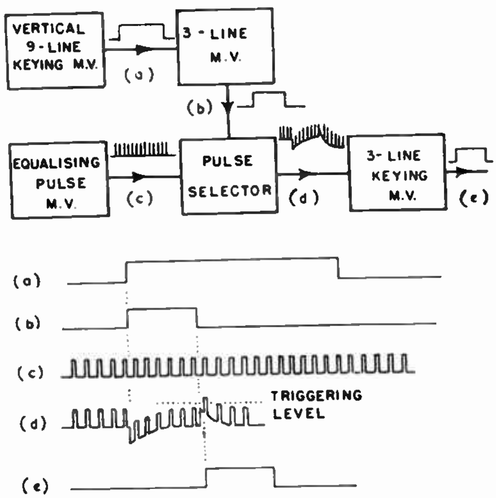


Fig. 19.—Block diagram and waveforms of a 3-line keying pulse circuit.

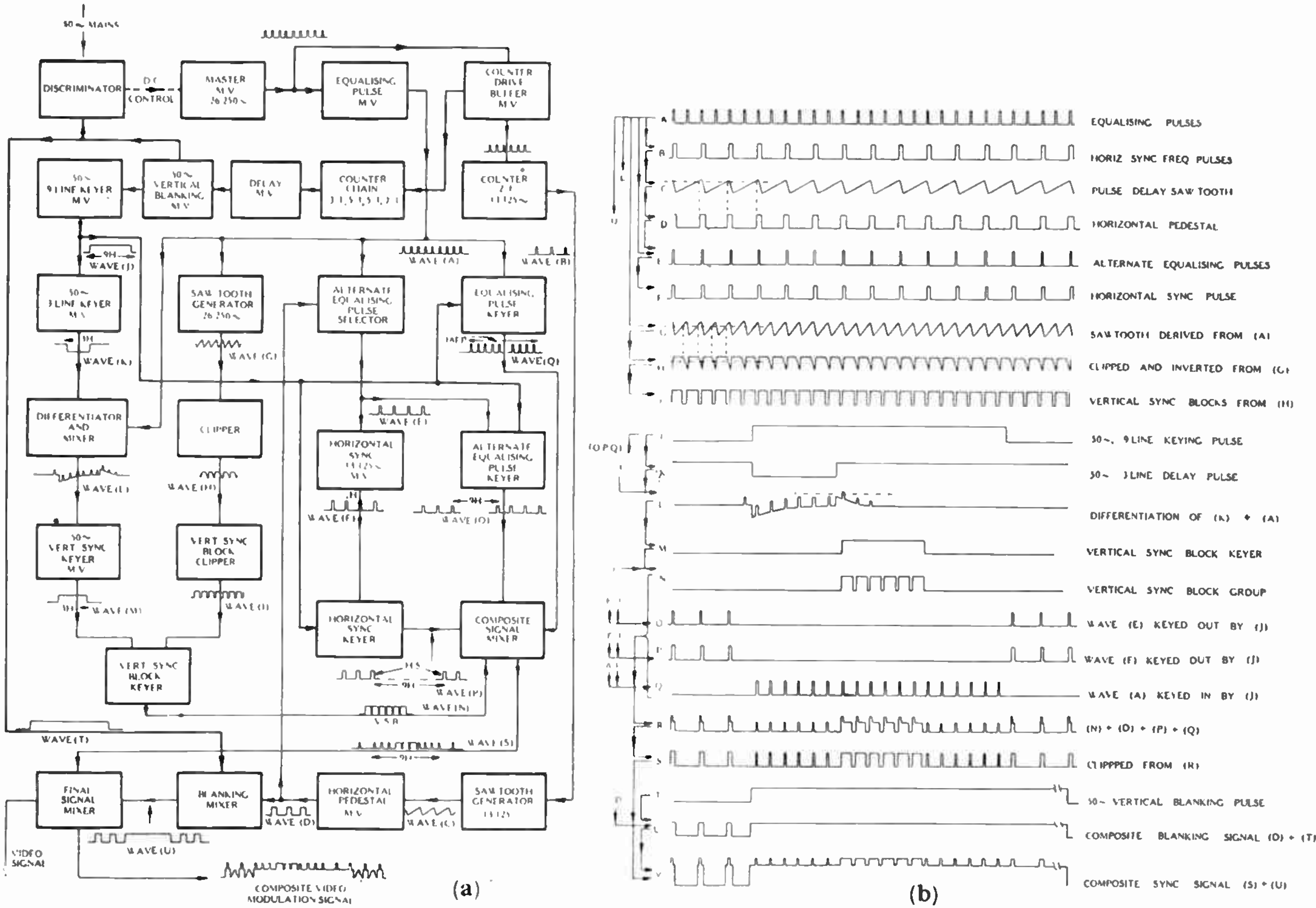


Fig. 20.—Functional diagram of the television synchronizing-signal generator (525 line, 25-picture 2:1 interlaced).

(This illustration and the accompanying description are reproduced from the *A.W.A. Technical Review*, Vol. 8, No. 3.)

generator whose output is differentiated and fed, together with a train of equalizing pulses (c), into a mixer, or pulse selector, where the two waves are added to produce the wave shown in (d). The seventh equalizing pulse from the leading edge of the 9-line pulse is seen to predominate over the others and is used to trigger a second 3-line pulse generator which produces the required wave (e).

5.0. The Complete Generator

A concise picture of the operation of the generator and the way in which the final synchronizing wave is built up from its component waves is shown in the functional schematic diagram of Fig. 20 (*a*) and the waveform diagram of Fig. 20 (*b*).

The interconnections of the frequency divider chain and the low frequency keying pulse circuits in Fig. 20 (*a*) are shown in heavy lines, and typical waveforms existing at the various parts of the circuit are indicated in diagrammatic form. These waveform sketches are linked by the letter code A, B, C—to the scale diagrams of the component and synthesized waveforms shown in Fig. 20 (*b*). The process of wave synthesis may now be traced from the diagrams by the aid of the letter code and arrow systems as follows.

The equalizing pulse wave A, of half line period, provides a common reference interval for the establishment of both horizontal and vertical synchronizing pulses in the two succeeding fields. The principal feature of the synthesizing process is that the leading edge of the equalizing pulse not only triggers both horizontal and vertical synchronizing generators, but, by a process of additive mixing, actually becomes the leading edge of all synchronizing pulses in the final waveform.

The horizontal synchronizing pulse (F) is triggered from a wave (E) consisting of alternate equalizing pulses which are keyed from the original wave (A) by means of the horizontal blanking pedestals (D). The leading edge of any horizontal pedestal (D) is caused to anticipate the corresponding leading edge of (E) by employing an electronic delay circuit to delay the previous pulse of wave (D) by slightly under a line period. The sawtooth for producing this delay is obtained by integrating a line-frequency pulse wave (B).

The vertical synchronizing block wave (I) is produced by double clipping of a sawtooth wave (G) derived by integration from the original wave (A). The vertical synchronizing block group (N) is keyed from the continuous train (I) by means of the 3-line keying pulse (M). The leading edge of (M) is triggered by a salient equalizing pulse on wave (L) which is formed by adding wave (A) to a differentiated version of the 3-line delay pulse (K) whose leading edge is triggered from the leading edge of (J) and whose duration establishes the 3-line period preceding the vertical synchronizing block group. The 9-line keying pulse (J) is used to key out a space in the pulse trains (O) and (P) preparatory to receiving the block of 18 equalizing pulses keyed in from wave (A) to give the wave (Q).

Addition of waves (N), (O), (P), (Q), gives the composite wave (R) which, after clipping to remove the leading portions of equalizing pulses which stand above the synchronizing block level, leaves the complete synchronizing wave (S).

The composite blanking signal (U), obtained by addition of waves (D) and (T), is then added to the synchronizing wave (S) to produce the composite synchronizing and blanking wave (Y) into which the picture modulation is added to form the final composite video modulation signal.

For purposes of illustration, the final synchronizing signal keying and mixing circuits are shown as independent units. In practice the final keying and mixing is done in a composite keyer and mixer unit consisting of a number of pentodes with common plate load; the high-frequency pulses are fed into the grids while the low-frequency keying pulses are fed into the respective cathodes as indicated in the schematic diagram of the practical arrangement shown in Fig. 21.

Fig. 4 shows the waveform requirements of the present generator. The details of wave shape are those specified by the F.C.C. but the time scale corresponds to a field frequency of 50 cycles.

5.1. Description of Equipment

The complete generator is constructed in six rack-mounted panels. The top four panels perform the functions shown in Fig. 20 while immediately below them is a connector panel

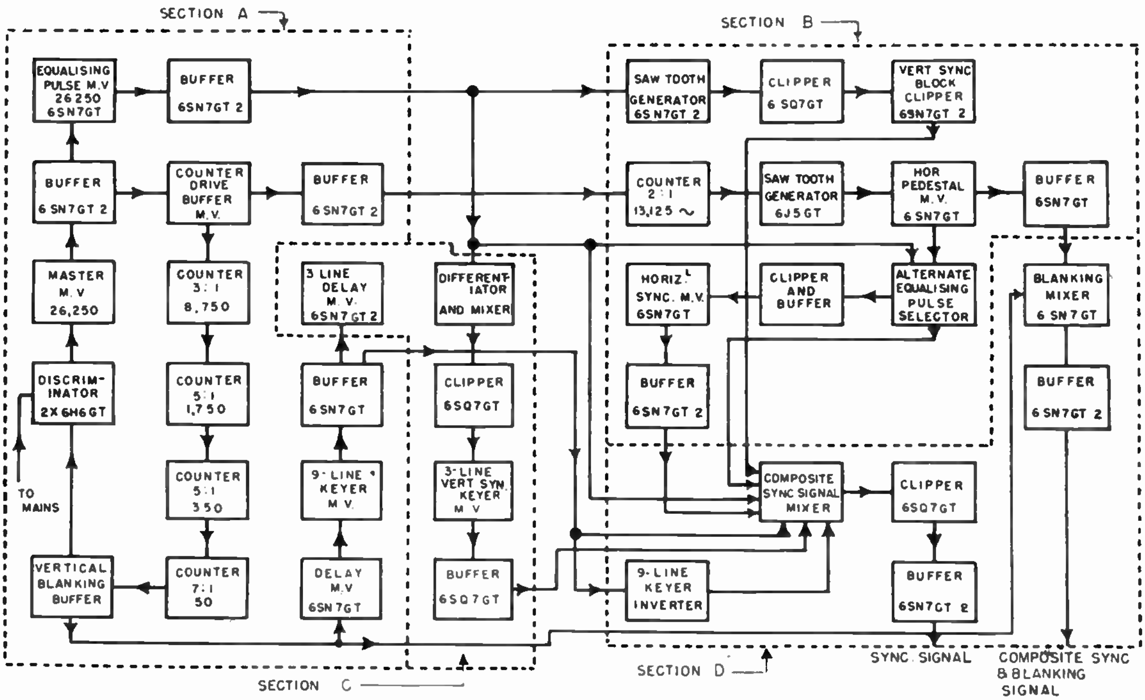


Fig. 21.—Block diagram of the television synchronizing-signal genrator described in conjunction with Fig. 20.

providing picture signal input and picture plus synchronizing signal and blanking output, together with outputs for horizontal and vertical synchronizing and blanking pulses. All outputs are at low impedance. At the bottom of the rack is the power-supply unit.

The four main panels will now be described in conjunction with the detailed block-schematic diagram of Fig. 21. The diagram is subdivided by broken lines into four sections, A, B, C, D, corresponding to the four panels taken in order from top to bottom.

The top panel (section A) is the master multivibrator which generates rectangular waves at twice line frequency and is controlled at 525 x mains frequency (i.e., 26,250 cycles nominal) by a direct voltage from the discriminator which consists of two transformers and two double diodes. Output from the master multivibrator, fed through a cathode follower buffer amplifier, feeds a driver multivibrator generating equalizing pulses, and also a buffer, providing drive for the counter chain. The counter chain comprises eight valves and four double triodes are employed in the 50-cycle circuits. A delay circuit consisting of a driven multivibrator produces a trigger voltage delayed in time for a period somewhat less than half a line from the leading edge of the output pulse of the final counter stage. This trigger pulse initiates two driven multivibrators in cascade, the first of which generates a vertical blanking pulse and the second a nine-line keying pulse. Delay was found necessary to prevent keying from the beginning during the period of that particular equalizing pulse which initiates the output pulse of the final counter stage. This ensures that a block of 18 complete equalizing pulses is selected. The vertical blanking pulse is also used for gating the A.F.C. discriminator. Cathode-follower buffer amplifiers are inserted between the counter chain and the delay multivibrator and in the outputs of the vertical blanking and nine-line keying multivibrators. Manual controls are provided for adjustment of the free running frequency of the master multivibrator and adjustment of the phase of the mains frequency input to the discriminator.

The remainder of the synchronizing and blanking pulses required are generated on the next panel. A horizontal blanking pulse generator, as indicated in Fig. 16, and two cathode-follower buffer amplifiers providing low-impedance outputs for horizontal synchronizing and blanking pulses are situated on the second panel. Three tubes are employed in the horizontal pulse generator shown in Fig. 15, while two valves constitute the vertical synchronizing block generator shown in Fig. 18.

The third panel contains the three-line keying pulse generator shown in Fig. 19. The two three-line pulse generators involved are driven multivibrators and the pulse mixing and selecting takes place in a pentagrid mixer tube which is followed by a phase-inverting amplifier.

Mixing of the various synchronizing pulses and the blanking and picture signals takes place in the bottom panel as shown in Figs. 17 and 20. Four pentodes are employed for mixing the synchronizing signal while a double triode provides a low impedance source of nine-line keying pulses of suitable polarity to be fed into the cathode circuits of three of the pentodes. Below are the blanking and picture mixing circuits. Two manual controls are provided for adjustment of the picture signal-input level and the composite video signal-output level.

6.0. References

1. U.S. Govt. Printing Office, " F.C.C. Standards of Good Engineering Practice Concerning Television Broadcast Stations." (1946).
2. R.M.A. Proposal 194, May 22nd. Reprinted *Proc. I.R.E.* (Waves and Electrons) **36** (1947), p. 932.
3. Fink, D. G., " Television Standards and Practice," New York : McGraw-Hill Book Co. Inc. (1943).
4. Schoenfeld, E. Brown, W., and Milwitt, W., " New Techniques in Synchronizing Signal Generators," *R.C.A. Rev.*, **8** (1947), p. 237.
5. Bedford, A. V., and Smith, J. P., " A Precision Synchronizing Signal Generator." *R.C.A. Rev.*, **5** (1940), p. 51.
6. Applegarth, A. R., " Synchronizing Generators for Electronic Television," *Proc. I.R.E.*, **34** (1946), p. 128.
7. Easton, A., and Odessy, P. H., " Counter Circuits for Television," *Electronics*, **21**, (1948), No. 5, p. 120.
8. Grosdoff, I. E., " Electric Counters," *R.C.A. Rev.*, **8** (1946), p. 448.
9. Schlesinger, Kurt, Australian Patent Application, 15692/47 (1947).
10. Benson, J. E., and Dash, E. M., " A Compact Piezoelectric Chronometer,' *A.W.A. Tech. Rev.*, **8** (1948), p. 69.

7.0. Bibliography

Sterky, H., " Frequency Multiplication and Division," *Proc. I.R.E.*, **25** (1937), 1153.

Blumlein, A. D., Browne, C. O., Davis, N. E., and Green, E., " The Marconi E.M.I. Television System," *Jour. I.E.E.*, **14** (1939), *Wireless Section*, p. 65.

Beers, G. L., Schade, O. H., and Shelby, R. E., " The R.C.A. Portable Television Pickup Equipment," *Proc. I.R.E.*, **28** (1940), p. 450.

Esply, D. C., and Walter, D. O., "Television Film Transmitters Using Apertured Scanning Discs," *Jour. I.E.E.*, **88** (1941), Part III, p. 145.

Campbell, R. L., Kessler, R. E. Rutherford, R. E., and Landsberg, K. U., " Mobile Television Equipment," *Proc. I.R.E.*, **30** (1942), p. 1.

Trainer, M. A., " Orthicon Portable Television Equipment," *Proc. I.R.E.*, **30** (1942), p. 15.

Howard, W. A., " Portable Video Pick-up Equipment," *Electronics*, **19** (1946), No. 8, p. 124.

Batcher, R. R., " Television Synchronizing Signal Generating Units,"Part I, *Tele-Tech.*, **6** Jan., 1947, p. 50.

THE VELOCITY OF LIGHT

An investigation recently completed at the National Physical Laboratory has shown inaccuracy in the normally accepted figure for the velocity of light. The difference is not great —only 17 km/sec. It is, however, far from being a matter of solely academic interest, for the velocity of light is used for many of the fundamental calculations in atomic theory. The more accurate figure is of immediate practical value in radio and radar.

A great deal of time and money has been spent since Römer first obtained a value of 307,200 km/sec. from astronomical observations in 1676. The first direct experimental measurement was made by Fizeau in 1849, while, in 1935, Michelson, in the U.S.A., performed a well-known experiment in which a beam of light travelled in a metal tube a mile long which could be evacuated. The final value he obtained was 299,776 km/sec. This figure was confirmed in other experiments and has been accepted ever since.

When Dr. L. Essen, of the National Physical Laboratory announced in 1947[1] that the figure should be 299,793 km/sec, the result was received with some scepticism ; he has now confirmed the result using more refined apparatus, and results recently obtained in Sweden and in the U.S.A. agree with this value to within 1 km/sec.

The method used by Dr. Essen makes use of the electrical resonance of a short length of cylindrical waveguide closed at both ends. This was evacuated and excited at a frequency in the region of 10,000 Mc/s.

The frequency of resonance of a cylindrical guide of diameter D and length L is :—

$$f_n = v\sqrt{\left(\frac{r}{\pi D}\right)^2 + \left(\frac{n}{2L}\right)^2}$$

where v represents $1/\sqrt{\mu k}$, r is a constant for a particular mode of resonance and n is the number of half-wavelengths in the guide. This formula assumes perfect conductivity of the walls of the guide. To take into account their finite conductivity, a small correction factor in terms of Q, the quality factor of the resonator, is applied so that the value of v becomes

$$v = f_n\left(1+\frac{1}{2Q}\right)\Big/\sqrt{\left(\frac{r}{\pi D}\right)^2 + \left(\frac{n}{2L}\right)^2}$$

In this expression, f_n, D, L and $(1 + 1/2Q)$ can all be measured to within a few parts in 10^6. It was found that slightly different (2 parts in 10^5) results were obtained for the E_{010} and E_{011} modes in one particular resonator, but Dr. Essen suggests in a later survey paper[2] that this may be due to mechanical and electrical imperfections in the resonator.

A value of 299,792 km/sec $\pm$ 9 km/sec was arrived at for the velocity of electromagnetic waves in vacuum. In later work a repetition accuracy of 2 in 10^6 was obtained.

The construction and subsequent measurement of the waveguide called for the devising of special techniques by the Metrology Division at N.P.L. and an accuracy of one hundred thousandth of an inch was achieved.

Dr. Essen considers that in the previously accepted measurements of the velocity of light-waves, a systematic error could easily remain hidden in spite of the large number of observations taken (about 3,000), as the observations were so scattered. The results obtained by Essen's method show a much greater consistency.

Additional confirmation of Essen's results was supplied by Bergstrand,[3] using a method based on the comparison of the phase of an intensity-modulated light beam over long and short paths. A measurement of the velocity of radio waves by Aslakson,[4] in 1949, gave a value of 299,792 km/sec $\pm$ 2·4 km/sec. This method compared a Shoran radar survey with a geodetic survey.

Full details of Dr. Essen's experiments are to be published shortly in the *Proceedings of the Royal Society*.

References

1. L. Essen. *Nature*, Vol. 159 (1947), p. 611.
2. L. Essen. *Nature*, Vol. 165 (1950), p. 582.
3. E. Bergstrand. *Nature*, Vol. 163 (1949), p. 338.
4. C. I. Aslakson. *Nature*, Vol. 164 (1949), p. 711.

THE RADIO TRADES EXAMINATION BOARD

formed by

THE RADIO INDUSTRY COUNCIL
THE RADIO & TELEVISION RETAILERS' ASSOCIATION
THE BRITISH INSTITUTION OF RADIO ENGINEERS
THE SCOTTISH RADIO RETAILERS' ASSOCIATION

RADIO SERVICING CERTIFICATE EXAMINATION—MAY 1950

Of the 255 candidates who sat the examination which took place in May of this year, 122 candidates satisfied the examiners in both the written and practical parts, 45 candidates passed the written examination but were referred in the practical test and 15 candidates completed the examination, having been referred in the practical test in the May, 1949, examination.

PASS LIST

The following candidates satisfied the examiners in the entire examination :

ARNOLD, Alfred Angus	Romford, Essex
ASKEW, Dennis Raymond	Preston
BALL, William Arthur	Leicester
BARTLEY, John Ernest	Christchurch, Hants
BELL, Maurice	Bolton
BEST, Leslie	Hetton-le-Hole, Durham
BEYNON, Basil John	Newcastle-on-Tyne
BLAND, John Eric	Preston
BLANN, Frederick Douglas	Southampton
BRAY, Geoffrey	Huddersfield
BURKE, Geoffrey Thomas	Wallington, Surrey
CHERRY, William	Belfast
CLARE, Oliver	Glasgow
CLEMENTS, George Arthur	Leicester
COCKAYNE, John Turner	Sheffield
CROFTS, Peter Charles	Fareham, Hants
CROWSON, Arthur	Beeston, Notts
CROZIER, Archibald	St. Anne's on Sea, Lancs
CUTTERIDGE, John Ernest	Cambridge
DAVIES, Kenneth Dorrien	Oldbury, Worcs
DAWES, Ian	Glasgow
DEAN, Leslie	Paisley
DICE, Leslie Eric	Woodford Green, Essex
DICKINSON, George Gregory	Liverpool
DUCKWORTH, Harold	Nelson, Lancs
DUFF, Colin	Auchinleck, Ayrshire
EDWARDS, Geoffrey Thurston	Halifax
FINLAYSON, Robert Morton	Edinburgh
FLOOD, Kenneth John	Southampton
GASIOROWSKI, Stanislaw	London, S.W.19
GENTRY, Leonard William	Hadleigh, Suffolk
GIBBS, Paul William	London, S.E.2
GILLARD, Raymond	Bristol
GILLESPIE, Denis Edmund	Belfast
GLASSFORD, John	Glasgow
GLEDHILL, Kenneth	Batley, Yorks
GLENDINNING, Robert	Glasgow
GODDEN, Bertram John	Romford, Essex
GOEMAERE, Serge	Cambridge
GRAHAM, Maurice	Croydon, Surrey
GRAYDON, Robert	Oldham
GRIMSHAW, Vincent	Blackburn
GROVES, David Thomas D.	Gloucester
HASTINGS, John Conway	Worthing, Sussex
HAXTON, Charles Howat	Paisley
HAYWARD, Brian William	Watford
HEWLETT, Donald Edgar	Bristol
HICKS, Brian Victor	Ipswich
HIGTON, Edward Thompson	Normanton, Derby
HOLE, Bernard Gerard	Thornton Heath, Surrey
HUGHES Colin Edwin	Alvaston, Derby
HUNT Eric Henry	Birmingham
HURST, Sydney	Blackpool
JACKSON, Arthur	Stainforth, Yorks
JACKSON, Robert	Blackpool
JESSUP, Lawrence Bernard	Southampton
JOHNSON, Leonard	Potters Bar, Middx.
JORDAN, Leo	Lincoln
KEMBLE, Anthony Gilbert	Leicester
KEMP, Brian Arthur	Gorleston-on-Sea
KITE, Albert John	Hove
LAVALLIN, George	Warrington
LAWRENCE, Royce Graham	Cheltenham
LLOYD, Richard	Cheltenham
LOVERIDGE, Jack	Shrewsbury
LUCKCUCK, Peter Derek	Leicester

(Contd.)

McDONALD, Douglas George	Nottingham
MacFARLANE, William George	Hemel Hempstead
MacKENZIE, Kenneth	Glasgow
MacLEAN, Thomas	Glasgow
MAPLETHORPE, Anthony Dring	Nottingham
MARSHALL, Robert	Ayr
MOORFIELD, George	Capel Curig, N. Wales
MURPHY, Daniel	Glasgow
MURPHY, Francis	London, E.12
NEWTON, Dennis William	Cheltenham
NORMAN, John Reginald	Barnehurst, Kent
OAKLEY, Charles Walker	Huddersfield
OAKLEY, Robert Wilford	Huddersfield
OSBORN, John William	Yarmouth
PARKINSON, William James	Leeds
PHILP, James	Dunfermline
POOLE, Ronald Jack	Nottingham
POPE, Thomas George	Purley
POPPLEWELL, Lawrence A.	Otley, Yorks
PRIESTLY, Eric	Wilmslow
PYKE, James	Coventry
RIDDLESDELL, Arthur F.	Carshalton
RIGBY, Stanley John	Birmingham
ROBERTSON, Robert Allan	Falkirk
ROSS, Donald Stuart	London, E.6
ROSSALL, Arthur Henry	Blackpool
SCOTT, David	Dunfermline
SHERWOOD, Kenneth Jack	Mansfield, Notts
SHOOTER, Leslie Tom	Nottingham
SIMPSON, David	Hamilton, Lanark
SIMPSON, John Wilson	Glasgow
SIMPSON, Peter James	Leicester
SINCLAIR, Roslyn Fewster	Warlingham, Surrey
SLATER, Horace Henry James	London, S.W.14
SLATER, Leslie James	Hounslow, Middx.
SMITH, Noel Hanson	Liverpool
SMITH, Wilfred Thomas	Cheltenham
SMITH, William Alexander Moir	Edinburgh
STILL, Henry Richard	Staines, Middx.
STOREY, Roy Alwyne	Cambridge
SURTEES, Eric	Middlesbrough
TAYLOR, Norman	Preston
TREVENA, Tom	Bolton
TURNER, Donald	Sheffield
WALKER, William	Murton Coll, Co. Durham
WANDEN, William Thomas G.	Chislehurst, Kent
WEINER, Heinz	London, N.W.2
WHITLOCK, George Edwin	Bristol
WILD, Benjamin	Bolton
WILD, Ernest	Oldham
WILKINS, John Albert	Winchester
WILTSHIRE, Ronald Frederick	London, S.E.13
WOOD, Alfred	Bolton
WORK, George William	Glasgow
WYLIE, Alwin	Edinburgh
YOUNG, William Arthur	Harrogate

The following candidates who were referred in the Practical Examination in May, 1949, *now qualify for the certificate :*

BAKER, Brian Thomas	Bromley, Kent
BATES, Milton	Winchester
BIXLEY, Douglas Edward	Eastleigh, Hants
COLEMAN, Raymond James	Birmingham
COOTE, William James	Glasgow
COSSAR, Archibald	Carluke, Lanark
EVERS, Charles Edgar	London, N.10
GRAY, Andrew Kidd	Dundee
JOHNSON, Geoffrey	Wolverhampton
LYON, James Gray	Falkirk
SAGER, Julian Frank	Liverpool
SALES, Victor Robert	Norwich
SAVILL, Frank	Peterborough
SMITH, Alexander	Aberdeen
WESTON, Martin Andrew	Wareham. Dorset

The following candidates satisfactorily passed the written papers but were referred in the Practical Examination

ALDERSON Ronald William	Coventry
BASSETT, Richard Anthony	Southall, Middx.
BLACK, Wallace John	Goodmayes, Essex
BROWN, Robert Anderson	Dundee
BURDETT, Edward Raymond	Wolverhampton
CEBULA, Wladyslaw Karol	Pittenweem, Fife
CHAMBERLAIN, Horace	Cambridge
CLARK Horace Ernest	Birmingham
COOKE Arnold	Coundon, Co. Durham
CROSSLEY, Alan William Leslie	New Malden, Surrey
DAYNES, Robert Stanley	Shrewsbury

DENNING, Stanley George	Bristol
DUNNING, Thomas Edward	Paignton, Devon
EYRE Charles Thomas	London, S.E.15
GARLICK, Michael James	Bolton
GLASSELL, Wilfred	Pontefract, Yorks
HALLAS, Arthur	Blackpool
HARBOUR, Harry	Bromley, Kent
HARRISON, Arthur	Warrington
HAWKES, Peter	Lowestoft
HENDERSON, Raymond Wilson	Rosyth
IDDON, Walter Edward	London, N.17
KATON, Edward	Cambridge
MacGREGOR, Henry George	London, N.W.11
McINTYRE, Hugh Alexander	Eastleigh, Hants
McPHEE, Denis	Glasgow
MERLE, Geoffrey Charles	London, N.18
MILLS, John S.	New Malden, Surrey
MITSON, Ronald Burt	Lowestoft
MUIR, Douglas, W. B.	Edinburgh
POLLOCK, James	Glasgow
ROAST, Ronald George	Southall, Middx.
SEAMAN, Kenneth	Manchester
SHEPPARD, Walter Thomas	Maidenhead
SUMMERHILL, James Edward	Wolverhampton
SYME, David McCulloch	Glasgow
TAYLOR, Leslie Frank	Gillingham, Kent
TOMS, Douglas Eric	Croxley Green, Herts
UBAID-UR-RAHMAN	London, N.1
WALTERS, Thomas William	Derby
WARD, Bertram Edward	Lincoln
WARD, Neville Stanley	Warrington
WARE, William Henry	London, S.E.19
WINCKLE, George Albert	Ilford
YATES, Peter John Leslie	Slough, Bucks

TELEVISION SERVICING CERTIFICATE EXAMINATION— MAY 1950

Of the 30 candidates who entered for the examination which took place in May of this year, 16 candidates satisfied the examiners in both the written and practical parts, and 12 candidates passed the written examination but were referred in the practical test.

PASS LIST

The following candidates satisfied the examiners in the entire examination:

BROWN, Edward Richard	Belvedere, Kent
BURKILL, Arthur Herbert	London, N.W.10
COLBOURNE, Geoffrey Arthur	Chichester, Sussex
EVANS, David Haydn	Harrow Weald, Middx.
FERMOR, Robert	Liss, Hants
FINCKEN, Jack Alexander	London, N.10
GREEN, Alfred Stanley	Wallington, Surrey
GUILDFORD, Leslie Henry	Haywards Heath, Sussex
ISAACS, Denis	London, N.1
LIGGINS, Roy	Leicester
MINTER, Owen Gough	London, N.10
POINTER, Edward Francis	Maidstone, Kent
REYNOLDS, John Charles	Cambridge
RICHARDS, Raymond Cecil	Gosport, Hants
SEWELL, John	Cranleigh, Surrey
THWAITES, Douglas	London, S.W.3

The following candidates satisfactorily passed the written papers but were referred in the Practical Examination:

BRASSINGTON, Clarence H.	Bath, Somerset
CROMPTON, Charles	Huddersfield
CURRINGTON, Leslie Ernest	Welwyn Garden City, Herts.
DOHERTY, Patrick Gerrard	London, S.E.10
DOLAND, Derek	London, S.W.16
DUFFY, Kenneth Charles	Birkhurst Hill, Essex
DUNN, Leonard Sydney	Sutton, Surrey
HAYSLEP, Robert Ernest William	London, N.8
HOLMES, Lionel Walter	London, N.1
PARTRIDGE, Alec William	Calverley, Yorks
SANDER, Peter	London, N.W.7
WALES, Arthur Norman	High Wycombe, Bucks

TRANSFERS AND ELECTIONS TO MEMBERSHIP

At a meeting of the Membership Committee held on October 26th, 1950, twenty-one proposals for direct election to Graduateship or higher grade of membership, and thirty-four proposals for transfer to Graduate or higher grade of membership were considered.

The following elections were approved by the General Council: eighteen for direct election to Graduate or higher grade of membership and twenty-six for transfer to Graduate or higher grade of membership.

Direct Election to Associate Member

Dickenson, Cuthbert Reginald	Zomba, Nyasaland
Jones, James Anthony, Flt./Lt.	Harrow, Middlesex
Lakin, Ralph Thornton	Mansfield, Notts.
MacFarlane, Geoffrey Norman Wilson, Flt./Lt.	Deal, Kent
Nysen, Thedoor Anton Marie, Lt.	Oegstfeest, Holland
Scholey, Douglas Herbert Allenby	Nairobi, Kenya
Talbot, John Vernon	Reading, Berks.
Turner, Geoffrey Cater, Cmdr.(L.)	Sevenoaks, Kent

Direct Election to Associate

Cockrill, Alexander Ross	Corbridge, Northumberland
Griffin, Thomas Edward, Flt./Lt.	Padstow
Knight, Thomas	Hoddesdon, Herts.
Neely, Terence Joseph Prescott	Grahamstown, S. Africa
Shahani, Durgdas Chattamal, B.Sc.	Nagpur, India
Smith, Frederick Thomas Sydney	Wolverhampton

Direct Election to Graduate

Cooper, Thomas Havana, B.Sc.	Ipswich, Suffolk
Oldham, Alan Edward	Altrincham, Cheshire
Ward, Eric Henry	Sherwood, Nottingham
Wild, Sydney	Ashton-under-Lyne, Lancs.

Transfer from Associate Member to Full Member

Burridge, Bernard Joseph	Sidcup, Kent

Transfer from Associate to Associate Member

de Beer, Baron Christian	London, N.W.9
Dunn, Gordon Leonard	London, N.W.5
Hipple, Henry	Liverpool
Record, Richard James, Lt.(L.)	Bromley, Kent
Scadeng, Peter	London, W.13

Transfer from Graduate to Associate Member

Whitwell, Arthur Leslie	Wolverhampton

Transfer from Student to Associate Member

Morgan, Stephen Lascelles	Johannesburg

Transfer from Associate to Graduate

Brown, Albert Geoffrey	Liverpool

Transfer from Student to Assciate

Haylock, George Vincent	London, S.E.13
Jones, Ian Bonnie Carter	Potchefstroom, Transvaal
Kemsley, John William Herbert	Boreham Wood, Herts.
Widdison, Geoffrey Canham, Lt.	Warrington, Lancs.

Transfer from Student to Graduate

Cooper, William John	Epping, Essex
Cottrell, John Gilmour	Bognor Regis, Sussex
Cundy-Borge, Roy	Plymouth
Duncan, Malcolm John	London, N.13
Gilson, Thomas John	Tullamore, Offaly, Eire
Hopkin, Peter Roy	Hadleigh, Essex
Joslin, Charles Albert Frederick	Chelmsford, Essex
Kelly, Leslie Charles	London, N.7
Raghanath Rao, A. L. N., B.Sc.	Bezwada, India
Robb, Ronald Laidlaw	Harrow, Middlx.
Srinivas, V. A.	Madras, India
Vadgama, Gulab Maganlal	London, E.C.2
Wilkinson, Stanley Henry	Three Bridges, Sussex