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REPORT OF THE TWENTY-FOURTH ANNUAL GENERAL MEETING

THE INSTITUTION'S TWENTY-FOURTH ANNUAL GENERAL MEETING (the sixteenth since incorporation) was held at the London School of Hygiene and Tropical Medicine, Keppel Street, London, W.C.1, on September 22nd, 1949, commencing at 6.30 p.m.

Mr. L. H. Bedford (President) was supported by other officers of the Institution and members of the General Council. In addition, fifty other corporate members were present at the start of the proceedings. Mr. J. L. Thompson (Chairman of Council) opened the meeting.

1. To confirm the minutes of the Annual General Meeting held on October 21st, 1948.

The Chairman stated that a record of the last Annual General Meeting was published on pages 261-263 of the November-December 1948 Journal and proposed that this record should be adopted as the official minutes. This proposal was unanimously approved and the minutes signed as a correct record of those proceedings.

2. To receive the Annual Report of the General Council.

The Chairman referred to the Annual Report of the Council, presented in the July 1949 Journal.

Whilst the report covered every important aspect of the Institution's work, Mr. Thompson felt that it was impossible to relate in detail all that had been undertaken and accomplished by the Council and Committees during the year. The first consideration must always be to maintain a high standard of membership and it was natural that with the increasing demands made upon the modern engineer, membership requirements would tend to increase. Nevertheless, as the Annual Report showed, there had been a further increase in the total membership of the Institution.

Much discussion had taken place on the qualifications for membership and in some cases it had been felt that the present regulations imposed hardship. Such cases, however, mainly referred to those whose experience may not, in the strict sense, be considered as falling into the requirements of a qualified engineer; on the other hand, the training and ability of such technicians must necessarily be of a high standard if the work of the responsible engineer is to be successfully completed.

Mr. Thompson stated that he did not propose to deal further with this subject, which had already been thoroughly explored in the Institution's Journal; he urged, however, that the question should be deliberated by every professional engineering body since the importance and status of the technician was not confined to the radio industry.

In the matter of qualifications for membership, the work of the Education Committee was of great importance to every member. Indeed, Council considered that the report of this Committee was one of the highlights of this year's Annual Report; apart from examining all applications for exemption from the examination, the Committee had the tremendous responsibility of arranging the Graduateship examination and notwithstanding the extension of the examination syllabus, it was encouraging to note that during the year under review the Institution had received a record number of examination entries. The 1948 figure has, moreover, already been exceeded by the entries received during the current year (1949).

Mr. Thompson stated that these facts, together with the increasing number of proposals now received for transfer to the higher grades of membership, showed how well the foundations of the Institution have been laid. Earlier difficulties were consequent upon the policy of adhering to a quality membership and this policy was now reaping its just reward.

The work of the Papers Committee should, Mr. Thompson said, particularly commend itself to every member of the Institution. He appealed, on the Committee's behalf, to every member to assist in contributing to the Proceedings of the Institution, either by presenting papers for reading before the various Sections and/or for publication in the Journal. Such assistance would be greatly welcomed by the Papers Committee, whose work was of the utmost importance in maintaining this aspect of the Institution's functions.

The Chairman felt that it was not necessary for him to comment further on the Annual Report and moved its adoption as a record of confidence in the General Council.

Mr. Oswald Mingay (Member) stated that it gave him very much pleasure to support the adoption of the Report. As an Australian Member of the Institution, he felt that he was speaking for all members overseas in congratulating the Council on the excellent work which had been done on the Institution's behalf, not only in the last year, but in the last decade.

Mr. Mingay was sorry not to see in the report further mention of the co-operation which existed between the Institution and the Australian Institution of Radio Engineers. It was, perhaps, indicative of the status of the Brit.I.R.E. that the Australian counterpart had quite recently remodelled its examination syllabus and part of its conditions for membership on the same lines as the regulations of the Institution. Since his arrival in Great Britain, Mr. Mingay had found further evidence of the Council's wish to give every possible assistance to members overseas and he stressed the importance of the Institution's Sections which, in New Zealand for example, provided one of the main, if not the principal, point of contact between members of the radio engineering profession.

The report was unanimously adopted.

3. To elect the President

Mr. Thompson then moved that Mr. L. H. Bedford be re-elected President of the Institution for a second year. Mr. Bedford's re-election would be a tribute to the professional esteem in which he was held as well as conveying an expression of thanks for the invaluable service he had rendered to the Institution. The proposal was carried with acclamation and the Chairman asked Mr. Bedford to preside over the remainder of the meeting.

Mr. Bedford then moved into the Chair and expressed his appreciation of having been re-elected President.

4. To elect the Vice-Presidents

The President first referred to the final comments in the Annual Report, with particular reference to Air Vice-Marshal R. S. Aitken, who had decided not to offer himself this year for re-election as a Vice-President. On behalf of the Council Mr. Bedford expressed appreciation for the help which Air Marshal Aitken had given to the Institution since he was first elected a Vice-President in 1943.

Mr. Bedford then proposed the acceptance of Council's recommendation that Mr. Paul Adorian and Mr. W. E. Miller be re-elected Vice-Presidents and reminded members that for the reasons given in the Annual Report, the approval of further elections to the office of Vice-President was deferred.

Mr. E. A. W. Spreadbury seconded the proposal, which was carried unanimously.

5. To elect the Ordinary members of the General Council

The President stated that Council's recommendations of members to fill the vacancies arising, and which had been circulated to the corporate members, had not been opposed and the following members would, therefore, serve on the General Council for the ensuing year :—

Sir Louis Sterling (Hon. Member) and Mr. J. L. Thompson (Member) were re-elected for a further term.

Group Captain S. Lugg, C.B.E., and Messrs. N. C. Cordingly, O.B.E., G. L. Hamburger, and E. T. A. Rapson, M.Sc. (Members).

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

6. To elect the Honorary Treasurer

Mr. Bedford stated that the Officers of the Institution and members of the Council were anxious to express at this meeting their appreciation of the considerable amount of work which Mr. Chapman had done for the Institution in his capacity as Honorary Treasurer. In these days especially, the work of a Treasurer was far from easy, but Mr. Chapman had given considerable service to the Institution in keeping the Council advised on the very important matter of finances.

From the approval which members had given to the accounts in past years, Mr. Bedford felt that there would not be any opposition to Council's recommendation that Mr. S. R. Chapman be re-elected Honorary Treasurer.

The proposal was carried unanimously.

7. To receive the Auditor's Report, Accounts and Balance Sheet for the year ended March 31st, 1949

Mr. Chapman suitably acknowledged his election as Honorary Treasurer by referring to the fact that this would be his fifth year in office and that with increasing improvement in the finances of the Institution it was a great pleasure to continue as Treasurer.

The Honorary Treasurer stated that the accounts for the year ended March 31st, 1949, together with the Auditors' report, were published in the July 1949 Journal. On the income side, subscriptions and receipts from the sale of Journals particularly showed a steep increase and in view of Mr. Mingay's remarks, it was interesting to note that the sale of the Journal overseas during the year had reached a record figure.

For the first time, the Institution had benefited from a bequest of a member and this had been of considerable help in reducing the deficit of the reserve account.

This year, the income and expenditure account, as well as the Balance Sheet, had been published with the figures for last year. Mr. Chapman stated that the comparison showed clearly the efforts of the Finance Committee to bring expenditure below the level of income. The present tendency for a continual upward curve in expenditure was a source of great worry to the Committee and Mr. Chapman suggested that members would be pleased to note that notwithstanding the growth of the Institution, expenditure on some items had, in point of fact, been considerablly reduced without affecting the activities of the Institution.

The Balance Sheet, which had been framed in accordance with the recommendations of the Cohen Committee, as now specified in the Companies Act 1948, was self-explanatory. It showed an increase in the Institution's fixed assets and Mr. Chapman felt that the overall position of the finances was most satisfactory.

Mr. Chapman suggested that it was not necessary to elaborate on the President's Prize Fund and the Partridge Memorial Fund accounts, which were quite clearly shown by the Accountants statement, and moved that those special Accounts and the Accounts and Balance Sheet for the General Fund for the year ended March 31st, 1949, should be adopted.

Mr. L. Grinstead seconded this proposal which was carried unanimously.

8. To receive the Annual Report of the Trustees of the Benevolent Fund and the Accounts and Balance Sheet for the year ended March 31st, 1949

The Honorary Treasurer then presented on behalf of the Trustees the Accounts and Balance Sheet of the Benevolent Fund for the year ended March 31st, 1949. Members had given generous support and Mr. Chapman had been asked by the Trustees to express thanks for the many donations which had enabled the Trustees to deal generously with the claims of those members, or their dependants, who had met with misfortune.

In this connection, Mr. Chapman made special reference to Reed's School, which had given most sympathetic consideration to the Institution's nomination of children of deceased members to enter the Schools. The Trustees of the Fund would be making a special report on the work of Reed's School which subscribers would see in the next Annual Report for the current year.

Finally, Mr. Chapman felt that the report of the Trustees, given on page 256 of the July Journal, showed how necessary it was for the Fund to receive continued support and he asked the subscribers to approve the Accounts and Balance Sheet of the Benevolent Fund for the year ended March 31st, 1949. The contributors indicated their approval and Mr. Chapman's proposal was carried unanimously.

9 and 10. To appoint Auditors and Solicitors

Mr. Bedford stated that he proposed to deal with those two items together and felt sure that members would support the Council's recommendation that Messrs. Gladstone, Titley and Company and Messrs. Braund & Hill be re-elected as the Institution's Auditors and Solicitors respectively. Both organizations had served the Institution for many years and considerable benefit had been derived from their advice. Mr. Bedford moved that Messrs. Gladstone, Titley & Co. be reappointed Auditors and that Messrs. Braund & Hill be re-elected Solicitors. The proposal was carried unanimously.

11. Award of Premiums and Examination Prizes

Mr. Bedford stated that this item was most pleasing to him and he congratulated most sincerely Mr. N. Morley and Mr. R. A. Bassett on receiving the *President's Prize* and the *Mountbatten Medal* respectively. Mr. Bassett was further complimented on qualifying also for the *S. R. Walker Prize.*

The *A.F. Engineering Prize* was presented to Mr. H. G. Anstey and the President regretted that the winner of the *Electronic Measurements Prize*, Mr. A. L. Whitwell, was unable to be present to receive his award.

The President then referred to the Institution's desire to thank those members and non-members who had made special contributions to the Proceedings of the Institution. Mr. Bedford stated that it was not possible to give every author a Premium since these awards were made for the most outstanding contributions on specified subjects. It was not surprising that a paper on Valve Design qualified for the award of the *Heinrich Hertz* Premium, which Mr. Bedford handed to Mr. I. A. Harris (Associate Member).

Referring to the award of the *Marconi* Premium to Mr. F. C. F. Phillips, Mr. Bedford stated that the author was not a member of the Institution and was, therefore, deserving of special thanks and congratulations for his paper on *A Direct Reading Frequency Measuring Set.*

The final Premium awarded by Mr. Bedford was, in his opinion, a most popular choice—to Mr. G. L. Hamburger for his paper *An Automatic Audio Frequency Response Curve Tracer.*

The recipients of the examination prizes and premiums made appropriate responses on receiving their awards.

12. 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.

After the Annual General Meeting, the President introduced Mr. C. O. Stanley, C.B.E., who presented a paper on "Future Television Development."

TRANSFERS AND ELECTIONS TO MEMBERSHIP

Subsequent to the publication of the list of elections to membership which appeared in the September issue of the Journal, a meeting of the Membership Committee was held on September 7th, 1949. Twenty-six proposals for direct election to Graduate or higher grade of membership were considered, and thirty-three proposals for transfer to Graduate of higher grade of membership.

The following list of elections was approved by the General Council : twenty-four for direct election to Graduate or higher grade of membership, and thirteen for transfer to Graduate or higher grade of membership.

Direct Election to Associate Member

Bailey, Richard John	Wallington, Surrey
Flavell, John Aubrey	Ipswich, Suffolk
Fotheringham, Dennis, B.Sc.	Hornchurch, Essex
Hryneczko, Wladyslaw, B.Sc.(Eng.)	Duns, Berwickshire
Hills, Augustus Frank	Stanmore, Middlesex
Vadgaokar, Manohar G., B.Sc., S/Ldr.	Baroda, India

Direct Election to Companion

Whiteley, Alfred Harold	Mansfield, Notts.

Direct Election to Associate

Bardsley, Howard	Hull, Yorks.
Haigh, Vernon Hollos	Huddersfield, Yorks.
Hancock, Harry James	Leek, Staffs.
Hannaford, Norman Clive	Gladesville, Australia
Hayes, Arthur William	Selangor, Malaya
Hiscock, Raymond Charles	Dudley, Worcs.
Lloyd, David Edward	Orpington, Kent
Masters, Norman Edward James	Watford, Herts.
Sulman, Ibrahim	Basrah, Iraq
White, Aubrey Hudson	Malvern Link, Worcs.

Direct Election to Graduate

Dallow, Raymond William	Birmingham, 32
Gibson, Stanley	Barbados, B.W.I.
Jones, Granville Paul	Blackpool, Lancs.
Langberg, Edwin	Philadelphia, 31 U.S.A.
Leathem, Albert	Belfast, N. Ireland
McDonnell Dennis	Malmesbury, Wilts.
Walters, Leonard Charles, B.A. (Cantab.)	London, S.E.15.

Transfer from Associate Member to Full Member

Allen, Charles Gilbert	Bromley, Kent
Thorne, Kenneth Gilbert	Chalfont St. Giles, Bucks.

Transfer from Associate to Associate Member

Au-Yeung, Wing Yip	Hong Kong
King, Kenneth William	South Croydon, Surrey
Nixon, Herbert	Wirral, Cheshire
Worsnop, Peter Allan	Marlborough, Wilts.

Transfer from Graduate to Associate Member

Anderson, Joseph Chapman	London, N.W.3

Transfer from Student to Associate Member

Stefani, Ivan Laurence, B.Sc. (Hons.)	Hillingdon, Middlesex

Transfer from Student to Associate

Nolan, John	Swindon, Wilts.

Transfer from Student to Graduate

Barker, John Kenneth	Cheltenham
Bates, James William	Coalville, Leicester
Crosdale, Frank	Manchester
Farrar, George Henry	Bradford, Yorks.

AN EXPERIMENTAL STUDY OF THE MAGNETIC AMPLIFIER AND THE EFFECTS OF SUPPLY FREQUENCY ON PERFORMANCE*

by

E. H. Frost-Smith, B.A.†

A paper read before the London Section on October 13th, 1949.

SUMMARY

Up to the present, the use of magnetic amplifiers has largely been confined to problems associated with the amplification of small quantities of D.C. power. In these cases, the A.C. supply to the device normally operates at power frequencies.

This paper shows that the time constant of the amplifier is limited by the supply frequency, and then goes on to discuss the possibility of reducing the response time by operating the device from a supply frequency of about 20 kc/s.

Results show that there is an optimum core size for a given frequency and power output, and that this optimum becomes more critical as the supply frequency is increased.

Finally, it is shown from experimental results that the magnetic amplifier has distinct possibilities in the field of audio frequency amplification.

The symbol $\bar{}$ above a quantity refers that quantity to mean values.

i_1 = instantaneous current in control circuit, control current = $\bar{i}_1$.

i_2 = instantaneous current in A.C. coils.

i_2' = instantaneous current in the load.

i_2'' = instantaneous rectifier capacity current.

i_o = value of i_2 when the control current $\bar{i}_1 = 0$.

i_s = value of i_2 when the amplifier is saturated.

E_2 = instantaneous supply voltage = $\hat{E}_2 \sin \omega t$.

E_S = supply voltage necessary to just saturate the core when $\bar{i}_1 = 0$.

E_T = transductor voltage corresponding to E_S ($E_T = E_S$ at low supply frequencies).

T_1 = control coil turns.

T_2 = A.C. coil turns.

A_1 = $i_1 T_1$.

A_2 = $i_2 T_2$.

a = core area.

f = supply frequency.

B_1 = polarizing or control flux density = φ_1/a.

B_2 = A.C. flux density.

B_S = saturation flux density corresponding to E_S.

R_L = load resistance.

R_1 = control circuit resistance.

R_i = parallel resistance representing iron losses.

C_r = equivalent rectifier capacitance.

X_s = reactance of transductor at saturation.

b = lamination thickness.

k_1, k_2 = eddycurrent and hysteresis constants

k_3 = saturation reactance constant.

τ = time constant.

t = time.

p = power amplification.

P = total power effectively controlled by transductor.

C_L = smoothing capacitance.

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= signal frequency.

1 = signal frequency at which amplification falls off.

ıtroduction

During the past two years several papers have een published which describe the principles and pplications of the magnetic amplifier, and it is ecoming increasingly evident that in certain elds this device has considerable potentialities, articularly in problems associated with D.C. mplification, or where a long life and miniıum servicing requirements are of primary nportance.

The magnetic amplifier in its present form, owever, does suffer from a serious defect, in ıat it has a comparatively low rate of response) variations of input signal. This fact obviously mits its application very considerably and, up) the present, magnetic amplifiers have found ıeir use mainly as D.C. amplifiers in instances 'here rapid response is of secondary importnce ; but for this defect, they would in all robability be replacing thermionic amplifiers ı many fields by virtue of their mechanical igidity and simplicity of construction.

Previous work on magnetic amplifiers has een undertaken using power supplies operating ı most cases at frequencies ranging from 0-500 c/s. This paper discusses the possibility f reducing the time constant and thereby nabling the device to be used as an L.F. A.C. mplifier by operating at much higher supply requencies, and a series of experiments is escribed which clearly indicates that there are onsiderable advantages to be gained by emıloying a power supply of 20-30 kc/s. Previous riters (see references) have already discussed he theory of magnetic amplifiers, and it will be ufficient, therefore, simply to call attention to he more important considerations.

. Fundamental Considerations

A magnetic amplifier in principle may be egarded as a low-impedance amplifier, by means f which a small signal current flowing in a coil f low impedance controls a comparatively large ower in the load device. The operation is based n the fact that when the core of an A.C. reactor s polarized by means of a direct current, the ermeability of the core is reduced, and therefore the effective impedance of the reactor is decreased.

The diagram in Fig. 1 shows the circuit connections of a simple magnetic amplifier unit or transductor. The more usual practical arrangements are shown in Fig. 2. Thus it will be seen that the essential parts consist of two identical iron cores A and B, with a pair of windings placed on each core ; the A.C. windings 2*a* and 2*b* are connected to the A.C. power supply, and the D.C. windings 1*a* and 1*b* are connected to the signal source.

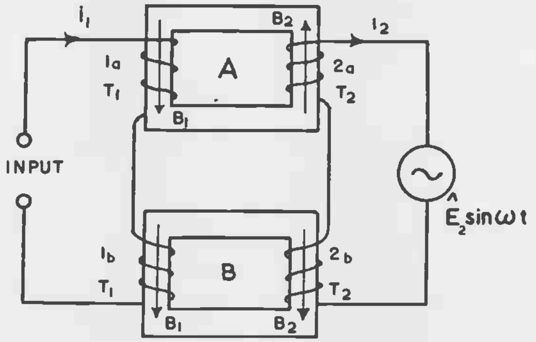


Fig. 1.—Circuit connections of a simple transductor unit.

The input circuit provides each core with magnetizing ampere turns i_1 T_1, while the A.C. load circuit provides ampere turns of magnitude i_2 T_2. Coils 2*a* and 2*b* are connected in opposition, thereby ensuring that no e.m.f. is induced in the input windings from the power supply. At any instant, if the total magnetic flux density in A is B_1+B_2, the flux density in B will be B_1-B_2.

For the purpose of elucidation, it is assumed that there is no resistance in the A.C. circuit. If there is no control current flowing, and the core characteristic is approximately linear over the operating range, then the total magnetizing ampere turns will be sinusoidal.

If, however, the cores are pre-magnetized with a polarizing flux B_1 due to an applied signal, so that they become saturated at intervals during the cycle of flux B_2, then the device will be operating in the non-linear region, and unsymmetrically with respect to the magnetization curve. Under these conditions the magnetizing ampere turns may be represented by a Fourier series containing both odd and even harmonics.

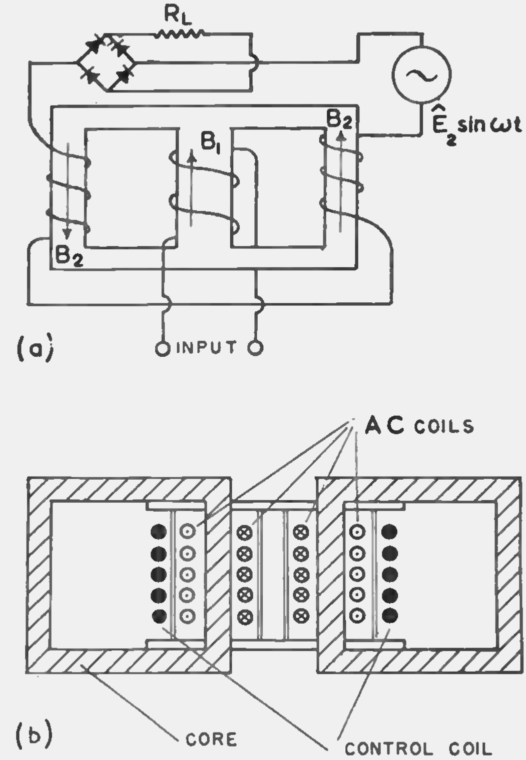


Fig. 2.—Practical arrangement of windings on transductor core.

The odd harmonics will be contributed by the load ampere turns i_2 T_2, while the even harmonics will be contributed by the current in the input windings and will be given by i_1 T_1. If the control circuit is of high impedance, the even harmonics will be reduced and the voltages across 2*a* and 2*b* will be distorted with even harmonic components. The harmonics present must of course add up to $\hat{E}_2 \sin \omega t$ since no load resistance has been postulated. If a load resistance is introduced in series with the A.C. windings, the voltages across 2*a* and 2*b* will be distorted with odd harmonic components and will no longer add up to $\hat{E}_2 \sin \omega t$. An analysis of flux and current waveforms for low-frequency operation has been given by Gale and Atkinson.[1]

In the majority of applications the load current is rectified and is therefore given by a unidirectional current of magnitude $\bar{i}_2$, so it has become common practice to regard mean values as having particular significance. Similarly, the useful power amplification or power output are expressed in terms of mean values of voltage and current.

Now the mean value of i_1, which is given by $\bar{i}_1$, corresponds with the D.C. input signal. If for the circuit in Fig. 1 a curve of $\bar{i}_1$ against $\bar{i}_2$ is plotted for a constant supply voltage of mean value $\bar{E}_2$, the general shape of this curve will be shown in Fig. 3. It may be seen that when there is no input, a small initial current $\bar{i}_o$ flows in the load, and this represents the current required to magnetize the core in the unsaturated state. It also provides that power which is absorbed in the iron core due to hysteresis and eddy currents. The maximum load current is given by $\bar{i}_s$, corresponding to the load current when the core is fully saturated. Its magnitude will vary with supply voltage and approximately inversely as the load resistance.

For an ideal system $\bar{i}_o$ should be zero and $\bar{i}_s$ given by $\frac{\bar{E}_2}{R_L}$. On these assumptions the following relations may be derived :—

$$\frac{\bar{i}_2}{\bar{i}_1} = \frac{T_1}{T_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Also, since the initial current $\bar{i}_o$ has been neglected, it is evident that the total power controlled by the device is given by the total power output

$$P = \frac{\bar{E}_2{}^2}{R_L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

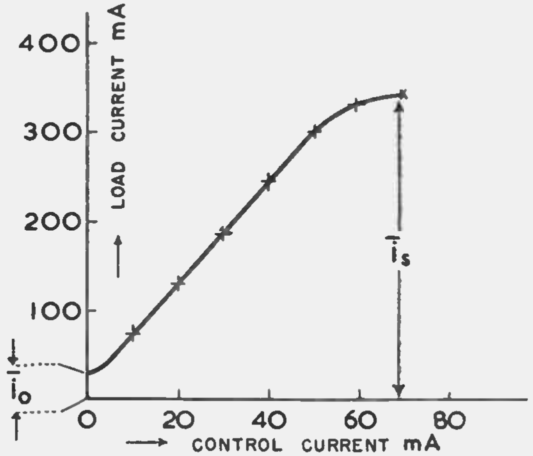


Fig. 3.—Control current characteristic for R_L = 50Ω.

If the control circuit resistance is R_1 then the power amplification is

$$p = \frac{T_1^2}{T_2^2} \; \frac{R_L}{R_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Now, Fig. 4 is an experimentally-derived characteristic in which the mean transductor supply voltage $\bar{E}_2$ is plotted against mean load current $\bar{i}_2$ for different values of $\bar{i}_1$, and zero load resistance. The value of T_1 was 750, T_2 was 130, and the supply frequency was 440 c/s approximately sinusoidal.

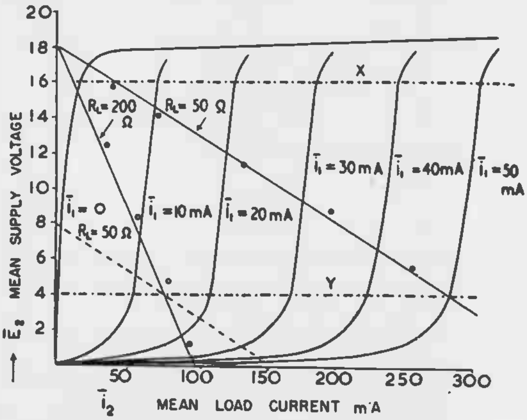


Fig. 4.--Transductor characteristic showing two possible load lines.

Two straight lines corresponding to resistive loads have been added to the diagram, and the experimentally-derived points for these actual loads are also shown. It may be observed that, although, as has already been pointed out, the waveform of the transductor voltage is considerably distorted, the experimental points agree surprisingly well with the load line provided that mean values are plotted.

On examination of this family of curves, it is apparent that within the region bounded by the lines X Y, the current is nearly independent of supply voltage, that is to say that the amplifier is operating as a constant current device within this region, and the value of the current depends upon the control current. For this reason equation (1) may be expected to apply almost independently of load resistance.

Another important observation is that, in order to get maximum power output, $\bar{E}_2$ should be given by $\bar{E}_S$ where $\bar{E}_S$ is the mean value of that particular supply voltage which causes the maximum flux in the core to be just below the knee of the magnetization curve.

The behaviour of the polarizing flux B_1 in relation to the quantities $\bar{i}_1$ and $\bar{E}_2$ is now examined. This is very important as it has a direct bearing on the transient behaviour of the magnetic amplifier. The approach is purely experimental and demonstrates very simply the chief factors on which the response may be expected to depend.

There is little doubt that the cause of time delays in the system is due to changes in the mean flux B_1, which occur when the control current changes. This suggests that as a possible starting point the behaviour of B_1 should be investigated when the control current and supply voltage are varied.

This was achieved using the same transductor whose characteristics are shown in Fig. 4, but with another coil wound over the control coil. This additional coil was placed in series with a high resistance and a ballistic galvanometer. When the value of $\bar{i}_1$ was changed, the galvanometer would swing by an amount proportional to the change in control flux B_1.

B_1 was plotted against control current by observing the total swing of the galvanometer when the control current was reversed. This was performed for several values of supply voltage $\bar{E}_2$.

Due to the even harmonics circulating in the flux search coil and ballistic galvanometer, random disturbances were liable to occur, but these were almost entirely removed by connecting a small condenser across the coil, of insufficient capacitance to disturb the operation, but large enough to provide a path for the parasitic currents.

The curves are drawn in Fig. 5 and the following points are to be noted :

(1) The parameter corresponding to $\bar{E}_2 = 0$ is the familiar magnetization characteristic.

(2) For the lower values of $\bar{E}_2$, the slope is given by the slope of the magnetization curve when $\bar{i}_1$ is small.

(3) After the initial bend in the curve, B_1 is nearly independent of $\bar{i}_1$ and given

approximately by $B_1 = B_S - k\overline{E}_2 \ldots\ldots (4)$

where $k \propto \dfrac{1}{afT_2}$.

The transient behaviour of a transductor to which is suddenly applied a signal voltage v at the input terminals is next considered.

Equating the e.m.f.'s in the control circuit :—

$$v = R_1\bar{i}_1 + T_1\frac{d\varphi_1}{dt}$$

$$= \frac{R_1\overline{A}_1}{T_1} + \frac{d\varphi_1}{d\bar{i}_1}\cdot\frac{d\overline{A}_1}{dt} \text{ since } T_1\bar{i}_1 = \overline{A}_1$$

$$= \frac{R_1\overline{A}_2}{T_1} + \frac{d\varphi_1}{d\bar{i}_1}\cdot\frac{d\overline{A}_2}{dt}$$

Since $\overline{A}_1 = \overline{A}_2$ (see equation (1)) the solution of this is given by :—

$\overline{A}_2 \propto (1 - e^{-t/\tau})$, assuming $\dfrac{d\varphi_1}{d\bar{i}_1}$ is a constant where $\tau = \dfrac{aT_1}{R_1}\cdot\dfrac{dB_1}{d\bar{i}_1}$ since $\varphi_1 = aB_1$; now one may write $\dfrac{dB_1}{d\bar{i}_1} = \dfrac{\partial B_1}{\partial\overline{E}_2}\cdot\dfrac{\partial\overline{E}_2}{\partial\bar{i}_2}\cdot\dfrac{\partial\bar{i}_2}{\partial\bar{i}_1}$.

From equation (4), $\dfrac{\partial B_1}{\partial\overline{E}_2} \propto \dfrac{1}{afT_2}$

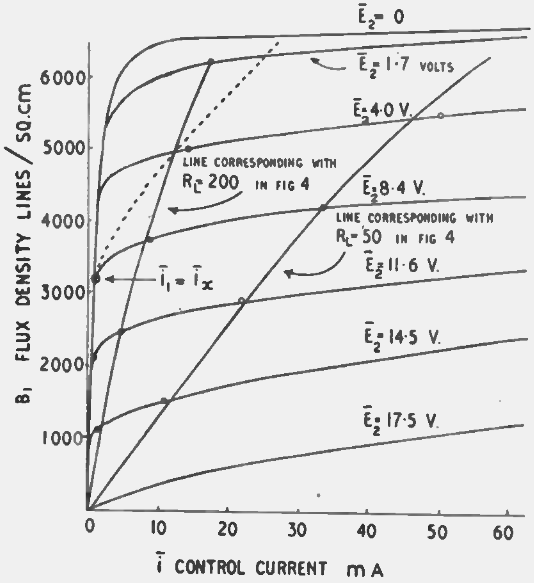


Fig. 5.—Curve showing how the mean flux B_1 varies with control current for different values of E_2.

and equation (1) gives $\dfrac{\partial\bar{i}_2}{\partial\bar{i}_1} = \dfrac{T_1}{T_2}$

$$\therefore \frac{dB_1}{d\bar{i}_1} \propto \frac{T_1}{afT_2^2}\cdot\frac{\partial\overline{E}_2}{\partial\bar{i}_2}.$$

Now $\dfrac{\partial\overline{E}_2}{\partial\bar{i}_2}$ may be obtained from Fig. 4 and has been shown to be given approximately by $-R_L$.

Thus substituting in the expression for τ

$$\tau \propto \frac{R_L}{R_1}\cdot\frac{T_1^2}{T_2^2}\cdot\frac{1}{f}$$

which from equation (3) gives

$$\tau \propto \frac{p}{f} \ldots\ldots\ldots\ldots\ldots (5)$$

In order to complete the above argument, two lines corresponding to 200Ω and 50Ω in Fig. 4 have been drawn in Fig. 5. These show that $\dfrac{dB_1}{d\bar{i}_1}$ is not constant and therefore the reasoning above is not strictly accurate, which means that the response will not be truly exponential. See Fig. 6 (*b*).

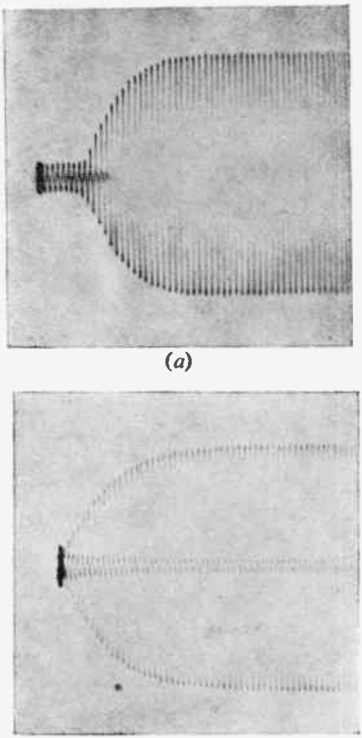
In Fig. 5 the dotted line indicates the variations of B_1 with $\bar{i}_1$ for a very low supply voltage. The corresponding line is drawn in Fig. 4, and this results in a very large value of $\dfrac{dB_1}{d\bar{i}_1}$ initially, which will cause a delay period before the amplifier starts to respond, i.e., before the current reaches a value given by $\bar{i}_x$ (Fig. 5).

For this reason it is important that the supply voltage should be sufficient to ensure the correct conditions of operation.

The two oscillographic recordings in Fig. 6 show the effect of supply voltage on performance, (*a*) with $\overline{E}_2 = \frac{1}{2}\,\overline{E}_S$, (*b*) with $\overline{E}_2 = \overline{E}_S$.

By applying self excitation to the transductor it has been shown that the power amplification increases approximately as the square of the self excitation, while the time-constant increases proportionally. The ratio of power amplification to time-constant may therefore be increased in this way[2]. Unfortunately, self excitation tends to cause zero drift in the amplifier and therefore it may be applied only to a limited extent.

From equation (5) it appears that by increasing



(*a*)

(*b*)

Fig. 6.—Showing effect of supply voltage on performance.

the supply frequency, the time constant will be reduced, and this therefore was considered to be a reasonable starting point for the investigation.

2. Factors which influence Transductor Performance at High Supply Frequencies

When the transductor operating at high frequencies is considered, a number of factors, which were hitherto considered negligible, become important, and it is the object of this section to attempt to indicate the way in which these factors may be expected to modify transductor performance. As the supply frequency is increased the problem assumes such a complex nature that a useful theoretical analysis seems almost impossible, and for this reason attempts at a mathematical investigation have been abandoned in favour of a direct interpretation of experimental evidence.

Up to the present, most theoretical analyses have started from the assumption that, when there is no control current flowing in the input circuit, the mean output current $\bar{i}_o$ is negligibly small. At the same time $\bar{i}_2$, the mean alternating current in the A.C. windings, is supposed to pass entirely through the load resistance R_L, and at saturation the whole supply voltage is regarded as developed across R_L. Such ideal conditions are, of course, never attained in practice, and while these simplifications may be to some extent valid at power frequencies, they are certainly not justifiable above 2 or 3 kc/s.

The main departures from the ideal case are therefore considered first. There is little doubt that the upper limit of supply frequency is determined by the magnitude of iron losses, due to hysteresis effects and eddy currents in the core.

A number of experiments have been carried out on the iron losses in mumetal using a parallel resistance wattmeter[3] and the results show that, to within reasonable limits, the iron losses may be represented by a fixed resistance across the A.C. terminals of the transductor. The self capacity of the rectifier must also be considered. Since a dry plate rectifier unit consists of two disc electrodes separated by a very thin semi-conducting medium, its capacitance is considerable and has the effect of reducing the impedance of the rectifier in the reverse direction particularly at high frequencies; this effect is difficult to estimate with any degree of accuracy, but Richards[4] has stated that, for a selenium rectifier, the capacitance is of the order of ·02 μF per cm^2 of rectifying surface.

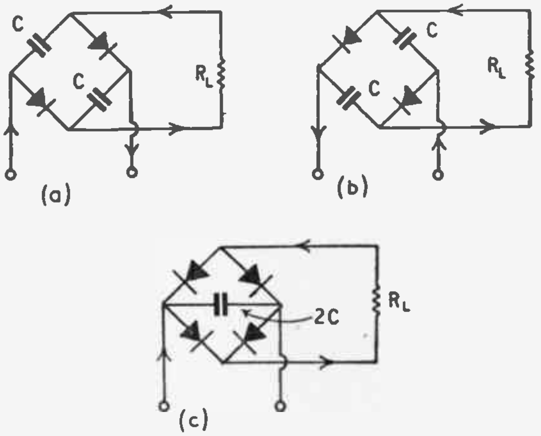


Fig. 7.—Showing derivation of equivalent circuit for rectifier.

Referring to Fig. 7 (*a*) and (*b*), in which four units each of capacitance C are combined to form a bridge, and assuming that the forward resistance of each element is zero while the reverse resistance is infinite, a diagram for each half cycle may be drawn as shown in (*a*) and (*b*). Under these ideal conditions the capacity of the conducting elements will be short-circuited.

Both diagrams can be combined to give Fig. 7 (*c*) which corresponds to an ideal bridge rectifier with a parallel capacitance 2C. Normally the reverse resistance is not infinite, and the forward resistance may be appreciable, so the equivalent capacitance between A and B will be represented by something less than 2C. Experiments on four rectifier units each having discs of 11 cm² area showed that under certain conditions the average shunt capacitance of each was about ·25 μF. When the four units were connected to form a bridge network the total effective capacitance of the bridge was about ·4 μF at full load and rather more for small load currents.

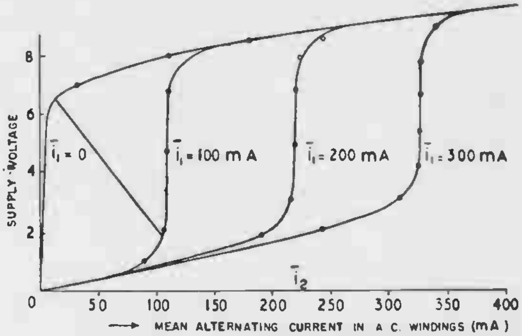


Fig. 8a.—No load characteristic for transductor operating at 1 kc/s.

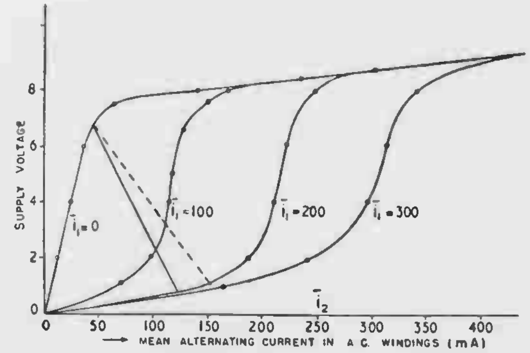


Fig. 8b.—No load characteristic for transductor operating at 13 kc/s.

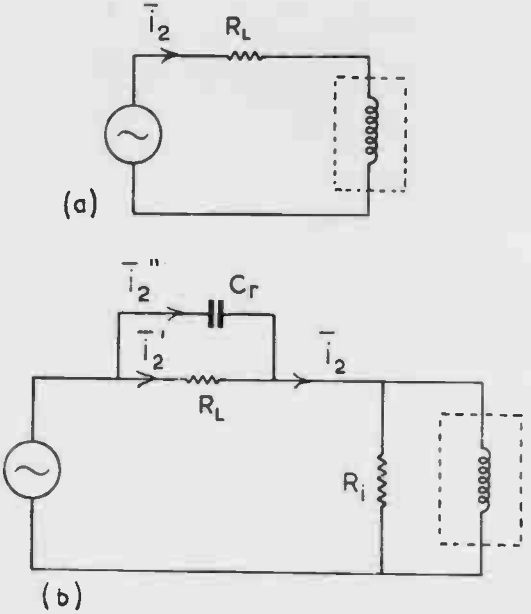


Fig. 9.—Equivalent circuit diagrams for transductor (a) at low frequency (b) at high frequency showing effects of losses and rectifier capacity.

An approximate representation of the transductor operating at high supply frequencies may therefore be obtained by considering an ideal transductor with an ideal rectifier. The various circuit elements introduced represent iron losses and rectifier capacitance as in Fig. 9 (*b*).

The quantity $\frac{\bar{E}_T^2}{R_i}$ represents the iron losses, C_r corresponds to the rectifier capacitance, whilst its resistance may be considered to be lumped with R_L, the load resistance.

An investigation of the properties of transductors over a wide frequency range was carried out on a toroidal unit, details of which were as follows. Two small toroidal cores made of ·003 cm mumetal strip had an effective cross-sectional area of about ·2 cm²; the A.C. coils were wound one on each of two cores and connected in series. These two cores were then bound together and the control coil was wound over them jointly so as to link both A.C. coils simultaneously. Both the control coil and the A.C. coils were tapped at intervals to enable the device to be operated under various conditions of supply voltage and frequency.

The source of supply for these experiments was a low impedance 20-W beat frequency oscillator giving any required frequency up to 25 kc/s, of approximately sinusoidal waveform.

Voltage-current characteristics similar to those in Fig. 4 are plotted in Fig. 8. The curves (*a*) correspond to a frequency of 1 kc/s, while those in (*b*) were taken at a supply frequency of 13 kc/s.

These curves show that the effect of iron losses at the high frequency is to decrease the slope of the control current parameters in the constant current region.

A load line has been drawn for both frequencies, and it may be seen that $\bar{i}_o$, the current in the load when $\bar{i}_1 = 0$, is increased by the presence of losses.

In Figs. 9 and 10 the effect of iron losses and rectifier capacitance is shown. At lower frequencies the load circuit diagram may be represented as in Fig. 9*a*, where losses and rectifier imperfections are comparatively negligible, whilst the circuit in Fig. 9*b* may be regarded as approximating to high frequency conditions. It will be shown that the mean load current $\bar{i}_2'$ is no longer equal to the mean current in the A.C. windings $\bar{i}_2$.

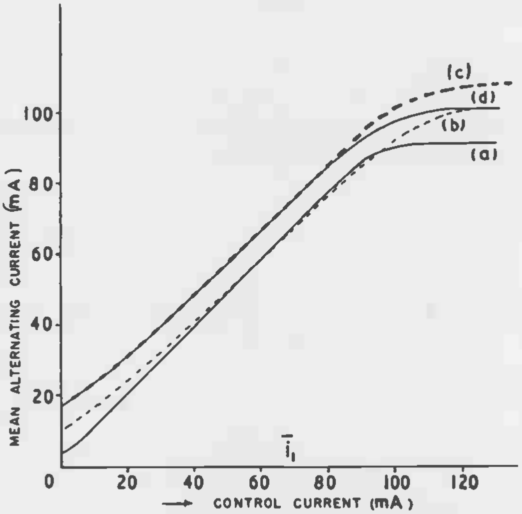


Fig. 10.—Showing the effect of losses and rectifier capacity on the control current characteristic (a) at 1 kc/s (b) at 13 kc/s.

Fig. 10 shows the control current $\bar{i}_1$ plotted against the load current $\bar{i}_2'$ (*a*) at 1 kc/s and (*b*) at 13 kc/s. In this case the transductor supply voltage $\bar{E}_T$ was the same in both cases; the load resistance was 100 Ω and the ratio $\frac{T_2}{T_1} = 1$.

The curve (*c*) shown chain dotted represents the mean value of the total current in the A.C. windings, $\bar{i}_2$ being plotted against control current at 13 kc/s; $\bar{i}_2$ was measured on a moving coil instrument employing diode rectifiers. Curve (*d*) corresponds to the load current when the bridge rectifier was omitted, and in order to maintain a comparable circuit resistance, the value of R_L was increased by an amount equal to the rectifier resistance.

It will be seen that in case (*d*) the load current at saturation is greater than in case (*a*) and the reason for this is as follows: it has been shown in the previous section that the supply voltage must be just sufficient to cause flux saturation in the core and that the supply voltage for these conditions is given by $\bar{E}_S$, the corresponding transductor voltage being $\bar{E}_T$. Now the saturation load current $\bar{i}_s$ is given by $\frac{\bar{E}_S}{R_L}$ and when $\bar{i}_o$ is negligible this is nearly equal to $\frac{\bar{E}_T}{R_L}$. When $\bar{i}_o$ is increased due to losses, however, $\bar{E}_T$ is decreased due to the voltage drop $R_L\ \bar{i}_o$ in the load; therefore the supply voltage must be increased slightly in order to attain the correct working voltage at the transductor terminals, and the load current at saturation will therefore increase correspondingly.

Assuming that curve (*a*) Fig. 10 represents ideal conditions, a parallel resistance R_i is now introduced into Fig. 9*a* and, whilst maintaining the original value of $\bar{E}_T$, a curve of control current against load current is plotted. This corresponds with Fig. 10 (*d*), in which it appears that the effect of iron losses has been to decrease the slope of the characteristic.

If a small condenser is now placed across the load resistance, then provided it is not large enough to cause resonances, it will bring about a decreased total impedance in the A.C. circuit and might therefore be represented by the dotted line in Fig. 8 (*b*). If under these conditions load current is plotted against control current a curve similar to that in Fig. 10 (*c*) will be obtained, and it may be seen that while the current gain is practically the same as in (*d*), the *total* current at saturation is now increased. The resistive load current $\bar{i}_2'$ is less than the total current and the final characteristic at the high frequency is therefore given by the curve (*b*).

In Fig. 11 the curves (*a*), (*b*), (*c*) and (*d*) have been redrawn, but with the conditions exaggerated to demonstrate the effects more clearly. This step-by-step process was verified experimentally at low frequencies by introducing the appropriate circuit conditions artificially at each stage.

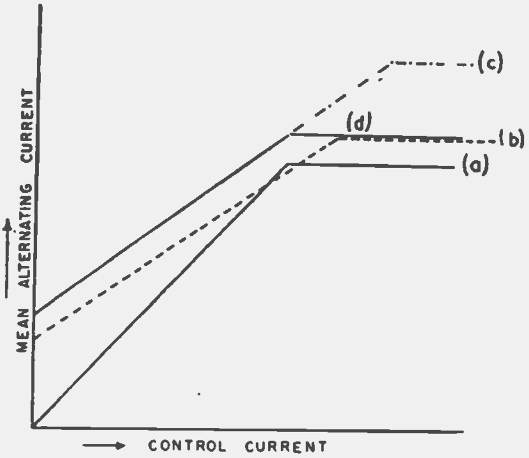


Fig. 11.—Sketch showing the salient points in Fig. 10 exaggerated.

It should be noted that if the rectifier capacitance is very large, it will determine to some extent the load current $\bar{i}_2'$; and any capacitance variations with temperature, corresponding to changes in load current, will cause instability, particularly if positive feedback is applied to the amplifier. For this reason the rectifier must be kept as small as possible consistent with handling the necessary load current.

It need hardly be emphasized that the effect of losses and rectifier capacitance will make prediction of the waveform of load current i_2' extremely difficult. If, however, the total circuit current i_2 is considered to consist of rectangular pulses of current (as in Fig. 12 (*a*)) applied to the rectifier-load circuit of Fig. 12 (*b*), the following equations may be written, and some idea of the effects of rectifier capacitance can be obtained :

$$i_2' + i_2'' = i_2$$

$$i_2'' = C_r \frac{dv}{dt} = R_L C_r \frac{di_2'}{dt}$$

$$\therefore \frac{di_2'}{dt} + \frac{i_2'}{C_r R_L} = \frac{i_2}{R_L C_r}$$

Now at x, Fig. 12 (*a*),

$$i_2 = I \quad \therefore \frac{di_2'}{dt} + \frac{i_2'}{R_L C_r} = \frac{I}{R_L C_r}$$

the solution of this is :

$$i_2' = I + Ae^{-\frac{t}{C_r R_L}}$$

At x let $t = 0$ and $i_2' = 0 \quad \therefore A = -I$

$$\therefore i_2' = I\left(1 - e^{-\frac{t}{C_r R_L}}\right)$$

At y, Fig. 12 (*a*), $i_2 = 0$

and similarly the solution of $\frac{di_2'}{dt} + \frac{i_2'}{C_r R_L} = 0$

is given by $i_2' = Ie^{-\frac{t}{C_r R_L}}$.

If i_2' is now drawn according to these two equations, the waveform of load current becomes as in Fig. 12 (*c*) after rectification.

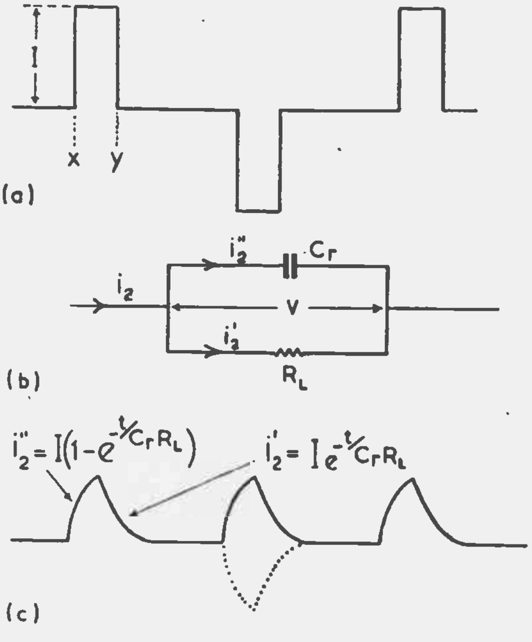
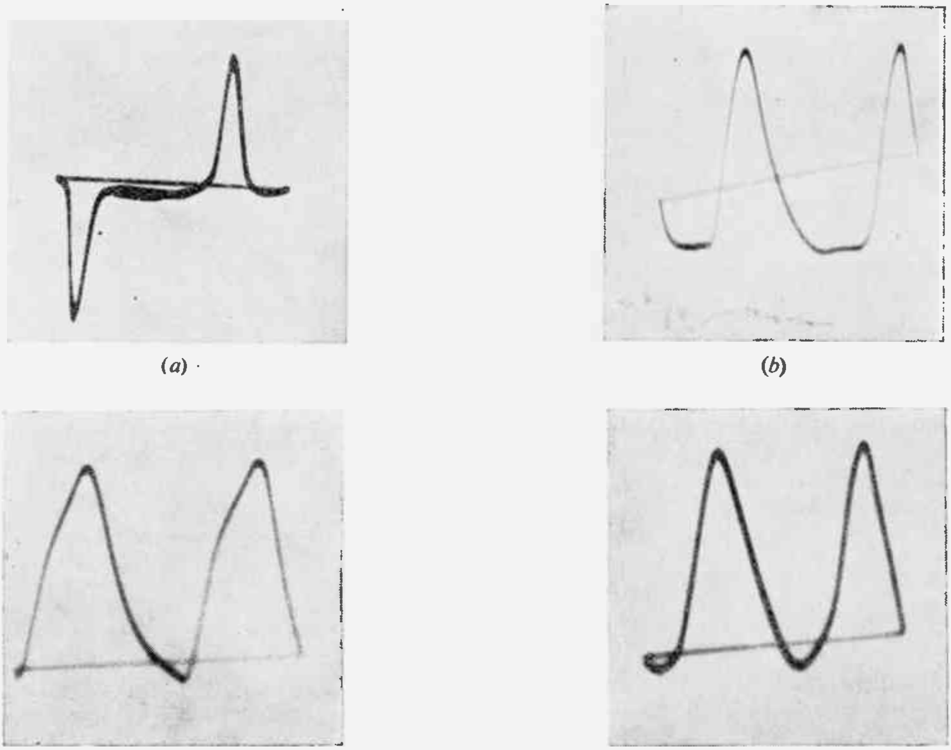


Fig. 12.—Showing waveform of load current after rectification.



(a) (b)

(c) (d)

Fig. 13.—Waveforms of unsmoothed load current after rectification.

In Fig. 13 four oscillograms are shown, representing (*a*) the waveform of i_2 which, according to the previous theory, was assumed to consist of rectangular pulses, and using a supply frequency of 1 kc/s, (*b*) the effect of the rectifier at 1 kc/s with a condenser placed across the A.C. terminals of the rectifier, (*c*) the effect of using a large rectifier underrun at 10 kc/s, (*d*) an oscillogram of unsmoothed load current for a transductor operating under normal conditions at 20 kc/s.

From the preceding discussion it is seen that, under the appropriate conditions, the magnetic amplifier can be operated satisfactorily from comparatively high supply frequencies, with a corresponding reduction in time constant.

It will be appreciated from equation (5) that the ratio of power amplification to time constant is of considerable importance, and this ratio has therefore been determined as a function of supply frequency.

The circuit diagram employed in obtaining this curve is shown in Fig. 14. The transductor was operated over a range of supply frequencies, and at each frequency the following quantities were measured :

(*a*) The change in control current required to produce a predetermined change in load current (corresponding to about 30 per cent of the total linear range).

(*b*) The response time of the amplifier measured over this range of load current.

(*c*) The total resistance in the control circuit R_1. During these measurements the transductor voltage $\overline{E}_T$ and the load resistance R_L were maintained constant.

The method of measuring the response has already been described[5] and will not therefore be discussed here.

The total control circuit resistance R_1 was measured on a bridge which was short-circuited when not in use by means of a switch S_1 (Fig. 14). While the bridge measurement was being made, the supply to the control circuit was switched off by means of the switch S_2. The resistance r (Fig. 14) was large in comparison with r' to ensure that when S_2 was opened, the total resistance R_1 was not substantially altered.

Knowing the input and load impedances and the current gain, the ratio of

$$\frac{\text{mean power amplification}}{\text{time constant}}$$

was plotted against supply frequency, giving the curve shown in Fig. 15.

It will be seen from this curve that there is only a slight tendency for the slope to decrease especially below 10-15 kc/s.

This decrease is less than would be expected from the reduction due to iron losses in power amplification. At 13 kc/s, the decreased slope of the control characteristic Fig. 10 (*b*) compared with Fig. 10 (*a*) corresponds with a more pronounced decrease in the ratio $\frac{p}{\tau f}$ than is actually depicted in Fig. 15.

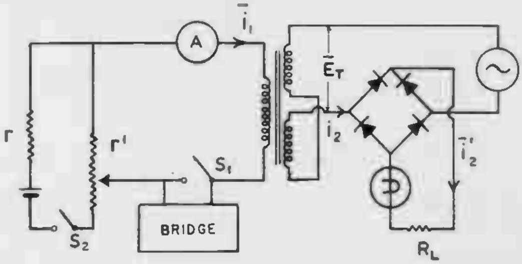


Fig. 14.—Circuit used for plotting p/τ against supply frequency.

The reason may be that iron losses cause a slight increase in rate of response, but it is difficult to obtain experimental evidence of this since the effects are all of the second order. By employing the equivalent circuit at low frequencies, however, and introducing artificial iron losses as described, there was a noticeable decrease in time constant which to some extent may have compensated for the decrease in power amplification.

The value of R_i was varied from ∞ to 400 Ω, and over this range the current gain in this particular instance decreased from 2·23 to 2·00, that is a decrease of about 20 per cent when expressed in terms of power gain. The time constant, however, decreased simultaneously from about 28·5 milliseconds to about 25 milliseconds, corresponding to a fall of about 14 per cent.

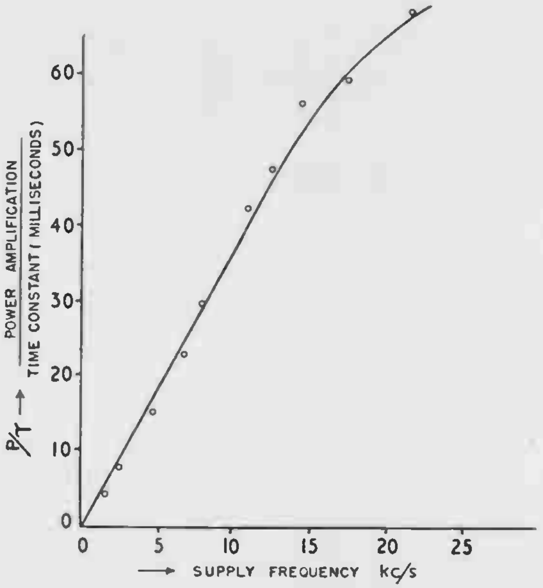


Fig. 15.—Showing how the ratio of power amplification to time constant varies with supply frequency.

The previous results were all obtained on the same transductor unit and the core area was the same for all supply frequencies. It will be shown that, based on the foregoing criterion of performance, there is an optimum value for the core area at any one frequency.

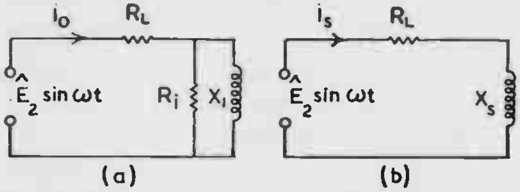


Fig. 16.—Two extreme states of operation in the AC circuit (a) for zero control current (b) for maximum control current at saturation.

When transductors are operated at lower frequencies the internal losses are considered to be of secondary importance, but, at higher frequencies, it is usually necessary to rely on a limited power supply and for this reason the matter assumes greater significance. If it is required to obtain the maximum range of control for a given source and load, it is necessary to achieve a balance between iron losses and reactive voltage drops in the A.C. windings at saturation.

Referring to Fig. 16, the two extreme conditions under which the transductor may operate are considered, (*a*) at zero input, and (*b*) at maximum input when the core is saturated.

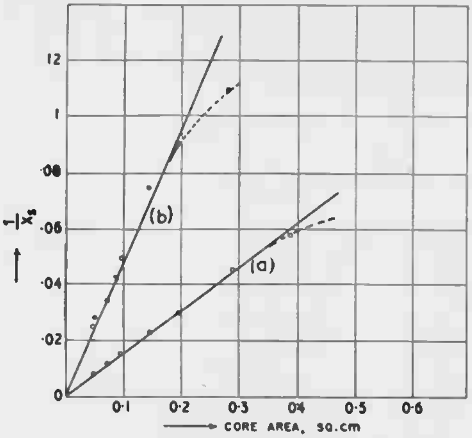


Fig. 17.—*Curves showing how (a) iron losses and (b) saturation reactance vary with core area.*

In case (*a*) the total current consists of the magnetizing current plus the loss current and, since the core is unsaturated, i_o will be approximately sinusoidal. As would be expected, the magnetizing component of the current is reactive, and the other representing the losses is resistive, being considered to flow in the parallel resistive path R_i.

In case (*b*) the total voltage developed across the load is less than the supply voltage due to the voltage drop across the transductor, and because the core is saturated, this voltage may also be considered sinusoidal. It is due mainly to the reactance of the A.C. windings, because, in most cases the effect of the resistance is relatively negligible.

The core permeability even at saturation is greater than unity, and therefore X_S will be greater than the air-cored reactance of the A.C. coils. This reactance is difficult to predict with any degree of accuracy, but depends primarily upon the core area, the turns on the A.C. coils and the frequency.

The effect of these factors on the operating range of the transductor is next investigated. Since second order effects are involved the following further assumptions will be made :—

(1) that $R_i \gg R_L$ and therefore $\bar{i}_o = \frac{\bar{E}_S}{R_i}$.

(2) that $R_L \gg X_S$ and therefore $R_L = \frac{\bar{E}_S}{\bar{i}_s}$.

Proceeding thus, the initial power in the load resistance for zero input is $\left(\frac{\bar{E}_S}{R_i}\right)^2 R_L$ ......(6)

The voltage across R_L at saturation when the input is maximum is given by :

$$\sqrt{\bar{E}_S{}^2 - X_S{}^2 \bar{i}_s{}^2}$$

and therefore the power consumed in the load at saturation $= (\bar{E}_S{}^2 - X_S{}^2 \bar{i}_s{}^2)/R_L$ ....(7)

The total power effectively controlled is therefore obtained by subtracting (6) from (7) and

$$P = \frac{\bar{E}_S{}^2}{R_L} - \frac{X^2{}_S \bar{i}_s{}^2}{R_L} - \frac{\bar{E}_S{}^2}{R_i{}^2} R_L \quad \text{....(8)}$$

$$\text{Now } \frac{\bar{E}_S{}^2}{R_i} = \text{the iron losses} = k_1 a f^2 b + k_2 a f$$

$$\therefore \frac{1}{R_i} = \frac{a}{E_S{}^2}[k_1 f^2 b + k_2 f] \quad \text{....(9)}$$

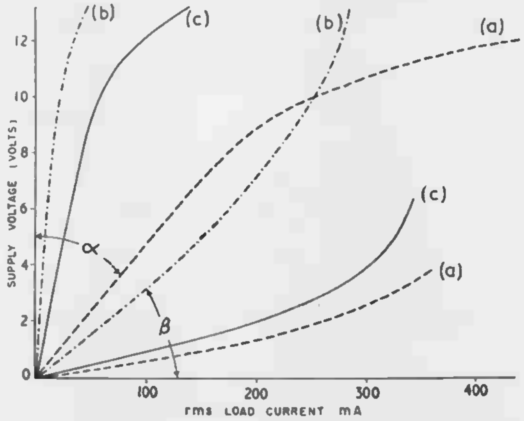


Fig. 18.—*Curves showing the effect of excessive iron losses or saturation reactance on the load characteristics.*

Fig. 17 (*a*) is an experimentally-derived curve of $\frac{1}{R_i}$ against core section at constant supply voltage and frequency.

The term X_S may be considered proportional to $aT_2{}^2 f$, so let $X_S = k'aT^2 f$ ....(10)

The relation between maximum flux density and supply voltage is $\bar{E}_s = k'' B_s a f T_2$ ......(11) and for mumetal B_s = approx. 6,000 lines/cm². Then combining (10) and (11) $X_s = \dfrac{k_3 E_s^2}{af}$ ..(12)

Fig. 17 (*b*) is a curve of $\dfrac{1}{X_s}$ against area for the same conditions as (*a*), and it will be seen that in this case the agreement is not so good.

If the expression for $\dfrac{1}{R_i}$ and X_s (9) and (12) is now substituted into the expression for P (8) and if $\bar{i}_s = \dfrac{\bar{E}_s}{R_L}$ then

$$P = \frac{\bar{E}_s^2}{R_L}\left[1 - \frac{k_3^2 \bar{E}_s^4}{a^2 f^2 R_L^2} - \frac{R_L^2 a^2 (k_1 f^2 b + k_2 f)^2}{\bar{E}_s^4}\right]$$

Differentiating with respect to a and equating to zero gives the condition for P to be maximum and shows that the optimum area is given when

$$a = \frac{\bar{E}_s^2}{f R_L}\sqrt{\frac{k_3}{k_1 b f + k_2}} \quad \ldots\ldots\ldots\ldots(13)$$

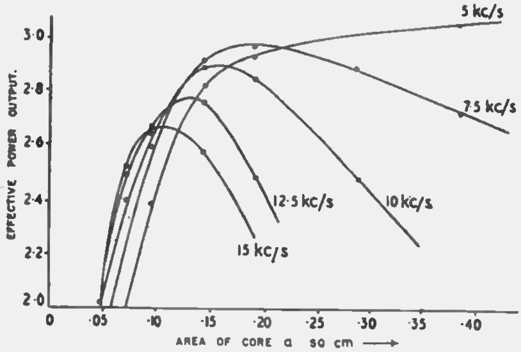


Fig. 19.—Curves showing how the effective output varies with core area at different supply frequencies.

and for this value of a

$$P = \frac{\bar{E}_s^2}{R_L}\left[1 - 2k_3 (k_1 b f + k_2)\right] \quad \ldots.(14)$$

If equations (9) and (12) are substituted in (13) then

$$X_s R_i = R_L^2 \;\therefore\; \frac{X_s}{R_L} = \frac{R_L}{R_i} = \frac{\bar{E}_s^2/R_i}{\bar{E}_s^2/R_L}$$

and so the condition for maximum controlling range is obtained when

$$\frac{\text{saturation reactance}}{\text{load resistance}} = \frac{\text{iron losses}}{\text{total power output}}$$

Thus it is seen that at any frequency there is an optimum core area and this is dependent upon supply voltage and load. Also that as the frequency is increased, the control range P is reduced linearly and that for this reduction to be small, the thinnest available laminations should be employed.

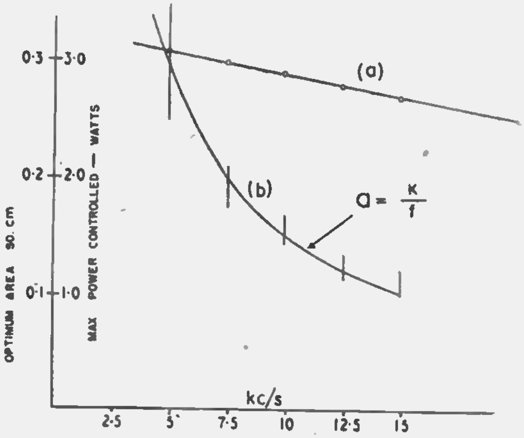


Fig. 20.—(a) Effective control range plotted against frequency. (b) Optimum core area plotted against frequency.

Fig. 18 shows three current-voltage characteristics for a supply frequency of 7·5 kc/s. They are plotted for r.m.s. values.

Fig. 18 (*a*) shows the effect of excessive iron losses, i.e., α is large ;

Fig. 18 (*b*) shows the effect of high saturation reactance where the angle β is excessive ;

Fig. 18 (*c*) shows the result of attaining a reasonable balance between these two factors.

The curves of Fig. 19, which were taken at various frequencies, indicate how the control range varies with core area. It is of interest to note that not only does the optimum area vary with frequency, but also that this optimum is much more precisely defined at the higher frequencies.

Finally, Fig. 20 (*a*) gives the maximum effective control range as a function of the supply frequency, whilst Fig. 20 (*b*) shows how the optimum area varies with supply frequency. On these curves, the optimum area at each frequency has been plotted as a vertical line, and an indication is thereby given of the approximate limits of area within which optimum results may be obtained. It may be noticed that the hyperbola $a = \frac{K}{f}$ lies reasonably well within these limits.

In the foregoing paragraphs, it was an assumed condition that the total power controlled should be a maximum, and on this assumption, the relations were derived. A possible requirement, however, is that the total swing of load current must be a maximum. This will lead to slightly different results. The total change of load current is :—

$$\bar{i}_s - \bar{i}_o = \frac{\sqrt{\bar{E}_S^2 - X_S^2 \bar{i}_s^2}}{R_L} - \frac{\bar{E}_S}{R_i}$$

From this, the following results are obtained :—

(1) The condition for $i_s - i_o$ to be maximum is that

$$\frac{\text{saturation reactance}}{\text{load resistance}} = \sqrt{\frac{\text{iron losses}}{\text{total power output}}}$$

(2) The optimum core area is given when

$$a = \frac{\bar{E}_S^2}{fR_L}\left[\frac{k_3^2}{k_1bf + k_2}\right]^{\frac{1}{3}} \text{c.f. equation 13.}$$

(3) The value of $(\bar{i}_s - \bar{i}_o)^2 R_L$

$$= \frac{\bar{E}_S^2}{R_L}\left[1 - \tfrac{3}{2} k_3^{\frac{2}{3}}(k_1fb + k_2)^{\frac{1}{3}}\right] \text{c.f. equation 14.}$$

This would be the maximum power swing if the amplifier were biased so that $i_o = 0$.

Results show that the optimum area, as given in these cases, is slightly less than that given in equation 13. For example, referring to Fig. 19, the optimum area is approximately ·1 cm² at 15 kc/s. For maximum current, however, the optimum is about ·08 cm².

The foregoing observations were all made using laminations for which $b = \cdot 005$ in.

3. The Magnetic Amplifier as an A.C. Amplifier

Up to the present the magnetic amplifier has been considered solely as a D.C. amplifier. It may, however, be utilized for the amplification of A.C. signals provided that their frequency is well below that of the excitation frequency and the time constant of the device is sufficiently small.

It has been shown that marked improvements in time constant occur when operating from a supply frequency of 20 kc/s, and, this being the case, it is felt worth while to give an outline of some of the more important considerations relating to the amplification of audio-frequency signals.

Before doing so, however, it is relevant to draw attention to the effect of a smoothing condenser on the transient operation of the amplifier. In most cases the rectified output current is smoothed by placing a condenser across the load.

Previous investigators have drawn attention to the fact that in certain circumstances this may improve the time constant of the amplifier. The principles involved here appear to be of a complex nature, but it appears that the effects of a load condenser are to make the amplifier sensitive to a certain frequency. Provided the circuit constants are correctly chosen, this can lead to a distinct improvement in the time constant of the amplifier when used to amplify D.C. signals, and better frequency response characteristics when used for audio-frequency amplification. If the smoothing condenser is too large, however, and the amplifier is self-excited, it will become unstable and generate internal oscillations. Fortunately this only occurs at capacitance values about twice those corresponding to normal operating conditions.

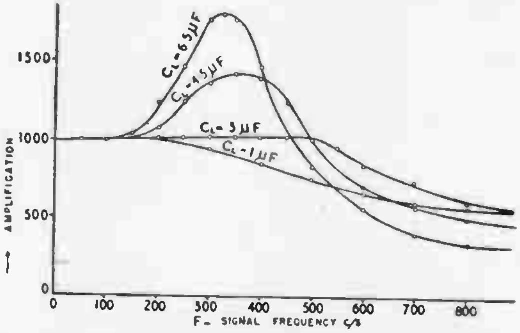


Fig. 21.—Frequency response characteristics for different values of smoothing for p = 1000.

The frequency response characteristics of a small toroidal-cored transductor were determined under various conditions of operation as follows. A low impedance beat frequency oscillator was shunted by a potentiometer of 6 Ω and a fraction of this output was tapped to the control circuit of the transductor which was biased to operate at 55 mA. The effective load resistance was 110 Ω and the rectifier resistance approximately 30 Ω. The current gain was increased by self-excitation from unity to 13·5. The input to the amplifier was maintained constant, and the output was measured at signal frequencies from 20 c/s upwards. Figure 21 shows the amplification plotted against signal frequency for a control resistance of 20 Ω (corresponding to a power amplification of 1,000) and for various values of smoothing condenser. It will be seen that for $C_L = 6 \cdot 5$ μF, the amplifier is highly sensitive from 250-350 c/s, after which the gain falls off rapidly, being 3 db down at 620 c/s.

As the smoothing capacity is reduced, the resonance is less pronounced and occurs at a slightly higher frequency, but the gain does not fall off so rapidly. For $C_L = 3 \cdot 0$ μF the response is constant up to 500 c/s and is 3 db down at about 1 kc/s. Further reduction in the value of C_L causes the response to start falling off at a lower signal frequency.

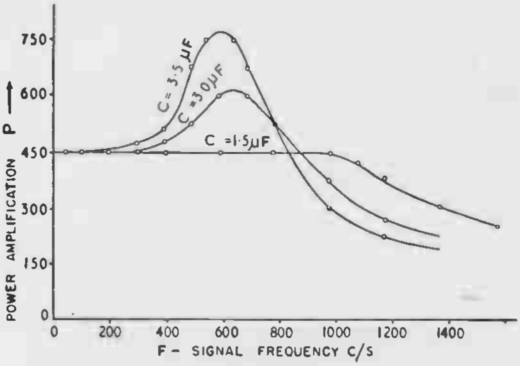


Fig. 22.—Frequency response curves for p = 450.

In Fig. 22 further characteristics are plotted for a D.C. amplification of 450, and in this case it may be seen that the response is reasonably constant up to 1 kc/s, but that the corresponding values of C_L are approximately halved. It thus appears that the signal frequency band may be increased by reducing the power gain. For direct proportionality the relation pF_1 = const. holds, where F_1 is the upper signal frequency, but in practice it appears that there is a slight reduction in pF_1 as F_1 is increased. This is probably due to the fact that the inherent time constant of the feedback winding is placing a limitation on the response characteristics, and for this reason, it was found uneconomical to reduce the power gain below 100, a value which gave reasonable response up to between 3 and 4 kc/s.

Under the various conditions of operation which have already been specified, the zero stability of the amplifier was measured over a period of about 6 hours during which time the total zero drift which occurred was of the order of ·5 p.c. expressed as a percentage of the total input power. This was in all probability largely due to variations in supply voltage. When two units are connected to operate in push-pull, such variations are to some extent nullified with the result that better zero stability may be expected.

The A.C. signal to any type of amplifier normally operates on the linear part of the characteristic about some mean position which is usually attained by biasing. Small variations in this mean position are usually unimportant provided the signal still operates over the linear region, and for this reason zero drift is less serious in an A.C. amplifier than in a D.C. one, for which a drift in the biasing point will correspond to a variation in the output. For this reason less self-excitation is permissible when the amplifier is used for D.C. signals.

Conclusion

To summarize the investigations described in this paper, it appears that the main defects imposed by employing high supply frequencies arise due to iron losses and rectifier imperfections. By using small toroidal cores, however, satisfactory results may be obtained at 22 kc/s, and in these circumstances very important improvements in the response characteristics are realized. It appears that even without using self-excitation power gains of the order of 1,000 can be achieved in single-stage amplifiers having a time constant of a few milliseconds.

It has also been shown that in order to obtain the optimum results from a given power supply, it is necessary to limit the losses by reducing the core size, and thereby attain a reasonable balance between the saturation impedance of the amplifier and iron losses in the core.

By choosing suitable component values for the smoothing circuit, the magnetic amplifier may be successfully utilized as an audio-frequency amplifier with linear response up to about one-sixth of the supply frequency.

Finally, it should be pointed out that while there is considerable promise of further advances in this field, it is felt that improvement to rectifier characteristics and reduction of iron losses are, at the present time, likely to provide the most profitable lines of investigation.

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Discussion

A report of the discussion which took place after this paper was read will be published in a subsequent issue of the Journal.

AN ELECTRONIC TRIGGER CIRCUIT AS AN AID TO NEUROPHYSIOLOGICAL RESEARCH*

by

H. W. Shipton (*Associate*)†

SUMMARY

This paper considers the electrical activity of the brain and shows especially how " feedback " plays an important part in the analysis of human behaviour. The existing recording techniques are summarized and their essentially " passive " nature emphasized. The use of external stimuli as a means of evoking waveforms of clinical importance, and the design of an electronic trigger circuit suitable for controlling these stimuli are considered.

Introductory Note

(*Conventions of Electroencephalographic recordings*)

To assist those who do not come into contact with E.E.G. recordings, the following conventions and nomenclature have been used in the text and in all figures.

(*a*) Channels are numbered in Roman numerals from the top downwards.

(*b*) The position of the recording electrodes is indicated by lines drawn from the sketch of the brain to the relevant channel.

(*c*) When that electrode indicated by the solid line is negative with respect to that indicated by the broken line, the recording pen is deflected upwards.

(*d*) Unless otherwise indicated, the time and voltage co-ordinates are as in Fig. 1.

Every effort has been made to avoid the use of physiological terms. Those which do occur in the text are enumerated below and are used in the sense indicated.

Cerebral cortex.—The much folded outer layers of the brain in which the nerve cells (grey matter) are principally concentrated.

Occipital region.—The area at the rear of the brain where impulses from the eyes first reach the cortex. Included in this region is the association area where the information given by these impulses begins to be transformed into a conscious form.

Basal Structures.—These lie beneath the cortex and may be considered roughly as the " junction box " of the central nervous system (C.N.S.).

Vestibular System.—Those parts of the central nervous system which supply information about posture and balance.

1.0. Introduction

At first sight the human brain does not seem a likely component of an oscillatory circuit, but a brief reflection will show that one essential condition of oscillation—feedback—is a commonplace of human behaviour. A complex feedback network is involved in such ordinary activities as standing, or riding a bicycle. For these actions to be performed at all, it is necessary that external forces due to gravity or centrifugal force should be neutralized by internal forces of correct magnitude and phase. To this end the vestibular and visual systems supply suitably coded signals to the motor areas of the brain, which in its turn provides impulses which release the amounts of muscle energy necessary for the maintenance of postural stability. This statement, like many others about the functions of the central nervous system, is a gross over-simplification, and in fact the mechanism involves the integrated action of other special senses. In this case the feedback is negative and has—for a mechanical system—an extraordinarily short time constant. Learning to ride a bicycle is mainly a matter of shortening the time constant of the system, and the path of the novice's cycle is a graph of the overall efficiency of the feedback loop. As in the case of servo mechanisms the efficiency can conveniently be expressed in terms of R.M.S. error.

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Many, if not all, modes of behaviour can be similarly analysed in terms of feedback systems, and very frequently abnormal behaviour results from a disturbance of some element in the feedback loop. To revert to the example, a drunken man may ride a bicycle quite adequately until some deviation from the steady state occurs; then he applies more correcting force than is required and oscillations build up until some limit is reached—say a pedal brushes the road—and the system is destroyed. The central nervous system in this case is unable to act normally owing to the inhibitory effect of the alcohol and the effective phase of the entire feedback system is reversed. It is worth noting that in these conditions, until the limit is reached, the absence of error-feedback gives the rider the impression that he is performing exceptionally brilliantly.

The consideration of central nervous activity in terms of feedback is being increasingly applied to the study both of normal and abnormal behaviour and the electronic engineer is correspondingly concerned. Electronic methods have in the past contributed greatly to the measurement of nervous activity. In the future both physiologists and engineers may find a surprising parallelism between their sciences. This paper will consider a small facet of this new study by describing certain experiments in photic and auditory stimulation. Only the briefest mention of existing electro-physiological echniques can be included in a paper of this length. However, the literature is extensive and a bibliography is appended for the benefit of any interested reader. The full significance of feedback systems in the brain is dealt with at length by Wiener in his recently published "Cybernetics".[1] Engineers should find this work both stimulating and salutary.

2.0. The Electrical Activity of the Brain

2.1. *Theoretical Considerations*

As a necessary preliminary to the present discussion, some aspects of the theory and practice of electroencephalography must first be considered. The study of the spontaneous electrical activity of the brain has been of great value in the investigation of diverse pathologic conditions, and the experiments to be described are an extension of its methods. Each of the millions of cells within the brain is capable of electrical activity, and it is the aggregate activity of cells which the electroencephalographer studies. The potentials can be recorded from the scalp although they suffer considerable attenuation as compared to their amplitude at the cortex. (In practice, recordings are only taken directly from the brain when it has been necessary to open the skull to permit some operative procedure.) In normal circumstances those parts of the brain concerned with vision give rise to the largest spontaneous voltages. There would appear to be an elaborate "scanning" mechanism involved in the interpretation of visual phenomena; this has been

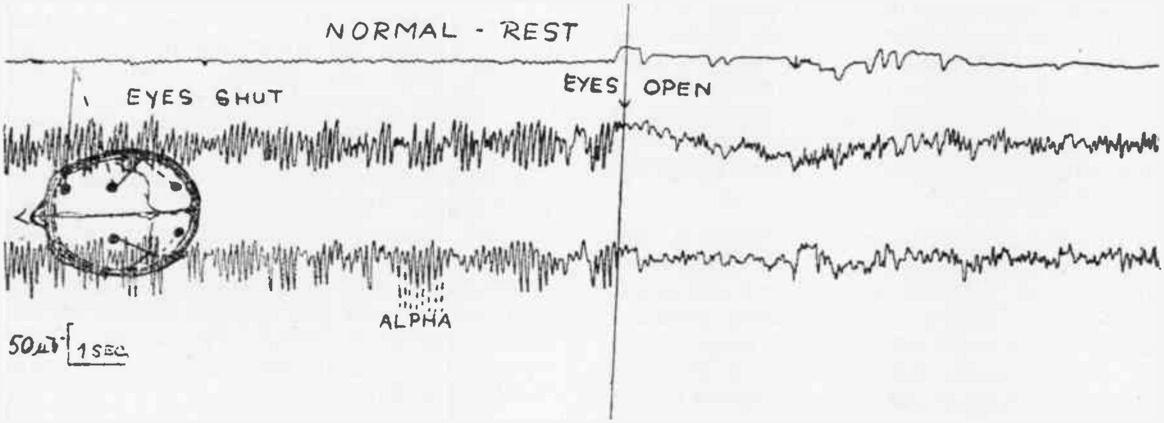

Fig. 1. Electroencephalogram from a normal subject. In the first half of the record the fast oscillations at 10-11 c/s in Channels II and III are the alpha rhythm, and arise from the back of the brain in the occipital region. Note disappearance of alpha waves when the eyes are open.

discussed elsewhere[2] and it is only necessary to note that the 8-13 c/s waveform which arises in the occipital regions is the largest seen in the normal adult brain (Fig. 1). At this point it is a useful digression to consider the feedback involved in visual activity. The lock-and-follow devices of radar are only crude imitations of the " servo " system which enables the eye to perform the same function. An image thrown on the retina is represented spatially and relatively undistorted on the visual cortex. The mechanism by which this image is transformed into consciousness is not as yet understood, although a scanning process is almost certainly involved. In order that the eye may follow or ignore a given object, informative feedback must be derived from the visual cortex, monitored at a higher functional level, and fed in suitable form to the areas of the brain whose function is to move the eyes. These are situated some distance from the visual cortex and an analysis of the complex " circuitry " is one of the major objectives for neurological studies. As about two-fifths of the whole brain is concerned with vision and eye movements, it is not surprising that a large proportion of the measurable electrical activity is also associated with vision.

It is also necessary briefly to consider in what ways the electrical activity of the brain varies in different subjects, normal and abnormal. The 8-13 c/s (alpha rhythm) activity discussed above is in general diminished by visual stimuli or preoccupation with phenomena involving the appreciation of pattern. In subjects having tumours or other conditions involving de struction of the cerebral cortex, large number of cells and their inter-connecting pathway are prevented from participation in the grou activity. Thus the electrical pattern of the grou is much simplified and high potential oscil lations of very low frequency (1-3 c/s) are see in the neighbourhood of the lesion. These so called delta waves are of great value in localizin the disturbance.

Psychological disorders are often known t be associated with disturbances in the comple feedback arrangements between the basa structures and cerebral cortex. (The basa structures serve as a distribution centre fo many of the nerve trunks entering and leavin the brain.) In such psychological disturbances a low potential oscillation can sometimes be see in the frequency band 4-7 c/s (theta rhythms).

Epilepsy can often be diagnosed by inspectio of the subject's E.E.G. since in this conditio certain cerebral circuits are exceptionally easil excited, each cell having a much lowe " threshold " than is normal. Because of this, very characteristic pattern is seen in whic many frequencies—usually harmonically relate —are present with a strict and consistent phas relationship. The change in the E.E.G. of a epileptic patient immediately prior to an during a seizure is shown in Fig. 2. Th striking regularity of the discharge during th fit contrasts with the random nature of th activity before the onset. This could well b the result of a change from negative to positiv feedback within the cortex.

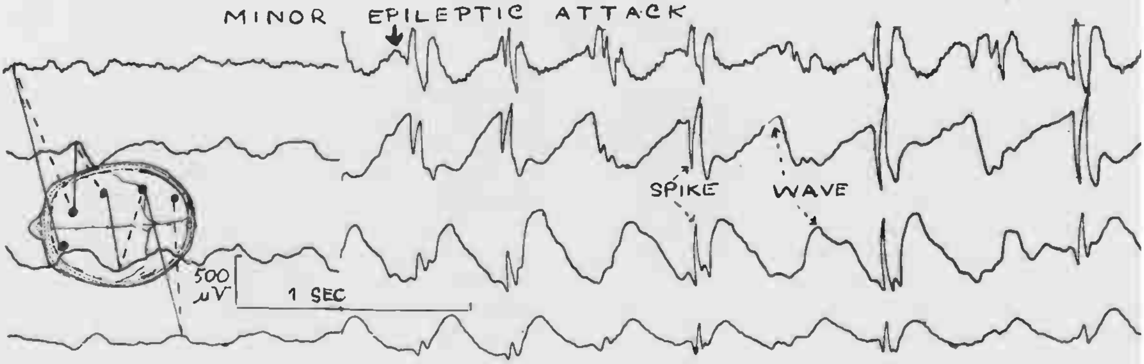

Fig. 2. E.E.G. taken at the commencement of a minor epileptic attack showing the sudden appearance of large fa and slow components. This discharge is called "wave and spike" and is diagnostic of this condition. Note longe time scale and greatly reduced amplification.

2.2. *Recording Methods*

The observation of the E.E.G. does not call for any fundamental departures from a normal electronic practice, although many practical difficulties are encountered. The potentials seen in normal subjects seldom exceed 50 μV, and the source impedance is high, complex and variable. The frequency range (1-30 c/s) presents certain difficulties. Direct-coupled amplifiers of sufficient gain would be impracticable, and if RC coupling is used the coupling time constants are necessarily so long that a momentary overload can cause the amplifier to block for long periods. A compromise arrangement commonly adopted is to use two R.C. coupled pre-amplifier stages followed by a two-stage direct-coupled power amplifier. Means are provided for varying the upper and lower limits of the frequency band. To avoid the pick-up of extraneous signals from the 50 c/s mains, etc., the amplifiers are connected in push-pull and are arranged to have a high discrimination against in-phase input signals. Ink writing oscillographs are generally used as recorders; they are cheap, robust, and in every way adequate to the purpose. The design of suitable apparatus has been considered in detail.[3,4,5] It is common practice to use four or six such amplifiers simultaneously so that instantaneous comparison of the activity at various parts of the brain may be obtained. Inspection of Fig. 2 will show the complexity of the waveforms normally encountered and, to facilitate interpretation, a number of methods of waveform analysis have been devised. That due to Walter[6] is in most common use. It has the great merit of displaying the analysis rapidly on the primary record and in an easily interpreted form.

3.0. Photic and Auditory Stimulation

3.1. *General*

Having summarized the normal E.E.G. techniques it is now possible to consider in some detail the rationale and method of photic and auditory stimulation. It has been observed that the E.E.G. represents the autonomous activity of a large number of synchronously acting cells and it is not possible to observe or interpret the activity of smaller groups or individual cells unless they are removed from their environment. With the object of widening the scope of E.E.G., various means of evoking electrical activity have been devised. These allow active rather than passive studies of the brain activity. A convenient analogy can be drawn from radar practice: if it is desired to locate an enemy transmitter, this can be done by receiving its signals on a suitable direction-finding receiver. This will involve continuous monitoring of the transmitter frequency until it sends for long enough for a " fix " to be obtained. If, however, a radar method is used to obtain re-radiated energy from the enemy's aerial system, location can be effected without co-operation from the transmitter. If the subject looks at a brief flash of light so arranged as to encompass his whole visual field and thus stimulate a large proportion of the receptors in the retina, the brain will receive a fairly large stimulus. This stimulus will suffer certain delays and distortions on its way to the cortex. The image will persist on the retina after the pulse has ceased and will thus be partially integrated. The impulse will be delayed by the time required for it to reach the occipital cortex via the optic tracts—this delay is commonly only a few milliseconds. An amplifier connected to electrodes placed on the scalp immediately above the visual areas will record the potential evoked at the cortex if it is sufficiently large. The stimulus may affect other areas of the brain in one or both of two ways. Firstly, in its interpretation by the visual association areas it will give rise to electrical activity in these areas and is occasionally conveyed to remote parts of the brain where it can be observed in the E.E.G. Secondly, it may spread for a short distance across the surface of the cortex away from the visual projection areas; this spread is more likely to occur if the cortex is easily excitable (e.g. in an epileptic patient).

One stimulus is unlikely to have any dramatic physiological or subjective effects, but if the flash is repeated at frequencies within the E.E.G. range, it is often possible to evoke potentials of considerable interest. The flash can conveniently be generated by an industrial stroboscope in which a gas discharge lamp is fired by some form of variable frequency multivibrator. The subjective and E.E.G. responses have been described elsewhere,[7,8,9] and the only repetition here will be Fig. 3, which shows the responses in typical cases. The method has had especial success in clarifying doubtful diagnoses of epilepsy, an epileptic type of record being evoked at certain frequencies of stimulation.

A difficulty which manifested itself in the clinical application of this method was that, if small rhythms were to be augmented, it was necessary to apply stimuli at certain critical frequencies and with due regard to phase relationship. Since no method of determining these constants was available, the frequency was varied over a wide range until suitable responses occurred. This "fishing" process was often tedious and always uncertain and it was considered useful to use the brain more directly in a feedback circuit. With this end in view the arrangement of Fig. 4 was set up. From this it can be seen that if oscillation is to occur, the trigger must contain arrangements for selecting the autonomous rhythm, and must fire the lamp after any desired time delay, so that the action of successive stimuli is cumulative. The design of this trigger presented considerable difficulty; frequencies of 1 c/s to 30 c/s were involved and it was thought that the delay between response and flash would require to be continuously variable over at least three waves at the lowest frequency for adequate investigation in some conditions. Thus, with the delay control at minimum, the shortest possible delay was required, extending to three seconds at the maximum setting. The design of this unit will now be considered in some detail as it gives some insight into the type of problem encountered by the electronic engineer in this branch of the science.

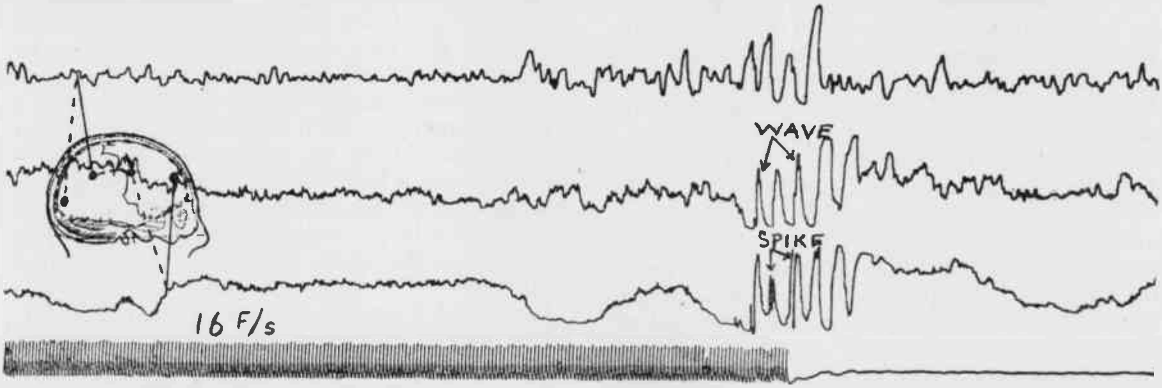

Fig. 3. Record showing photic stimulation at 16 c/s. The slow discharge from the posterior regions of the brain (Chan. I) increases in amplitude until finally a wave and spike discharge is evoked. Chan. IV is recording the flash from the Stroboscope as recorded by a photo cell. Note: the spike of the wave and spike discharge appears only in the frontal regions of the brain (see Chan. III). This record showed no definite spontaneous abnormality but became diagnostic of minor epilepsy during stimulation.

4. Trigger Design

4.1. *Signal Circuit*

The basic circuits are not original and the author wishes to acknowledge the help he received from the lucid account of the "Phantastron" contained in "Ranging Circuits, Linear Time Base Generators and Associated Circuits," by F. C. Williams and N. F. Moody.[10] Nevertheless, because of the unusual range of operating frequencies, a good deal of experimental work was necessary before the final arrangement shown in Fig. 5 was adopted, and a

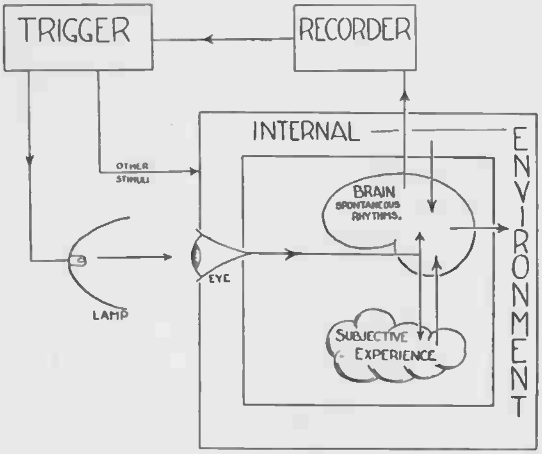

Fig. 4. Block diagram showing the internal and external feedback networks used in these experiments.

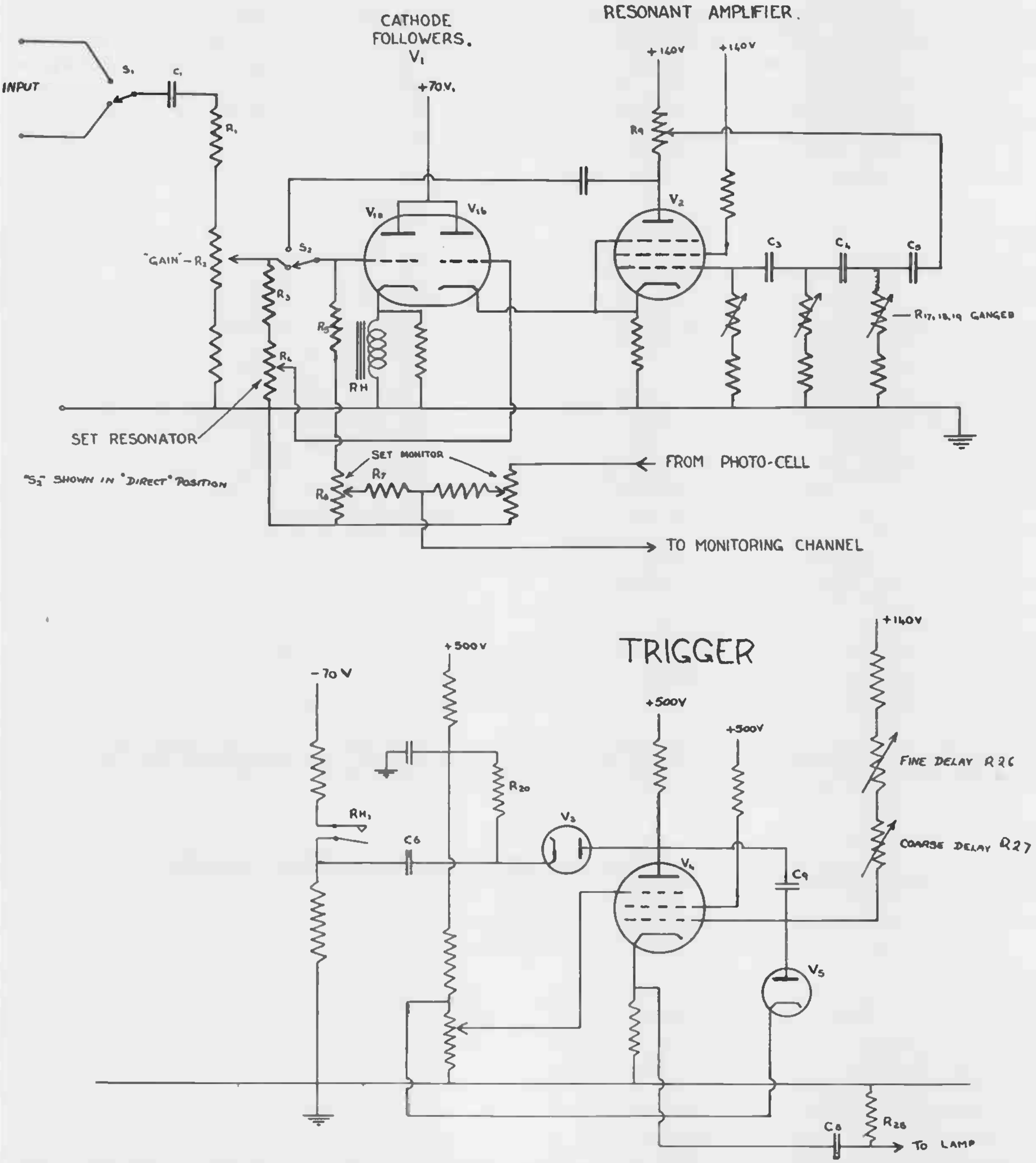

Fig. 5. Complete circuit diagram. Note: only those components to which reference is made in the text have R and C numbers.

brief account of the operating principles may be of interest.

The output stage of the E.E.G. amplifier is a push pull pair, feeding high impedance centre-tapped pen coils. The minimum deflection which can be interpreted with any certainty is of the order of 2 mm. This will correspond to an output signal of approximately 15V. The frequency of the signal will be between 1 and 30 c/s. Full scale deflection of the pens involves a signal of approximately 150V anode to anode. These data are the starting point in the trigger design.

Originally, a Tönnies compressor stage[11] was used to refer the signal to earth without losing the discrimination against in-phase hum afforded by the push-pull amplifier. Experience showed that this extra complication was unnecessary and that the signal appearing between one anode and earth was adequately smoothed for all practical purposes. The channel to be used is selected by a push button switch and the input taken from either anode of the pair by means of the "phase reverse" switch S.1. The signal across the attenuator network R_1, R_2, lies between 15V-75V (half the peak/peak voltage). When S_2 is in the "Direct" position this voltage is applied to the cathode follower V_{1a}, which has a Siemens H type high speed relay as its cathode load. This has been adjusted to operate when the grid voltage of V_{1a} exceeds 15V. Over the operating frequency range the relay operates in a negligibly short time (0·3 milliseconds). This constitutes a fixed delay independent of input frequency. A relay was used in place of the more obvious squaring stage or flip-flop, because the latter are notoriously good amplifiers in their active (i.e. change over) regime—hum and noise causing irregular operation and jitter. The complex and irregular nature of biological signals makes it exceedingly difficult to design an adequate squaring stage. The wanted signal is often superimposed on large slow swings of voltage and may have associated with it an irrelevant high frequency component (e.g. muscle action potentials). Reference to any of the figures showing E.E.G.'s will give some measure of the difficulties. Radio engineers will be familiar with the analogous problem of television synchronizing in conditions where high levels of interference prevail. The relay gives an excellent output waveform and is comparatively unresponsive to extraneous signals.

The input waveform is often extremely complex and it is necessary to incorporate some device to select wanted and reject unwanted constituent frequencies. This is accomplished when S_2 is in the "Resonant" position by the amplifier V_2. This type of feedback amplifier was developed for use in waveform analysers[12] where it has given excellent results. The circuit is essentially that of the well-known phase shift oscillator. If the gain is varied—in this case by R_9—the circuit becomes a resonant amplifier of extremely high selectivity when the voltage feedback is just unable to maintain oscillation. The "Q" diminishes as the feedback is further reduced. It is not possible to use the tuned amplifier in all applications, because necessarily associated with it are finite build-up and decay times, of the order of several cycles when the "Q" is high. As will be seen when use of the equipment is discussed, the "flywheel" effect, which the tuned circuit imparts to the trigger, may lead to misleading interpretations of the observed effects; on the other hand this effect is sometimes desirable, as when a large evoked physiological transient would otherwise block the trigger action. In the waveform analysis application the input is applied via a high isolating resistance to the signal grid. When a wide frequency range is required however, $R_{17, 18, 19}$ are varied proportionately, and the applied signal suffers increasing attenuation as the frequency is raised. To overcome this defect whilst still retaining a simple circuit, cathode injection is used via the impedance transforming cathode follower V_{1b}. This has the added advantage of applying a fixed bias to V_2 with

Fig. 6. This figure gives an indication of the performance of the resonant amplifier. Channel I shows a complex Waveform, and Chan. II the 8 c/s component obtained from a monitoring point on the output of V_2.

corresponding improvement in the stability and waveform of the resonator. The performance of the resonant amplifier can be judged by reference to Fig. 6.

The resonator output drives the grid of V_{1a} and operates the relay as previously described.

Reference to the circuit diagram Fig. 5 will show that the grid voltage of V_{1a} is taken via suitable attenuators to a monitoring point. The output from a miniature barrier type photoelectric cell, mounted between the subject's eyes, s also fed to this point so that the temporal relations between flash and wave can be studied on a spare channel of the E.E.G.

4.2. *Delay Circuits*

Two identical delay circuits are incorporated n the instrument so that the flash can be supplemented by auditory, tactile or other pulsed stimuli. These were designed when a valve squarer was used in place of the relay and it is possible that some simplification of the drive circuits could now be accomplished.

The operation of the time delay circuits of Fig. 5 can best be understood if the static conditions (i.e. those obtaining in the absence of a drive pulse) are first noted. V_4 is a valve having a short suppressor base and V_3 and V_5 are conventional 6H6 diodes. The cathode of V_5 is held at a fixed potential by the network across he supply rails: the grid of V_4, although eturned to +140V through the delay controls, cannot rise above this voltage. Since the cathode resistance of V_4 is not decoupled, this potential appears across it by cathode follower action.

The suppressor grid is returned to a lower point on the network such that the anode current s completely cut off. The anode voltage would ise to the supply voltage were it not "caught" by V_3 whose cathode is returned to a +400V point on the divider network. The screen potential s low, since the entire cathode current flows hrough its load.

The relay produces square waves of about -70V amplitude: these are differentiated by C_6 R_{20} and produce the drive pulses which disturb he quiescent conditions Only the negative going "pip" can traverse the diode V_3 and this s coincident with the leading edge of the square wave. The drive pulse causes the anode voltage to fall momentarily and the fall is communicated to the grid by C_9. The cathode voltage falls with the grid and the suppressor grid is now "opened" (made well positive to cathode) so that anode current can flow through the high anode load. The first result of this is that the valve is almost completely cut off, both grid and cathode being near earth potential. V_5 is now non-conducting and the grid of V_4 begins to rise towards 140V. The anode current rises with it. The consequent fall in anode voltage opposes the increase at the grid by feedback through C_y. The anode voltage falls at a substantially linear rate of $\frac{140}{\text{R.C.}}$ volts/sec. Thus variation of R causes a corresponding change in the duration of linear sweep and this is used as the delay control.

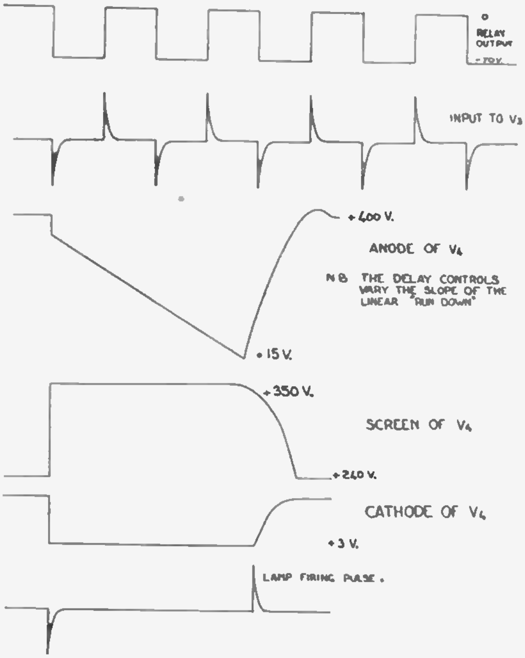

Fig. 7. Delay circuit waveforms.

The termination of this linear fall occurs when the anode and cathode voltages approach each other closely. The increase in "space" current brought about by the increment of grid voltage no longer offsets the drop in anode current which occurs when the P.D. between anode and cathode is low. As soon as the anode voltage is stationary, feedback through C_9 stops, and the grid potential rises rapidly towards 140V.

Detailed analysis of the flyback will show that this takes place in two stages. Initially the rise of the grid and consequent increase in cathode potential causes the suppressor to turn off the anode current. The anode potential rises with the grid, and C_9 does not require to be charged because both sides are moving positively. The factor determining the rate of the first part of the flyback is therefore the time taken to charge the strays through the delay controls. When the grid potential is equal to the cathode potential of V_5 however, this diode takes current and the grid voltage cannot increase further. C_9 is then charged exponentially through the anode resistor until the anode voltage is high enough for current to flow in V_3. The cycle is then complete. Waveforms are shown in Fig. 7. From these it can be seen that the voltage at the cathode of V_4 is a variable width, negative going, square wave. Differentiation of this by C_8 R_{25} gives a positive pip which fires the gas discharge tube in the Scophony high power Stroboscope used as the light source. With the values chosen the delay can be continuously varied from a minimum of 10 milliseconds to a maximum of 1·5 seconds, this being accomplished without change of C_9. The coarse and fine delay controls (R_{26}, R_{27}), are mounted concentrically and permit easy searching for the required setting.

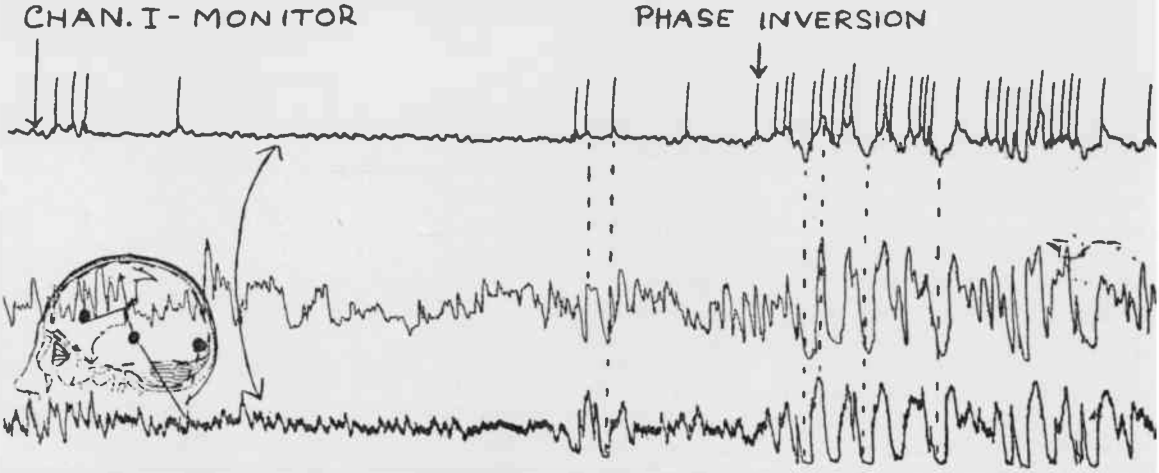

Fig. 8. This record shows a recording made with the trigger in use. For description see text.

5. Clinical Results

The medical aspects of this work are to a great extent outside the scope of this paper and have in any event been adequately reported elsewhere.[7] A brief summary of some of the more important observations is included here merely for the sake of completeness.

Figure 8 gives an impression of the way in which records may be modified by use of the trigger. The resonator is not connected and in the first half of the record, Channel I displays the same signal as Channel III inverted, the trigger being fired at the trough of the signal as seen in Channel III. At the arrow the phase relations are inverted so that the flash appears at the crest of the Channel III signal. This combination evokes irregular wave and spike patterns diagnostic of epilepsy. From this the importance of correct phase relations can clearly be seen.

The technique has especial value in clarifying a provisional diagnosis of epilepsy and there are numerous cases on record where a diagnostic record of a " wave and spike " type could be obtained only by rhythmic sensory stimulation. Since the chief manifestation of an epileptic condition may be a disorder of behaviour, such a finding can radically modify the physician's treatment of the patient.

It has also been found that the E.E.G. diagnosis of some deep-seated brain tumours is assisted by photic stimulation, but space does not permit a description of the very complex records which are obtained in these circumstances : it should be mentioned however that the response at the fundamental flash frequency is usually absent, whilst a high proportion of its harmonics appear on the affected side.

Perhaps the most interesting observations have been made on normal subjects, or on those in whom there is only a minor psychiatric disturbance. Different people report the sensation of looking at the lamp in different ways. In some the change of flash repetition frequency causes a subjective change in the colour of the light : in others sensations of " swimming " or movement are reported. Moreover the subjective sensations and the observed electrical responses both change with changes of mood. An extensive series of experiments is now being undertaken with a view to clarifying these psychological phenomena but it is as yet too early for any helpful comment. As a further extension of the method, Professor F. L. Golla has suggested that long exposure to such rhythmic stimulation might, in certain circumstances, succeed in effecting a " conditioned " or permanent change in the E.E.G. accompanied by a change in the subject's mental state.

In conclusion it may be said that the technique of rhythmic sensory stimulation has increased our knowledge of neurophysiology and it is reasonable to predict that in the future it will play an increasing part in the diagnosis and the treatment of diverse mental and physical conditions.

Acknowledgments

The author would like to thank Professor F. L. Golla, F.R.C.P., Director of the Burden Neurological Institute, for permission to describe this work. Also W. Grey Walter, M.A., Sc.D., under whose supervision the experiments were conducted. In addition the author would like to acknowledge the assistance of Mrs. V. J. Walter for her help in providing the clinical material and describing the records which illustrate this paper.

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NOTICES

Obituary

The Council deeply regrets to record the death of the oldest member of the Institution, Miss Alice Everett, of Sunbury-on-Thames.

Graduating at Cambridge (Mathematical Tripos) in 1889, Miss Everett subsequently took an honours degree in mathematical physics at the University of Dublin. Her first work was at the Royal Observatories at Greenwich and Potsdam until in 1917 she joined the National Physical Laboratory. An early contributor on Television and Optics to such journals as " The Philosophical Magazine," Miss Everett invented a gauge for measuring the curvature of lenses and with the early Baird Company was named as the joint inventor of a " Mirror Drum." She was granted a Civil List Pension in 1939 for services to science.

Miss Everett was the first woman to be admitted to Associate Membership of the Institution and had been most helpful in undertaking the preparation of abstracts and translating from German and French technical papers.

Until recent years she regularly attended London Section meetings. She died at the age of 84 years after a short illness.

Unified Screw Thread

Our contemporary, " The Machinist," publishes a trenchant argument in favour of implementing the agreement between the United Kingdom, Canada and the United States to adopt a common thread system. It is pointed out that the mere publication of a British Standard specification involves no compulsion on anybody to use it, and some further stimulus is needed if industry in general is to adopt the Unified thread within a reasonable period.

It is suggested that professional institutions in this country can do a great deal in this connection, by organizing discussion lectures. A small central panel should also be set up in order to assist manufacturers in overcoming organizational and practical problems which will arise in the change over.

Professor Barlow

It has been announced that Professor H. E. M. Barlow (Member), a Member of Council, has been appointed Dean of the Faculty of Engineering, University College, London, for the 1949-50 session. He succeeds Professor H. J. Collins.

New Transmitting Station

The B.B.C. opened a new transmitting station on Sunday, June 19th, at Postwick Grange, near Norwich. The wavelength of the station is 296 metres (Midland Home Service) and the transmitting power, 5 kW, is a considerable increase over that of the old station.

The transmitter employs the high efficiency Class B system of modulation, and two interesting points in the design are the heavy negative feedback that is applied over the audio frequency stages and the remotely controlled motor-driven tuning controls.

The aerial system, which is directional, consists of two 126 ft tubular steel masts spaced 240 ft apart, which corresponds to a quarter wavelength at the operating frequency of 1,013 kc/s. The easterly mast is energized while the westerly mast acts as a parasitic reflector and increases the signal strength towards the east.

E. E. Zepler

A Chair in Electronics has recently been created at the University College, Southampton. E. E. Zepler, Ph.D.(Member), Chairman of the Education and Examinations Committee, has been appointed Professor. Previously Dr. Zepler was Head of the Electronics and Radio Engineering Department at University College.

Ericsson-Pye Agreement

An agreement has been signed between Ericsson Telephones Ltd., of London and Beeston, and Pye Ltd., of Cambridge, in the telephone and radio communications field.

The two companies have agreed to pool their technical, engineering and marketing resources, the main emphasis being on the development of multi-channel V.H.F. telephone links.

Radiolympia

Radiolympia was opened by the Rt. Hon. Herbert Morrison, P.C., M.P., Lord President of the Council, at 3 p.m. on Wednesday, September 28th. The ceremony was broadcast in the Home Service. Other speakers were Mr. J. W. Ridgeway, O.B.E. (Member), who is Chairman of the Radio Industry Council, and Mr. F. W. Perks, Chairman of the Organizing Committee.