JOURNAL OF

The British Institution of Radio Engineers

(FOUNDED IN 1925 – INCORPORATED IN 1932)

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

Vol. XII (New Series) No. 10 OCTOBER 1952

INDUSTRIAL PROGRESS AND THE SPECIALIST

The Address of the Twelfth President* of the Institution focused attention on the difficulties arising from specialization. "The age of specialization, with all its new ideas and intricate circuitry, has meant that today it is virtually impossible for any one engineer to be an authority on any but a few aspects of radio or electronics on which he himself is closely engaged, or which impinge upon his work."

It is one of the purposes of the Institution to help to overcome such difficulties by regularly holding meetings and publishing proceedings. The President's proposals have already been applied to many fields outside the scope of the Institution, but have particular importance at the present stage of radio development. In order to appreciate the latest work in his own field the specialist engineer must have a clear understanding of the relationship of new advances to radio engineering as a whole.

The purpose of the review or survey paper therefore becomes apparent: it might be termed a "refresher" course for the established engineer, re-emphasizing, as it does, the development of a subject and relating it to the latest advances.

The continued need for specialist papers will be obvious. Giving a detailed account of new ideas, such papers usually lead also to additional contributions describing the application of specialized work to new techniques. Subsequently, development in any one field should be summarized at fairly frequent intervals in the form of a survey paper. Indeed, the survey paper may be regarded as a record of industrial progress based on the initial work of the specialist.

Examination of the Index of Papers published in the *Journal* in recent years will show the very large range of topics with which members of the Institution are concerned. The Index also reveals the comparatively neglected subjects on which surveys are required in order to redress the balance between specialized and review papers.

The application of radio technique to problems outside the communications industry frequently involves novel ideas. An account of such work is often of use in other industries and should be recorded in the proceedings of the Institution.

These considerations are occupying the Programme and Papers Committee in its work of obtaining papers for publication in the *Journal* as well as for presentation before meetings.

The Committee has already invited a number of experts on various subjects to contribute survey papers. Some will deal with fields in which advances have been particularly spectacular during recent years; others with work only on the fringes of radio engineering. Work by engineers overseas will also be discussed, and the first paper in this category is published in this issue of the *Journal*.

Thus it will be seen that the *Journal* can maintain its present standard, but by being more comprehensive can, in each issue, contain something of specific interest to every member. Whilst the result will mean a larger *Journal* the cost can be equated against improved services to the membership. The implementation of the policy must, however, largely remain with the membership.

The Presidential Address at the beginning of a new session of meetings is a reminder that all members share the responsibility to contribute to the proceedings of the Institution. The pooling of experience and ideas is essential to the work of the specialist; without co-operation industry could not exist and progress would be stifled.

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* Delivered by Mr. W. E. Miller on October 8th. To be published in *J.Brit.I.R.E.*, 13, January 1953.

NOTICES

Mr. L. H. Bedford

The Council has congratulated Mr. L. H. Bedford, O.B.E. (Past President) on his receiving the distinction of Fellowship of the City and Guilds of London Institute, awarded for distinguished services.

Mr. Bedford is a graduate of the City and Guilds College and of the University of Cambridge, where he was in residence at Kings' College, and he received his first appointment at Standard Telephones and Cables, Ltd. He joined A. C. Cossor, Ltd., in 1931, and was first concerned with television research. Just before the war he took part in the development of the first radar equipment, and in 1943 was appointed an O.B.E. in recognition of his services. Since 1947 Mr. Bedford has been Chief Television Engineer with Marconi's Wireless Telegraph Co., Ltd.

Elected a member of the Institution in 1943, Mr. Bedford was made a Vice-President in 1945, and in 1948 he assumed the Presidency. He was chairman of the Television Engineering Session of the 1951 Convention and has served on a number of Institution committees.

Norman W. V. Hayes Memorial Medal

The Institution of Radio Engineers, Australia, has recently instituted an award to be made annually to the author of the most outstanding paper published in the Proceedings; adjudication for the medal, which commemorates a former President of the Institution,* is carried out in alternate years by the Institute of Radio Engineers of America and the British Institution of Radio Engineers.

This year the General Council has recommended to the Australian Institution that the award for 1951 should be made to Mr. J. E. Benson for his paper, "A Survey of the Methods and Colorimetric Principles of Colour Television." Mr. Benson who is with Amalgamated Wireless (Australasia) Pty, Ltd., was co-author of a paper on a television synchronizing-signal generator reprinted in the *Journal* for November, 1950. The Papers Committee is considering the present paper for publication in the *Journal*.

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* *J.Brit.I.R.E.*, 10, April 1950, page 157.

Examination Exemption Fees

As from January 1st, 1953, applications for exemption from the Graduateship Examination must be accompanied by a Registration Fee of 10s. 6d. The present system of charging exemption fees will be discontinued.

The Registration Fee is payable by all applicants, irrespective of the number of parts from which exemption is claimed. The Institution will not undertake the investigation of qualifications; every application for exemption must be supported by documentary evidence.

E.M.I. Group Microgroove Recordings

Mention was made in the May issue of the *Journal* that the gramophone-recording companies within the Electric and Musical Industries Group were proposing to issue long-playing microgroove recordings. It has now been announced that production of two distinct types will commence in October.

These will be: (1) 33⅓ r.p.m. 10-in. and 12-in. records giving playing times of 35 and 50 minutes per disc (both sides) respectively; (2) 45 r.p.m. 7-in. records with a playing time equivalent to standard 78 r.p.m. records. The latter type has not hitherto been produced by British firms.

Radio gramophones and record players suitable for these "long play" records are soon to be announced. Production of standard 78-r.p.m. recordings by members of the group will continue as before.

Canadian Television Service

The first two Canadian television stations, in Montreal and Toronto, were officially opened on September 6th and 8th. These two transmitters will be the forerunners of a nation-wide service by the Canadian Broadcasting Corporation, which plans ultimately to open stations at Ottawa, Vancouver, Winnipeg, Quebec, Halifax, and Windsor (Ontario). The Ottawa station is expected to be completed in 1953, and will be linked to Montreal and Toronto by a micro-wave radio relay.

SERVOMECHANISMS, A SURVEY*

by

George R. Arthur, Ph.D.†

A paper specially invited with the object of acquainting British workers in this field, and members of the Institution generally, with American work on Servomechanisms

SUMMARY

This paper is intended as a general review of the servo art. A brief historical outline is given followed by descriptive discussions of the most useful design techniques. They include frequency and time analysis, relay servos, pulsed servos, statistical design techniques and others. These are covered qualitatively with numerous references cited for the interested reader. An outline of some present problems is then given in light of the preceding material.

1. Historical Notes

The idea of automatic control has been one which has fascinated man for hundreds of years. However, it has only been since 1920 that the scientific literature has contained a great deal of material on this art. The present science of servomechanisms received much of its background and impetus from the work of Nicholas Minorsky[1] in 1922 and Harold L. Hazen[2] in 1934. Both of these papers summed up some of the early work in the field and have extensive bibliographies on that earlier work, most of which was in the field of ship control and the beginnings of automatic flight. The method of approach was a direct analysis by differential equations and was the only design method available for many years. Although during this same period the classical paper of H. Nyquist[3] was published which used the frequency domain analysis in studying the stability of feedback amplifiers, a number of years passed before this method found its way into the servomechanisms field.

The early work along this line was by John Taplin of the Massachusetts Institute of Technology and was carried along by Herbert Harris[4] also of M.I.T. In fact it may be said without much argument that the major developments in the servo field in the U.S.A. were pioneered chiefly by men from that school. The coming of World War II created a tremendous demand for high performance servomechanisms and it was during the period after 1940 that the servo field really grew into its present mature state. This stimulated condition has now continued up through the present, due mainly to continuing military demands and also to the fact that the immediate outgrowth of wartime developments was a mushrooming of automatic control in industrial fields. Although considerable developments took place during the early Forties, it was not until after the war that this information became widely known and available. This, of course, was due to the strict military security enforced in this period. Important contributions during this time were the reports of Gordon Brown[5] and Albert C. Hall.[5,6] Hall's work contains a bibliography of numerous wartime reports and also information on some of the work done in the Thirties. Several references there are to the work of Bode,[7] and others, much of which was done in terms of feedback amplifiers with no immediate application to the servo field until several groups working more or less independently applied and extended Bode's techniques to servomechanism design.

All of the above techniques used the concepts of transfer functions in terms of frequency and dealt with "loop gain" or "transmission around the loop." The classical differential equation approach was more or less discarded in favour of the operational or Laplace transform techniques which were well adapted to the frequency domain. Along with these developments came considerable information on pulsed and sampling servos, that is, devices which operate with data supplied at intervals instead of continuously.

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*Manuscript received 11th March, 1952.

†Formerly Yale University, New Haven, Conn.; now with Sperry Gyroscope Co., Great Neck, N.Y., U.S.A.

Another important concept and technique developed during the war years and mentioned by Hall[6] and Phillips[8] was the r.m.s. error criterion in designing servos. Much of the work in this field was made possible by the studies of N. Wiener[9] and others. Following along these lines, there has been considerable activity in the field of probability and statistics as applied to servo design since 1945.

The circulation of the general servo developments during and since the war has also been aided immeasurably by the publication of several books which cover in detail many of the methods and techniques mentioned above.[10-16] Several of these texts contain very useful bibliographies of both books and articles during the immediate post-war period. In this paper an effort will be made to give a general summary of some of the material mentioned and some of the new approaches and techniques with an eye toward a general evaluation of the state of the art today. Some of the present problems which are faced today will also be summarized.

2. The General Problem

When designing a servomechanism for a particular application there is usually a definite goal set for that design. The device is to do some given task with some desired quality of performance. The problem of translating this physical information into mathematics is a formidable one. There are several different ways to specify the accuracy of performance of a servomechanism. The manner of design is usually largely dependent upon the nature of the input signals. For simple continuous inputs one usually specifies maximum errors at certain frequencies and under certain conditions, such as various velocities and accelerations. Some restrictions may also be placed upon the transient response. The design here may, in general, be carried through in terms of the frequency transfer functions using the methods of Nyquist and Bode.

On the other hand, the input data may be random in nature or have a certain regularity but be masked by noise, e.g. radar signals. Here another criterion of goodness, the r.m.s. error is more applicable and a statistical method of design more fruitful.

Numerous systems operate with pulsed data. In this case some other method of approach or, at least, a modified frequency response method is necessary to give a reasonably good system. Other types might include relay servos and servos with considerable non-linearity. All of the above have certain design techniques which are particularly well suited to their types. The next section offers a general survey of some of the most useful of these techniques.

3. Design Methods

Since this is not intended to be a textbook on servomechanisms, the general survey of the subject will be in terms of brief descriptive outlines of a qualitative nature on some of the available design techniques. The nature of this paper necessitates very little mathematics and numerous references will be cited to allow the interested reader to pursue the subjects further.

3.1. *Transient Analysis*

The most popular methods of present day design use transient or frequency analysis of the system under consideration or both. The general system is usually represented by that shown in Fig. 1. The δ is the desired quantity or input, θ the actual output and ϵ, the difference of the two, the error signal which actuates the mechanism.

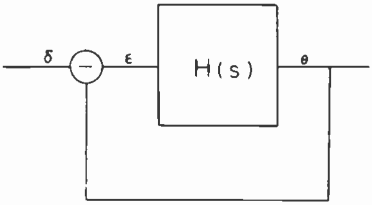

Fig. 1.—Basic block diagram of servomechanism.

Actual systems, of course, are often more complicated and may involve several loops, but the basic methods of analysis and synthesis are the same.

It should be noted that the transfer of the block has been written $H(s)$ which is in terms of the Laplace operator[17, 18] which gives an indication of transient as well as steady state behaviour. The basic equations for analysis and synthesis are:

$$\frac{\hat{\theta}}{\hat{\delta}} = \frac{H(s)}{1 + H(s)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\frac{\hat{\epsilon}}{\hat{\delta}} = \frac{1}{1 + H(s)} \quad \ldots\ldots\ldots\ldots\ldots (2)$$

$$\frac{\hat{\delta}}{\hat{\epsilon}} = H(s) \quad \ldots\ldots\ldots\ldots\ldots (3)$$

where $\hat{\theta}$ indicates Laplace transform notation. These equations, of course, may be written in terms of steady state quantities by letting $s = j\omega$ but in any event they have the same form and the manner in which they are written is the choice of the designer.

A knowledge of these equations gives the designer considerable information about the system; for example, frequency response, step response, degree of stability, etc., all may be obtained from these equations in some fashion. From this information he may, by various methods, seek to modify the system to meet a number of preselected specifications.

Considering equation (2) first, the designer may determine the difference between output and input for a step of input. This, of course, is general transient analysis and the Laplace technique offers a more powerful tool in its solution than the classical differential equation approach. The nature of this step response, i.e. heavily damped, oscillatory, etc., gives an indication of the stability of the system and various nomographs may be drawn to indicate the effects of varying components on these properties. Damping factors and natural frequencies may be found in terms of the components of the system and in the case of simple systems the manner in which they may be modified to yield a desired response is often evident.

However, in complicated systems this work often leads to high order differential equations with considerable labour in getting solutions. Of course, if it is merely necessary to know whether or not the system is stable, a condition which depends upon the location of the roots of the expression $[1 + H(s)]$, the methods of Routh[17] or Hurwitz might be used, since it is not necessary to solve the equation when using these methods. Even this becomes tedious for high order systems and usually it is not sufficient merely to have a stable system. The degree of that stability is often most important as is a knowledge of what one must do to control that degree of stability. Thus the transient method of analysis is not, of itself, especially effective when the problem of synthesis is being attacked because of the relative obscurity surrounding the identification of the particular parameters whose magnitude must be changed to yield a desired performance.

Computers[19] and simulators[20-21] have received much attention in recent years in order to reduce the complexity of analysis. Of course, considerable information must be known about the actual system in order to build a simulator. The analogue computer is often very valuable and has found wide use in the automatic flight and missile field where it may simulate the aircraft or missile, often in conjunction with the actual control servo. However, unless a long study is to be made on a single system and the equipment is well instrumented, the direct analytical approach may take less time. Also not everyone has a computer.

3.2. *Frequency Analysis*

The steady-state frequency method[22-31] requires a knowledge of the frequency

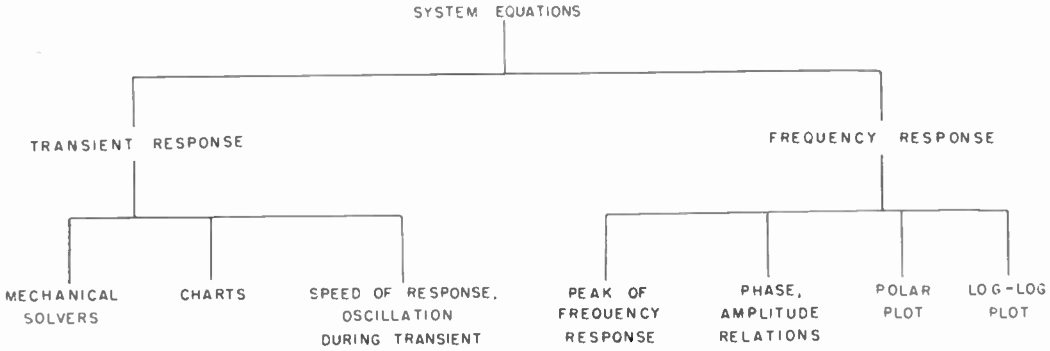

Fig. 2.—Summary of time and frequency information.

characteristics of the equipment under study over a reasonable frequency band. The method then followed is to insert phase correcting networks either in series or in parallel in the loop in order to yield (*a*) a desired degree of stability, and (*b*) a dynamic performance satisfying certain error specifications. This work leads to studies in terms of Nyquist diagrams and to expressions and plots which may be investigated by methods suggested by Bode and others.

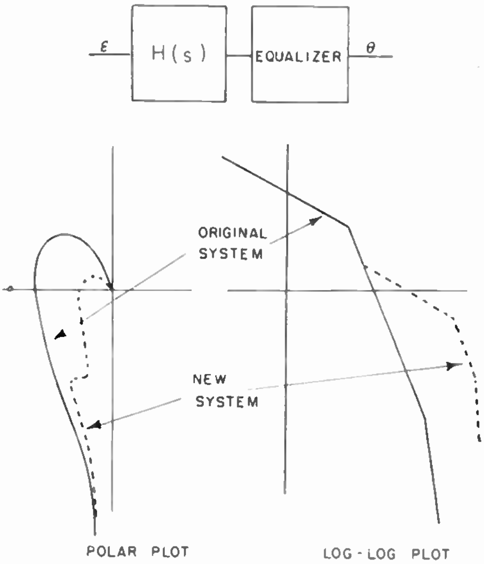

Fig. 3.—Series equalization by lead network.

It should be pointed out here that although transient and steady state studies yield the same information, the manner in which this information is presented and used makes the sinusoidal approach superior in designing conventional systems to fulfill the majority of performance specifications. Of course, no single mathematical tool should be given priority or undue emphasis. Each gives a certain clarity to the problem and together they lead to an integrated understanding of behaviour and design.

The efficient utilization of the sinusoidal procedure requires correlation of the frequency and time functions.[32] Correlation in a manner useful for engineering work is made by noting speed of response and frequency of oscillations, overshoot and steady-state error of the transient response, resonance conditions from input to output, phase variation of the loop gain function, *et al.* These features are paired for design purposes.

Two forms of frequency response plots give considerable information to the designer. The Nyquist plot of the loop gain, which is a polar plot, gives the variation of both magnitude and phase with frequency. The nearness of the plot to a critical point (-1, 0, in this case) is an indication of the degree of stability. In fact various contours may be drawn on the plot to show certain peak ratios of output to input. These are the so-called M curves. Other contours of useful quantities may be drawn as this is nothing more than an application of conformal mapping techniques. Along these lines it is quite possible to construct many types of nomographs which may prove useful in design.[12–13] In most of these cases the problem is to shape the locus to avoid some specified region and thus exhibit a desired response with frequency.

Another useful tool is the plot of loop gain *vs* frequency on a log-log scale. The technique here is to approximate this plot by a series of straight line asymptotes[12–16] and thus by the method of Bode determine the phase variation rather quickly.* The most important phase value is that occurring at the cutoff or crossover frequency, this being the frequency for which the loop gain goes through unity. If this phase shift is less than π, the system, in general, is stable. The difference between this shift and π gives a good indication of the degree of that stability. This quantity is given the name phase margin. It may be shown that shaping this plot in a certain fashion will give a desired degree of stability and also the error response of the servo is more evident from this type of plot than from the Nyquist diagram. This is due to the fact that in the region in which the loop gain is greater than unity the error to input ratio is approximately given by the reciprocal of that loop gain.

Considerable material is available in the literature concerning error analysis in terms of the so-called error coefficients,[12–16, 33–35] the most important being the position, velocity and

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*This approach applies only for minimum phase systems which is not a serious restriction as a great number of useful transfer functions fall into this category.

acceleration coefficients. For the log-log plots it is quite easy to observe the values of these coefficients directly and in many cases to make certain error-input characteristics a major goal and design toward this end. A summary of the above methods is given in Figs. 2, 3 and 4.

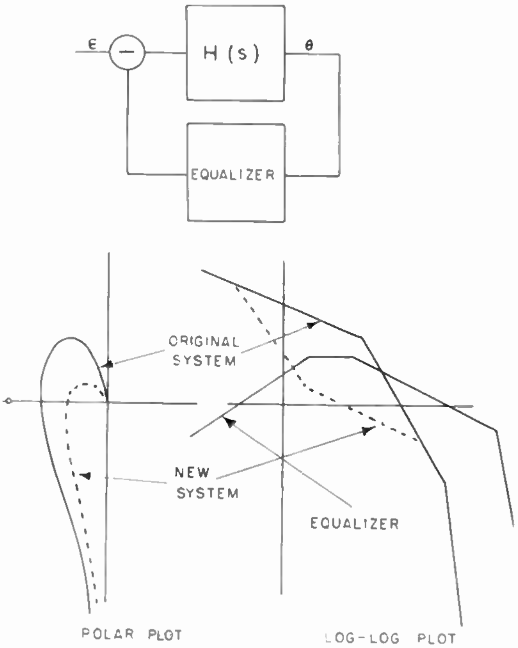


Fig. 4.—Parallel or minor loop equalization.

Although the functions used here are the loop gain functions, many designs may be based upon shaping the inverse function plots which are the reciprocals of those just considered.[16, 47, 48] This is especially useful in systems in which the output quantity is not compared directly with the input, e.g. the feedback is not unity or devices in which there are subsidiary loops present. Actually these techniques all have a common origin and the selection of a particular one is up to the designer. One or the other may be particularly well suited to his problem, or he may have more familiarity with one type of approach. The ideal situation, of course is that the expert be quite familiar with all the useful methods of design.

Another method of system synthesis worthy of note which falls under the frequency-time category is the root-locus method[36] which determines all of the roots of the differential equation of a control system by a graphical plot which readily permits synthesis for a desired transient or frequency response. The base points for this plot on the complex plane are the zeros and poles of the open loop transfer, which are readily available. The plot can be made in approximate form by inspection and significant parts calculated accurately. The plot gives a complete picture of the system which is particularly valuable for unusual systems or those which have wide variations in parameters.

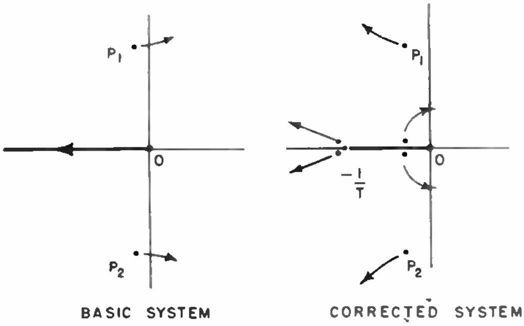


Fig. 5.—A representative root locus plot of a system corrected by three cascaded lag networks of time constant T.

Fig. 5 shows the plots for the basic and corrected system in an unusual type of instrument servomechanism.

3.3. *Pulsed Servos*

So far only design techniques for systems in which error information is supplied continuously have been considered. These are the most common types of systems. It is now necessary to consider some of the more specialized design methods which are applicable to devices operating from a very special type of input, or ones in which non-linearities are so great as to require special design methods. In this section the pulsed or sampling servo[12] will be discussed while the following section will be devoted to relay servos and other non-linear devices.

For the pulsed system it is reasonable to observe that if the sampling period is short compared with the system time constants, then the continuous data approach yields satisfactory results. However, when this is not true the stability criteria become somewhat different from that for the continuous system.

The approach to this system is essentially a time domain method. It considers instead of the weighting function of the usual time domain techniques, a weighting sequence. The system under study can be shown to be stable if this weighting sequence is bounded. A comparison of some of the formulas for pulsed and continuous systems is given in Table 1.

TABLE 1

Comparison of Continuous and Pulsed Systems

Input	Output	
	Continuous	Pulsed
Impulse	$W(t)$	$y_n(t) = W_n$
Step	$\int_0^t W(t)\,dt$	$y_n = \sum_{k=0}^{N} W_k$
$x(t)$	$\int_0^\infty d\lambda\, W(\lambda)\, x(t-\lambda)$	$y_n = \sum_{k=1}^{\infty} W_k x_{n-k}$

The properties of this sequence may be examined in terms of function theory and various conditions for stability specified. Frequently methods of conformal transformation are useful for specifying stability in terms of the locations of the singularities of the functions under study. All these may be shown to reduce to the continuous case for high pulsing rates.

A rather simple example of a sampling servo might be to consider a system in which input and output are shaft rotations with the correcting action furnished by exerting a torque on the output which is proportional to the error existing at the preceding measuring period. In this case one would find that if the servo were of the continuous type, it might have a loop transfer of the form.

$$H(s) = \frac{K}{s(Ts+1)} \quad \ldots\ldots\ \ldots\ldots\ldots\ldots (4)$$

This is a stable system regardless of K. However, if this were operated as a pulsed system and the analysis outlined used, one would find very definite conditions between K and sampling rate which would yield instability. For those who wish to pursue the pulse problem further, the reference cited for this section gives an excellent detailed treatment of this type of servo.

3.4. *Relay Servos*

Many systems incorporate relays into the loop. (See Fig. 6 for example.) A relay is merely a particular type of non-linearity and since much has been done on this subject in recent years, rather elegant design techniques are available.

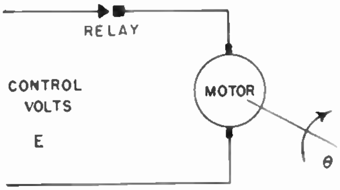
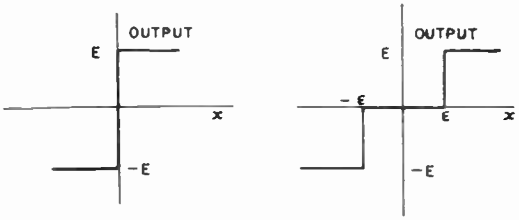


Fig. 6.—Incorporation of relay into system.



(a) (b)

Fig. 7.—Relay characteristics.

The simplest type of relay displays the characteristics shown in Fig. 7(a). It is simply an on-off device. Usually it is more realistic to consider the relay as having both dead band and hysteresis which naturally complicates the analysis somewhat. A relay with dead band is shown in Fig. 7(b).

One of the earliest analyses of contactor type servos was by H. Hazen[2] in 1934. He employed a direct differential equation approach which becomes very cumbersome when the system is at all complicated. The phase plane approach which is a simple graphical method was applied to relay servos by Weiss[37] and MacColl.[10] This method is also a very useful tool in dealing with other types of non-linearities in servo systems.[38-41] However, the method is limited to systems with few energy storage elements, and it is felt that the two approaches to be discussed here are the most useful at the present time.

One approach to this problem is to consider the input to $H(s)$ as a series of positive and negative steps as the relay opens and closes and determining whether the response is a divergent or convergent one.[42] This may be done by considering the output velocity at successive intervals of time. By examining plots of these functions against time the stability of the system may be established. This is illustrated in Fig. 8.

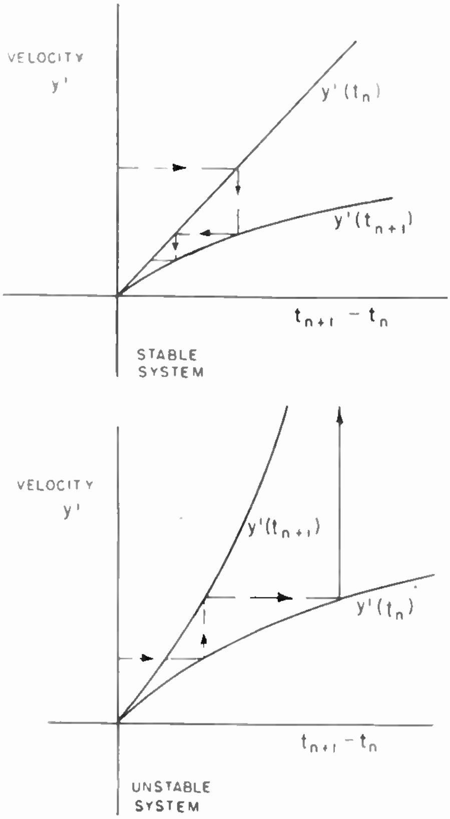


Fig. 8.—Velocity plots for relay servomechanisms.

For the stable system the output velocity converges to a finite value, while for the unstable system it diverges. The curves shown are for systems with no dead band or hysteresis. If these are present it is necessary to draw several diagrams to study stability.

Another approach to the relay servo utilizes a frequency response method.[43] This represents a definite departure from previous methods of attack. It is useful in that it allows analysis and synthesis from a knowledge of the response of the components to sinusoidal signals of various amplitudes and frequencies. The method is based upon the approximation of the contactor in terms of a linear describing function. The approach is to apply a sinusoidal signal to the contactor and represent its output in terms of a Fourier series. Since most servo output devices act as low pass filters the system may be considered as a quasi-linear device with a zero and fundamental frequency correction signal. However, the magnitude and phase of this fundamental component very definitely depends upon the input amplitude relative to the relay characteristic. Thus the contactor servo may be considered as equivalent to a system involving all linear components if a single constant amplitude signal is impressed. The method of determining stability is to consider the transfer in terms of:

$$\frac{1}{\text{Transfer}} = \frac{A_c^{-1}(s) + \dfrac{D_1}{C_1}}{\dfrac{D_1}{C_1}} \quad \ldots\ldots\ldots\ldots (5)$$

$A_c^{-1}(s)$ is the reciprocal of the loop gain of the continuous portion of the loop and is in itself considered stable. The D_1 over C_1 is the complex ratio of the relay output to input at the fundamental frequency and may be plotted on polar coordinates. One may then apply a somewhat modified Nyquist criterion by plotting $A_c^{-1}(s)$ and the relay output-input ratio on polar paper.

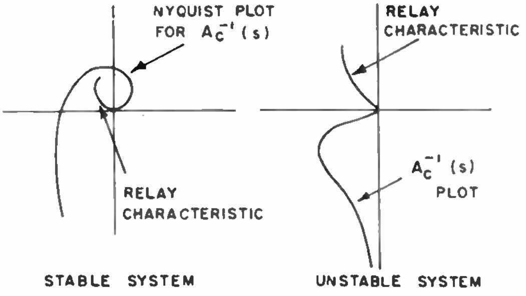


Fig. 9.—Modified Nyquist plots for relay servomechanisms.

The nonlinearity is taken care of by that ratio which for any frequency is different for different input levels. If the relay plot remains within the $A_c^{-1}(s)$ plot, the system will be stable. Fig. 9 shows several conditions. Obviously the manner in which the continuous portion of the system may be shaped for stability is clearly presented and compensating networks may be used. It is also possible to have the two plots intersect which, of course, means the system is stable for some input levels and unstable for others. It might be interesting to note here that the relay plot terminates when the input is less than the dead band. This would indicate that a relay with no dead band would probably have some unstable region regardless of the $A_c^{-1}(s)$ shape.

It is important also to point out that other nonlinearities might be handled in this way. Such things as backlash, coulomb friction, saturation, etc., would probably lend themselves rather nicely to this method. It thus seems reasonable to say that this approach, while being developed mainly for the relay type of servomechanism, offers broad possibilities in the solution of some of the more pressing nonlinear problems.[44-45]

3.5. *Statistical Design Methods*

So far only design methods in terms of errors to specified signals, damping, and other definite specifications have been considered. Nothing has been said about uncontrolled noise sources, random load disturbances, and random inputs. In many cases the actual input, noise interference, and other disturbances can, in general, be described only on a statistical basis. The radar tracking problem is an excellent example of this. Although it is possible to design a tracking servo from the methods of Section 3.2, obviously noise and other random signals must be virtually ignored in that design technique. All servomechanisms are, of course, subject to noise disturbances, especially those involving vacuum tube and radar systems. If this is to be seriously considered in design, a statistical approach is necessary.[12, 49, 50]

If a servomechanism error were reduced perfectly, the output would follow both desired input and noise perfectly. This, of course, is undesirable. Perfect signal response is therefore, not compatible with noise rejection. It is thus clear that one must seek a compromise in design.

As is true for input signals, noise is not usually a simple function of time but is characterized by statistical properties. The term, noise, may be used to refer to any unwanted signal. Due to the random characteristics only optimization of the average performance can be obtained.

Signal and noise are usually handled in terms of time and ensemble averages. Two of the most commonly used quantities are power spectrum and correlation function. The power spectrum is essentially the mean square value of a time function per cycle per second. The correlation function is the time average of a function separated in time by some interval. If one is considering the same function, the term autocorrelation is used, if one considers two different functions, a cross-correlation is obtained. The power spectrum and correlation function have the useful property of being a Fourier transform pair.

The minimization of the mean square error is usually considered as the desirable criterion in the statistical approach. Based mainly on Wiener's theory,[9] application to servomechanisms is difficult due to the fact that many servos have power devices often determined by other than dynamical considerations. Thus, some of Wiener's philosophy with modifications has been applied to servo design by Phillips[6, 8] and others. This approach optimizes the system constants whose form has already been found. These yield the most satisfactory results from an engineering standpoint.

The choice of the criterion is not always clear. The minimization of the mean square error is not necessarily the optimum criterion. Cases often arise where it is desired to keep the output of a control system within certain tolerances.[51] In other words, the undesirability of the error instead of being proportional to the error squared is zero up to a point and infinite beyond. This may be shown, for many cases to yield the same result as the r.m.s. criterion.

Generally, these methods are useful only for linear devices. The non-linear problem presents many formidable analytical obstacles. Some contributions have been made, however, in this field.[52, 53]

In general then, the statistical approach is reasonable for the optimization of control systems where the statistical properties of noise and signal are obtainable either theoretically or experimentally. The present criterion used are the r.m.s. minimization and minimizing the probability of the error falling outside a tolerance limit. The obtaining of the statistical information is usually the most difficult, as is the length and complexity of analysis occurring in large systems. However, if the noise and signal can be characterized by definite statistical properties, and if the criterion of goodness is not too involved, engineering procedures will yield suitable designs for the servo system.

4. New Problems and Trends

The preceding sections have attempted to point out some of the highlights of the more widely used design techniques and problems in the field of servomechanisms. Although each section has been necessarily brief, it is felt sufficient references have been made available for those interested in details.

It might be well now to consider some of the other problems not already covered. One formidable one, while not strictly a servo problem of design, is of paramount importance to the art. This is the distribution of information on many of the new design techniques, the statistical ones especially. Frequently, many new approaches are developed but much literature of a tutorial nature must appear before these techniques become useful tools for everyday use. The first methods considered, those on frequency, and time domain are pretty well digested. This is not true for some of the newer methods. It would seem, then, that there is a definite need for more material on the statistical and other approaches to the servo problem to supplement that which has already appeared. Examples of the applications of these techniques to actual systems would be most useful. Of course, in this regard, problems of continuing military security and keen competition among companies act as a definite retarding force on a completely free interchange of ideas.

As another problem to be considered there is still much to be done in the field of non-linear servos. An approach, using the frequency response methods of Kochenberger, will probably prove most rewarding as already suggested. Along these lines many problems are being considered now where non-linearities are purposely introduced into the loop to obtain certain desirable characteristics.

Perhaps the most fascinating problem in servomechanisms is the incorporation of the human link into the closed loop.[54-55] This problem is being considered in detail in the design of displays and controls, tracking equipment, instrumentation and controls for high-performance aircraft and other similar equipment. The approach has been to concentrate on biological research categories such as motion skills, perceptual skills, responses to stimuli varying in rate, magnitude and frequency, stress responses, fatigue, etc. These problems, of course, demand skills of those outside the engineering profession, medical man, psychiatrists, and others working hand in hand with those experienced in usual servo systems. The approach may be linear or non-linear—both have been considered—but this is surely one of the newer and more demanding problems of this ever-growing field. Here again, however, this particular problem has been considerably covered by military security due to its extreme importance in that field and, therefore, not much literature is available.

It seems entirely reasonable, then, to conclude this survey of the servomechanism art by stating that feedback control system engineering is a relatively new, rapidly growing profession. It is one that demands a new type of thinking that cuts across traditional categories in both education and industrial organization. The skilled engineer in servo is usually required to know advanced mathematical techniques, electrical engineering, mechanical engineering, and various other topics. The efficient utilization of this talent demands a re-styling of the attitudes of engineering management and the education of young men for this level of professional competence requires a restyling of ideas in post graduate engineering training. It is clearly indicated in both the United States and abroad that this situation has been recognized.

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HONORARY LOCAL SECRETARIES IN INDIA

Prem Chand Saggar, who was born at Ludhiana in the East Punjab in 1917, received his general education at the Government School in Hoshiarpore. His technical education was obtained at Agra and at St. Xavier's College, Bombay, where he gained various City and Guilds Certificates.

In 1938 he became a lecturer in various radio subjects at the College, and during the war years Mr. Saggar was Chief Instructor of the War Trainees Centre. Since 1946 he has been Senior Lecturer responsible for the teaching of Advanced Radio Communication, Acoustics and Radio Physics.

Mr. Saggar was elected an Associate of the Institution in 1951, and in 1952 he was transferred to Associate Membership. He assisted the Indian Advisory Committee in convening the first meeting of members of the Institution in India, and in September last year he was appointed Honorary Secretary of the Bombay Section.

Dr. Jatindra Nath Bhar was born in Chandernagore in 1911 and educated at the University of Calcutta, taking his B.Sc. (with honours in Physics) in 1931; he was awarded a Doctorate of Science in 1939 at the age of 28 years. From 1940 to 1942 he was research assistant, C.S.I.R. (India), and from 1942, for five years, he acted as secretary of the Radio Research Committee, C.S.I.R.

One of the most fruitful periods of his career began in 1944, when he became lecturer in Physics at Calcutta University; in 1949 Dr. Bhar was appointed to the Readership in Radio-physics and Electronics at the University. Ionospheric research has claimed much of his attention, and he has been in charge of this work at the Ionosphere Laboratory, Calcutta, since 1944. Dr. Bhar has done much pioneer work in the investigation of radio reflections of the ionosphere and made the first substantial survey of ionospheric conditions in subtropical regions, correlating them with geophysical and geomagnetic phenomena. Dr. Bhar was an original worker in developing the theory of the formation of the E region and its stratification and has numerous other published papers to his credit on this and similar topics.

Dr. Bhar was elected to full Membership of the Institution in June of this year. He is Honorary Secretary of the Calcutta Section.

Professor Richard Filipowsky, Head of the Department of Electronics at the Madras Institute of Technology, was born in Vienna in 1915. He received his "Diploma-Ingenieur" in Applied H.F. Physics from the Vienna Technical University in 1938 and was appointed a television research engineer with Telefunken, Berlin.

For the next six years he was engaged in pulse technique development, and in 1946 he was made Director of the R.A.T.E.M. Institute for scientific documentation in Roethis, Austria, and co-editor of "Elektronentechnische Berichte." In 1948 he became Chief Engineer of the Laboratory of Companhia Portuguesa Radio Marconi in Lisbon, and in 1950 he obtained his present appointment. He has recently been also appointed a member of the Board of Studies in Engineering of the University of Madras.

Professor Filipowsky has written numerous scientific papers and other publications and he is originator of 23 German, Swedish, British, American and Portuguese patents on various aspects of television, pulse technique and multiplex telephony. He is co-author of "English-German Electrotechnical Dictionary" published in 1948 in Vienna.

He was elected a full Member of the Institution in 1951 and he is Honorary Secretary of the Madras Section.

APPLICANTS FOR MEMBERSHIP

New proposals were considered by the Membership Committee at a meeting held on September 17th, 1952 as follows: 31 proposals for direct election to Graduateship or higher grade of membership and 23 proposals for transfer to Graduateship or higher grade of membership. In addition 27 applications for Studentship registration were considered. This list also contains the names of 3 applicants who have subsequently agreed to accept a lower grade than that for which they originally applied.

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

Direct Election to Full Member

ROBERTSON, Norman Charles, M.B.E. *Burnham-on-Crouch, Essex.*

Transfer from Associate Member to Full Member

KRAUSE, Vivian Rupert. *Johannesburg.*

WASHTELL, Colin Charles Henry. *Cambridge.*

Direct Election to Associate Member

EYET, Hubert. *Isleham, Cambridgeshire.*

HANNA, George Victor, Flight Lieutenant, R.A.F. *Great Yarmouth, Norfolk.*

HORDER, Wilberforce Charles, Squadron Leader, R.A.F. *Bristol.*

KRISHNAMURTI, T., M.A. *Madras.*

MAYHEW, Kenneth Walter Stewart. *Surbiton, Surrey.*

MONNERY, Kenneth Charles Ashcroft, Lieutenant (L), R.N. *Effingham, Surrey.*

MUKHERJEE, Amiya Bhushan, Squadron Leader, Indian Air Force. *Bihar, India.*

PHATAK, Ramachandra Kondo. *Bombay.*

PRICE, William Laurence, Flight Lieutenant, R.A.F., B.Sc. *Derby.*

PULSFORD, Edgar William, B.Sc. *Abingdon, Berkshire.*

ROBERTS, Graham Estyn. *Stoneleigh, Surrey.*

WIEGERINCK, Hendrikus T. J. *Lowestoft, Suffolk.*

WRAY, Arthur George, M.A. *Welwyn Garden City, Hertfordshire.*

Transfer from Associate to Associate Member

RAMANATH, Koduvayoor Ramakrishna, Lieutenant (L), Indian Navy. *Poona, India*

RAMNANY, Parmanand, Flight Lieutenant, Indian Air Force. *Madras, India.*

Transfer from Graduate to Associate Member

MEADOWS, Clement Arthur, B.Sc.(Eng.). *London, W.13.*

Transfer from Student to Associate Member

GNANAM, Miss Panchapakasan, M.Sc. *Madras State.*

PARTHASARATHY, Mandayam Nayak, M.A. *Madras.*

Direct Election to Companion

DESAI, Dhansukhlal Maneklal. *Bombay.*

Direct Election to Associate

FINCH, Joseph Devonshire. *Tonbridge, Kent.*

Transfer from Associate to Graduate

EAST, Alexander Maurice. *Aveley, Essex.*

SQUIRES, Terence Leighton. *Pontypridd, Glamorgan.*

Transfer from Student to Associate

CASPERD, Stanley George. *Crowborough, Sussex.*

WHARFE, Stanley. *Bedford.*

Direct Election to Graduate

CORNFORD, Basil, Sub-Lieutenant (L), R.N. *Newhaven, Sussex.*

CROXSON, Derek Henry. *London, S.E.9.*

DAVEY, Norman Charles. *Thornton Heath, Surrey.*

JAMES, Michael. *Romsey, Hampshire.*

LAL, Satish Chandra, Pilot Officer, Indian Air Force, B.Sc. *Delhi, India.*

PEART, Albert John, Squadron Leader, R.A.F., *Harrow, Middlesex.*

READ, Peter George. *Harrow, Middlesex.*

SHUTTLEWORTH, Peter, B.Sc. *Newcastle-upon-Tyne.*

SPOKES, Frederick Kenneth. *Crewe, Cheshire.*

SURI, Kishori Lal, Lieutenant, Indian Army, B.A. *London, W.1.*

WHITAKER, Peter Kenneth, Flight Lieutenant, R.A.F. *St. Albans, Hertfordshire.*

WILKINSON, Donald Edgar, Flight Lieutenant, R.A.F. *Leeds.*

Transfer from Student to Graduate

CHAUDRI, Enver Hussain. *Ipswich, Suffolk.*

GREEN, Sydney William. *London, S.W.11.*

HEAD, Reginald Edward Albert. *Wolverhampton, Staffordshire.*

HICKLING, Alfred. *Malvern, Worcestershire.*

PEARSON, Gordon Pitt. *Limpsfield, Surrey.*

RACHERLA, Sitaram, M.Sc. *Morvi, Saurastra State, India.*

RODMELL, Edward Cripps. *Didcot, Berkshire.*

SKINNER, Leonard Malcolm. *London, E.5.*

WOODS, John Joseph. *Co. Kerry, Eire.*

Studentship Registrations

BEAUMONT, Raymond Kenneth. *Bulawayo, Rhodesia.*

BRUNSKILL, David Moss. *Liverpool.*

CAVOUROPOULOS, *John. Athens.*

CHARLTON, George Peter. *Helston, Cornwall.*

CHUGH, Joti Prakash. *Lucknow, India.*

DAVIS, Trevor. *Sydney.*

KHADKIKAR, Ganesh Dinkarrao. *Jabalpur, India.*

KOUMBOURIS, Themistoclis. *Athens.*

LANE, Dennis Edward. *Woking, Surrey.*

LONG, Kenneth David. *London, N.W.11.*

LUTHRA, Suraj Parkash, B.A. *Ludhiana, East Punjab.*

MARSHALL, Gerald William Arthur. *Harrow, Middlesex.*

MENON, Karunakaran, C.P. *Chittur-Cochin, South India.*

MUBARAK, Ch. Mohd Hassan, B.A., B.Sc. *London, W.5.*

RAGHAVAN, Narayan. *Bangalore.*

RAJAPAKSHA, Hercules. *Mount Lavinia, Ceylon.*

RAY, Nirmalendu. *Ambala Cantt, India.*

SAROOPA, Anand, M.Sc. *Glasgow.*

SILVESTER, Arnold. *London, N.W.11.*

SREENIVASAN, Nangapuram. *Calcutta.*

SUKHDANI, Madhukar Govindrao. *Nagpur, India.*

TAYLOR, Charles Ernest. *London, S.W.19.*

THAMPY, K. Krishnan, B.Sc. *Madras.*

THORPE, Frederick Arthur. *London, W.14.*

THUMALA VARADHARAJULU, Jayaram. *Mathurai, India.*

VALASSIS, John. *Spartis, Greece.*

YOUNG, William Arthur. *Harrogate, Yorkshire*

REACTIVE TIME BASES*

by

A. B. Starks-Field, B.Sc.†

A Paper presented at the Fifth Session of the 1951 *Radio Convention on August* 23*rd in the Cavendish Laboratory, Cambridge*

SUMMARY

The use of wide-angle large screen cathode-ray tubes for television purposes has led to the necessity for high-efficiency line time bases.

The paper describes the various methods which can be employed to recover the energy present on the deflection field at the end of the scan, either to be returned to the H.T. rail or alternatively to provide a voltage boost to supply the driver stage.

The design of the voltage booster circuit either with an auto-transformer, or with a multi-wound transformer, is discussed in detail with reference to efficiency, linearity and convenient operation from H.T. supplies of the order of 200 V.

Particular reference is made to the design problems of the transformer and mention is also made of a direct-drive system whereby the circuit can operate directly on to high-impedance deflection coils.

The use of wide-angle large-screen television tubes has led to the necessity for high-efficiency line time bases. The method of using some system of damping during the time base fly-back in order to dissipate all the deflector-coil energy at the end of the scan can be ruled out on the score of inefficiency. For convenience, the term VA output will be used to mean the product of the voltage across the deflector coils during scan, and the peak-to-peak scan current. To scan a 53-deg. angle tube with 9-kV final anode voltage requires about 30 VA and with such a time base the power drain from the H.T. rail is something of the order of 28 W. A 70-deg. angle tube with 14-kV final anode voltage, requires 120 VA, and would demand about 120 W from the rail, quite apart from the fact that at least two line amplifier valves in parallel would be needed. In view of the fact that nearly all the energy fed to the circuit is stored in the magnetic field in the deflector-coils system at the end of the scan and normally this would have to be dissipated during the fly-back, the logical approach is to attempt to recover this energy.

Figure 1 shows a simple form of circuit capable of recovering the energy in the deflector-coils system and supplying it to a battery.

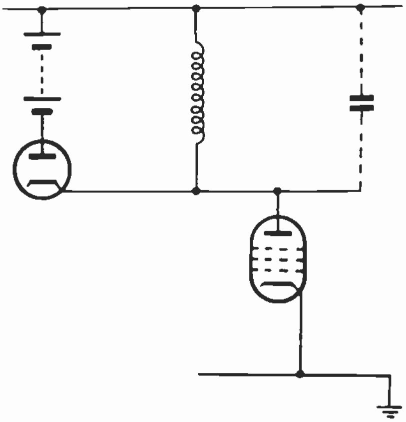

Fig. 1.—Simple energy recovery circuit.

The deflector coils are connected directly in the anode circuit of the line amplifier or driver valve, and their stray capacitances make this up into a resonant circuit. Considering the conditions at the end of a scan, a current I_c has been established in the deflector coils (Fig. 2*a*). At instant T_0 the driver valve V1 is cut off. The current in the coils would then execute at least half a cycle of free oscillation resulting in the current and voltage waveforms shown in Figs. 2 (*a*) and (*b*) respectively. At the instant T_f the voltage at the diode cathode would be more negative than its anode and it would start to conduct. Neglecting the resistance of the diode and any circuit resistance the battery voltage would prevent any further rise in coil voltage and the current would decay to zero linearly. If at this instant the driver were fed with a suitable waveform to supply the circuit for the remainder of the scan the whole process could be repeated.

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* Manuscript received July 20th, 1951.

† Marconi's Wireless Telegraph Co., Ltd.

U.D.C. No. 621.397.621.

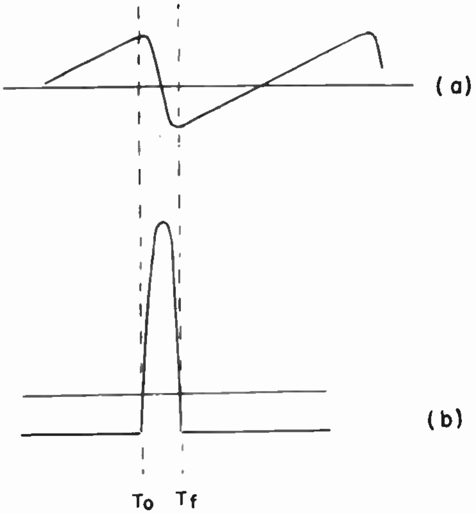

Fig. 2.—Current and voltage waveforms in a simple energy recovery circuit.

In a lossless system, and wasting all energy supplied to the battery, it can be shown that this simple system results in an improvement of efficiency by a factor of 4 over that of a class A scanning circuit.

The introduction of a transformer does not alter the basic performance of the circuit, but it permits the use of tappings to match the system to any reservoir and Fig. 3 shows a system where by the energy can be returned to the H.T. supply. So far for a given output the actual peak current through the driver valve has only been halved, compared with a class A scan.

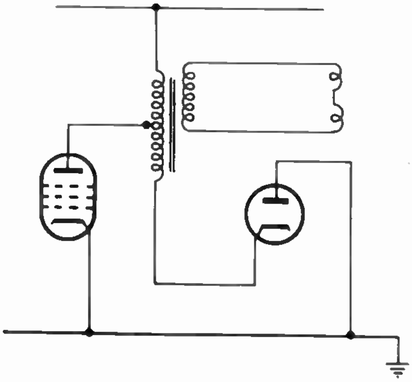

Fig. 3.—Circuit for returning recovered energy to H.T. source.

If the H.T. supply to the drive valve could be raised, the peak current taken could be reduced and the scheme leads to one of the forms of the now almost universally accepted voltage booster circuit shown in Fig. 4. Here the damper current is used to charge C_B which then provides a boosted voltage from which the driver valve can be operated.

It is proposed to discuss the detailed design of this circuit in conjunction with the alternative arrangement shown in Fig. 5.

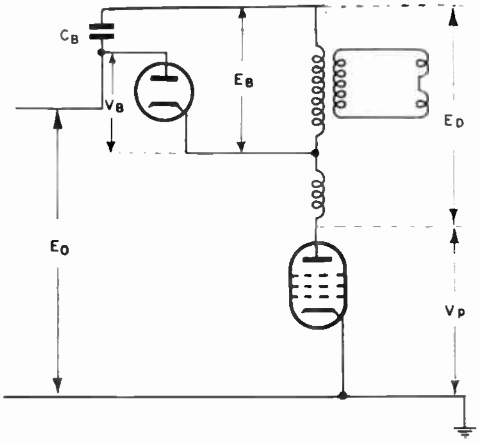

Fig. 4.—Circuit for supplying recovered energy to a boost voltage source.

SYMBOLS

L_c = deflector coil inductance
E_0 = H.T. rail voltage
E_D = voltage across driver winding
E_B = voltage across damper section
I_D = peak current through driver valve
I_B = peak current through damper valve
$\hat{I}_c$ = peak-to-peak coil current
V_p = voltage across driver valve
V_B = voltage across damper valve
R_D = apparent source resistance of driver valve when "bottomed"
R_B = resistance of damper valve
R = deflector-coil resistance
α = decrement ratio
T_f = fly-back time
T_s = scan time
n = transformer ratio damper to driver
VA = volt amperes output
W = power from H.T. supply
η = co-efficient of performance $= \dfrac{VA}{W}$.

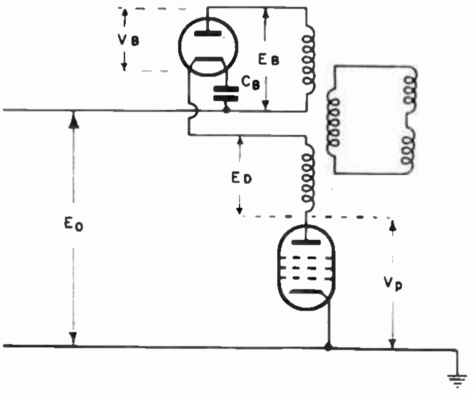

Fig. 5.—Alternative arrangement to Fig. 4.

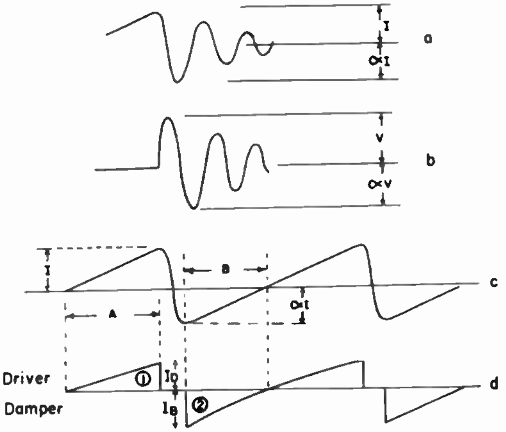

Fig. 6. Current and voltage waveforms showing the mechanism of energy recovery.
Note.—Rise waveform in (d) should be two straight lines.

Consider a current of I established in the deflector coils at the end of the scan. At this instant, assume the driver valve is cut off and that the circuit is left entirely free. The coil current and voltage would then follow a damped harmonic train as shown in Fig. 6 (*a*) and (*b*). If T_n is the natural period of the circuit then at approximately $T_n/2$ sec after cut-off the current will have reversed and its value will then be αI where α (the decrement ratio) is defined as the amplitude of the second half-cycle over that of the first. If then, at this instant the damper valve conducts, the waveform shown in Fig. 6 (*c*) would result and if the rate of change of current were the same as that during the driven portion of the scan then $B = \alpha A$.

Referring now to Fig. 4, the actual current delivered by the damper valve to C_B must always equal that required by the driver. Therefore, for this condition, which incidentally is not the only possible condition, the ratio of driver winding to that of the damper must be arranged so that the actual area of the damper waveform equals that of the driver. Fig. 6 (*d*) shows these waveforms as required at the valves. For convenience, in the following argument it will be assumed that the coils are connected across the damper section of the transformer. Fig. 6 (*c*) can then be regarded as the coil current and its peak-to-peak value as $\hat{I}_c$. Portion B is that which is delivered through the damper, and portion A is the driver valve current referred to the damper winding. Referring to Fig. 6 (*d*), area (1) must equal area (2)

$$I_D A = I_B B \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

from Fig. 6 (*c*)

$$I_B = \alpha I \text{ or } I = I_B \frac{1}{\alpha}$$

$$I_D = In \text{ or } I = I_D \frac{1}{n}$$

$$I_D \frac{1}{n} = I_B \frac{1}{\alpha}$$

$$\text{or} \quad I_D = I_B \frac{n}{\alpha} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

substituting (2) in (1)

$$I_B \frac{n}{\alpha} A = I_B B$$

$$\text{but} \quad B = \alpha A$$

$$\therefore I_B \frac{n}{\alpha} A = I_B \alpha A$$

$$\text{or } n = \alpha^2$$

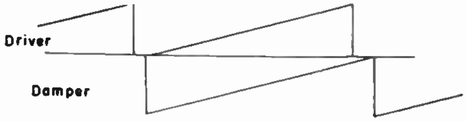

Fig. 7.—Valve current waveforms for $AB_{100/100}$ *condition.*

This then is the most important thing to achieve in a circuit design where this condition is required. However, there is an alternative condition, which is also worth considering, and this is shown in Fig. 7 where driver stage and damper stage conduct during the whole scan. In this case the transformer ratio $n = \alpha$. There are innumerable conditions between these two which are possible and indeed are quite satisfactory, some of which at first sight seem to be ridiculous. For the present the discussion will be confined to that of the condition which it is suggested should be known as the B condition, where driver takes over as soon as the damper ceases, and the others as various A.B. conditions.

Referring again to Fig. 4, during the scan the following equation must hold:—

$$E_0 - V_B + E_B - E_D - V_p = 0 \quad \ldots\ldots\ldots\ldots (3)$$

For the conditions required $n = \alpha^2$.

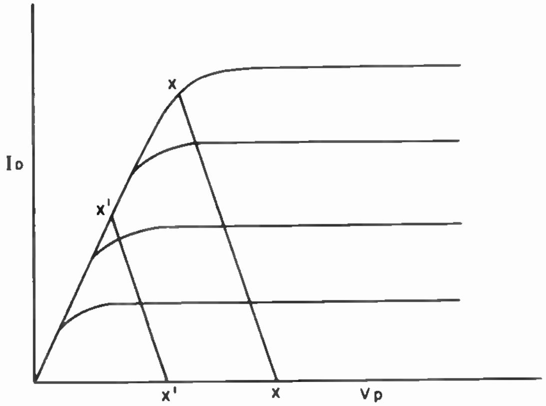

Fig. 8.—Load lines for resistive and reactive load to a saw-tooth current waveform.

Ignoring for the moment methods of achieving linearity, under the conditions of maximum damper current, i.e., at the start of the scan, $V_B = I_B R_B$. Fig. 8 shows the characteristic of a pentode, and if linearity is to be achieved by controlling the valve grids in some way, then at the end of scan the knee of the characteristic at the maximum current required is the limiting condition of the circuit. XX indicates the load line of the valve under such conditions; X′X′ shows a load line for somewhat lower current conditions. The volt drop across the valve under this condition is $I_D R_D$.

$$V_p = I_D R_D$$

To evaluate I_D and I_B from Fig. 6 (*c*)

$$I_D \frac{1}{n} + I_B = \hat{I}_c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$I_B = \alpha I_D \frac{1}{n} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

substituting (5) in (4)

$$I_D \frac{1}{n}(1+\alpha) = \hat{I}_c \qquad n = \alpha^2$$

$$I_D = \frac{\hat{I}_c \, \alpha^2}{(1+\alpha)}$$

similarly $I_B = \dfrac{\hat{I}_c \, \alpha}{1+\alpha}$

$$\therefore \quad V_B = \hat{I}_c \frac{\alpha R_B}{1+\alpha}$$

and $V_p = \hat{I}_c \dfrac{\alpha^2 R_D}{1+\alpha}$

If resistance R is included and linearity is maintained

$$E = L\frac{di}{dt} + Ri$$

$$E_B = \frac{L}{T_s}\hat{I}_c - R\frac{\hat{I}_c}{2} \text{ at beginning of scan}$$

and $E_B = \dfrac{L}{T_s}\hat{I}_c + R\dfrac{\hat{I}_c}{2}$ at the end of scan

It is therefore necessary that some component be included in the cathode of the damper tube, or in some other suitable part of the circuit, to compensate for this rise in E_B during the scan so as to allow the damper valve to cease to conduct towards the middle of the scan.

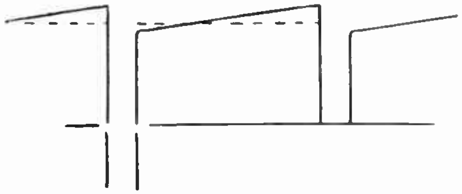

Fig. 9.—Voltage across damper during scan for linear operation.

Referring to Fig. 9, which shows the voltage waveform required across the deflector coils for a linear scan, that across the inductive component being drawn dotted, it will be seen that if this in fact were the voltage at the diode cathode, it could never cease to conduct except during the fly-back. It is therefore necessary that the component referred to must in some way absorb this rise in voltage, and somewhat more to provide a falling voltage at the cathode.

This will necessarily mean that the voltage on the boost condenser will be reduced by $\dfrac{R\hat{I}_c}{2}$.

Further at the end of scan E_D will be

$$\frac{1}{\alpha^2}\left(\frac{L}{t_s} + \frac{R}{2}\right)\hat{I}_c$$

Substituting in equation (3) E_B and E_D taken for worst conditions

$$E_0 - \hat{I}_c \frac{\alpha R_B}{1+\alpha} - \hat{I}_c \frac{\alpha^2 R_D}{1+\alpha} + \left(\frac{L}{T_s}\hat{I}_c - \frac{R}{2}\hat{I}_c\right) - \left(\frac{L}{T_s}\hat{I}_c + \frac{R}{2} I_c\right)\frac{1}{\alpha^2} = 0$$

$$\hat{I}_c = \frac{E_0}{\frac{\alpha}{1+\alpha}\left(\alpha R_D + R_B\right) + \frac{R}{2}\left(1 + \frac{1}{\alpha^2}\right) + \frac{L_c}{T_s}\left(\frac{1}{\alpha^2} - 1\right)} \quad \ldots\ldots\ldots\ldots\ldots(6)$$

$$VA = \frac{L_c}{T_s}\hat{I}^2{}_c$$

$$= \frac{\frac{L_c}{T_s}E^2{}_0}{\left\{\frac{\alpha}{1+\alpha}\left(\alpha R_D + R_B\right) + \left(1 + \frac{1}{\alpha^2}\right)\frac{R}{2} + \frac{L_c}{T_s}\left(\frac{1}{\alpha^2} - 1\right)\right\}^2} \quad \ldots\ldots\ldots\ldots\ldots(7)$$

This expression gives the maximum VA output available for a given rail voltage with a given set of components provided that α is known for a given coil and transformer combination and $\frac{L_c}{t}\left(\frac{1}{\alpha^2} - 1\right)$ is made equal to

$$\frac{\alpha}{1+\alpha}\left(R_D + R_B\right) + \left(1 + \frac{1}{\alpha^2}\right)\frac{R}{2}$$

It is interesting to note that as $\alpha \to 1$ the second term in the denominator tends to 0, and L_c can be made as large as we like with a corresponding increase in VA output.

The H.T. consumption is equal to the mean current taken by either driver or damper valve.

$$\text{Mean current} = \tfrac{1}{2}\frac{\hat{I}_c\alpha}{(1+\alpha)}\frac{\alpha}{(1+\alpha)}$$

$$\text{Power consumption } W = \tfrac{1}{2}\frac{\hat{I}_c\alpha^2}{(1+\alpha)^2}E_0 \text{ Watts}$$

Substituting for $\hat{I}_c$

$$W = \frac{\tfrac{1}{2}E^2{}_0\,\alpha^2}{\left\{\frac{\alpha}{1+\omega}(\alpha R_D + R_B) + \frac{R}{2}\left(1 + \frac{1}{\alpha^2}\right) + \frac{L}{T_s}\left(\frac{1}{\alpha^2} - 1\right)\right\}(1+\alpha)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(8)$$

and coefficient of performance

$$\frac{VA}{W} = \frac{\frac{L_c}{\alpha^2 T_s}(1+\alpha)^2}{\frac{\alpha}{1+\alpha}(\alpha R_D + R_B) + \frac{R}{2}\left(1 + \frac{1}{\alpha^2}\right) + \frac{L_c}{T_s}\left(\frac{1}{\alpha^2} - 1\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(9)$$

This tends to a max. value of $\frac{1+\alpha}{1-\alpha}$ as L_c tends to infinity so that the best method of approach in the design of a stage is to use the largest value of deflection yoke inductance possible, consistent with other requirements. Practically the author has succeeded in obtaining coefficients of performance of the order of 7 to 9. This means that a 70-deg angle of deflection tube can be scanned with a H.T. consumption of 80 to 100 mA from a 200-V supply.

Up to the present the design of the stage has been based on the assumption that the deflector coils will be connected directly across the damper section of the transformer. This as will be seen has certain advantages which will be discussed later, but it suffers from the disadvantage that very high voltages, of the order of 4 kV are developed across the coils. Most designs therefore arrange that the coils are tapped in at a suitable matching point on the transformer winding and the equations above hold if the coil inductance and resistance are referred to the damper section.

Taking the condition shown in Fig. 7 the equations are as follows:—

VA output =

$$\frac{\frac{L_c}{T_s}E^2{}_0}{\left\{\frac{\alpha}{1+\alpha}(R_p + R_B) + \frac{R}{2}\left(1 + \frac{1}{\alpha}\right) + \frac{L_c}{T_s}\left(\frac{1}{\alpha} - 1\right)\right\}^2} \quad \ldots\ldots\ldots\ldots\ldots(10)$$

Coefficient of performance =

$$\frac{\frac{L_c}{\alpha T_s}(1+\alpha)}{\left\{\frac{\alpha}{1+\alpha}(R_p + R_B) + \frac{R}{2}\left(1 + \frac{1}{\alpha}\right) + \frac{L_c}{T_s}\left(\frac{1}{\alpha} - 1\right)\right\}} \quad \ldots\ldots\ldots\ldots\ldots(11)$$

It is suggested that this condition should be referred to as $AB_{100/100}$ condition, both valves conducting for 100 per cent. of the scan.

It is interesting to note that expression (11) tends $\frac{1+\alpha}{1-\alpha}$ as $L_c \rightarrow \infty$.

Substituting the value of L_c for maximum output, i.e.,

$$\frac{L_c}{T_s} = \frac{R}{2} \frac{\left(1+\frac{1}{\alpha^2}\right) + \frac{\alpha}{1+\alpha}(\alpha R_p + R_B)}{\frac{1}{\alpha^2} - 1}$$

for B condition in eqn. (7)

and
$$\frac{L_c}{T_s} = R \frac{\left(1+\frac{1}{\alpha}\right) + \frac{\alpha}{1+\alpha}(R_p + R_B)}{\frac{1}{\alpha} - 1}$$

for $AB_{100/100}$ condition in eqn. (10)

Maximum VA for B condition:

$$VA_B max = \frac{R \dfrac{1+\frac{1}{\alpha^2}+\frac{\alpha}{1+\alpha}(\alpha R_p + R_B)}{\frac{1}{\alpha^2}-1} E_0^2}{4\left\{1+\frac{1}{\alpha^2}+\frac{\alpha}{1+\alpha}(\alpha R_p + R_B)^2\right\}}$$

$$= \frac{E^2_0}{4\left\{\left(1+\frac{1}{\alpha^2}\right)R + \frac{\alpha}{1+\alpha}(\alpha R_p + R_B)\right\}\left(\frac{1}{\alpha^2}-1\right)} \quad \ldots.(13)$$

Maximum for AB $_{100/100}$ condition:

$VA/AB\ (_{100/100})\ max. =$

$$\frac{E^2_0}{4\left\{\left(1+\frac{1}{\alpha}\right)R + \frac{\alpha}{1+\alpha}(R_p + R_B)\right\}\left(\frac{1}{\alpha}-1\right)} \quad \ldots.(14)$$

The VA for a circuit is therefore independent of the scan time.

Figure 10 shows the performance curves for a circuit in which $\alpha = 0{\cdot}84$, $R_p = 120\Omega$, $R_B = 80\Omega$. It will be seen that for a given inductance loading to the circuit the B condition gives a higher coefficient of performance than does the $AB_{100/100}$ condition, but a higher output is always possible under the $AB_{100/100}$ condition, and further the $AB_{100/100}$ condition seems to give an almost identical coefficient of performance provided that the correct inductance is selected. This last statement is based on a visual extrapolation of the VA and η curves to values of 200 and 5 respectively.

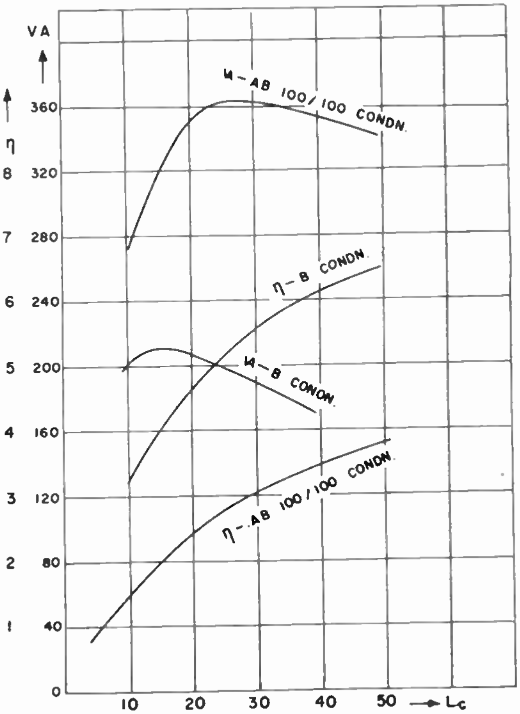

Fig. 10.—Efficiency and output curves for B and $AB_{100/100}$ condition.

In practice the author has never achieved such outputs in spite of the fact that the value of α for the coil and transformer assembly has by direct measurement proved to be in some cases as high as 0·9.

It must be remembered that so far leakage inductance and magnetizing VA for the transformer have been neglected. By including these values circuits have shown themselves capable of delivering 200 VA, but under these conditions were working approximately under the $AB_{100/100}$ condition. It would appear, therefore, that an additional damping is present when the circuit is operating which reduces the effective α. Recent tests carried out by absorbing the damper power into an artificial load and supplying the driver circuit from a suitably high H.T. voltage, have shown that with a deflector circuit. with $\alpha = 0{\cdot}85$ $A/B = 0{\cdot}7$ (referring to Fig. 6 (*c*))

Perhaps at this stage some of the requirements of linearity should be discussed. If the resistance of the deflector coils is ignored for the moment, the voltage cross the coils should be maintained constant during the scan. This implies that E_B must also remain constant, and if the reservoir condenser C_B be considered as large enough to maintain its voltage constant, the drop across the damper tube must also be maintained constant. Since the current through this tube must decay to zero at some period during the scan, it is evident the circuits shown in Fig. 4 and 5 must prove to be non-linear. Resistance in the deflector coils makes matters worse, for to maintain linearity under these conditions E_B and therefore V_B rises towards the end of the scan.

One very good solution is to make the damper tube a triode when it becomes possible to control the current to its correct waveform even though the voltage across the tube be maintained constant or rising.

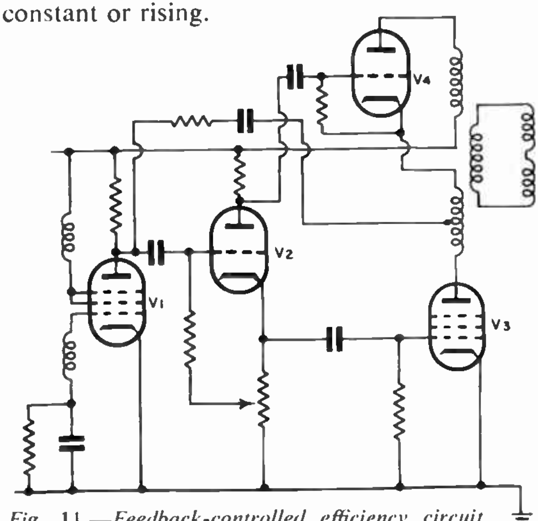

Fig. 11.—*Feedback-controlled efficiency circuit using triode damper valve.*

Figure 11 shows a circuit, developed from Fig. 5 which is very successful. V3 and V4 are the driver and damper tubes respectively the grids of which are controlled from the cathode and anode respectively of V2. The cathode and anode loads are adjusted to give the correct waveforms with a saw tooth drive to the grid of V2. The complete circuit is then converted into a magnetic Miller circuit by means of the RC network from the coil circuit back to the grid of V2. V1 is then a blocking oscillator for timing the scan.

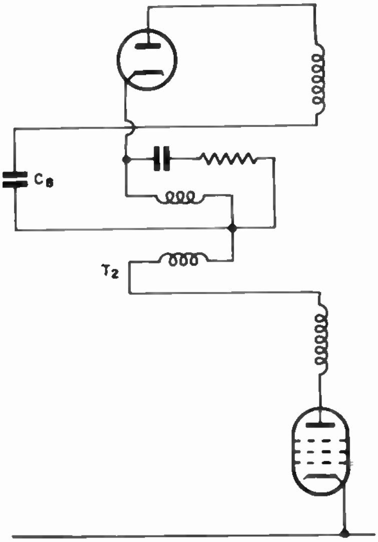

Fig. 12.—*Circuit using linearity system developed by Schade.*

The circuit is quite suitable for camera work where a high degree of linearity is required, but unfortunately a sufficiently low impedance triode to permit the large outputs, required to scan a wide angle tube, has not yet been produced.

Another system due to Schade of R.C.A.,* and shown in Fig. 12, attempts to produce the necessary voltage change at the damper cathode, by transforming some of the current saw-tooth in the driver stage in the auxiliary transformer T2. Now, in order to transform the current waveform, it is necessary that the transformer be loaded by pure resistance, since this resistance, however coupled, appears as a resistance in the damper cathode, the loss voltage across it during the period when the damper is conducting tends to defeat the object of linearity correction. Further, in the B condition there is no current waveform in the driver circuit during the early part of the scan. The transformer is therefore made resonant at some frequency near the line scan recurrence frequency when the voltage waveform across the winding in the damper cathode becomes the sum of a phaseable sinusoidal waveform and the sawtooth voltage present in the driver circuit as shown in Fig. 13 (*a*) and (*b*), resulting in a waveform shown in (*c*). This last waveform is capable of ensuring that the

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* O. H. Schade. "Magnetic Deflection Circuits for Cathode Ray Tubes." *R.C.A. Review*, 8, September, 1947, pp. 506-538.

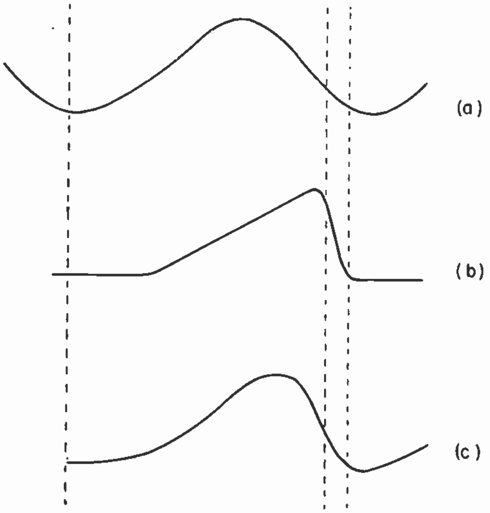

Fig. 13.—Waveform in linearity corrector circuit.

damper tube ceases to conduct towards the middle of the scan but unfortunately permits fairly heavy conduction right at the end of the scan.

If linearity is to be maintained, the driver valve must supply its normal scan current, plus this excess in the damper circuit at a time when the demands of the scan current are large, thus giving the driver valve a very onerous task.

The most successful linearity circuit so far tried is the one advocated by Emlyn Jones* which requires a saturable inductance. The principle is to accept the fact that the output voltage of the circuit will fall during the scan and arrange that as the scan proceeds, the effective inductance of the deflector coil circuit decreases. This can be done by including in the coil circuit a cored inductance whose field is polarized into the saturated region where the incremental permeability becomes dependent on the current flowing.

The coil current at the beginning of the scan then opposes the polarization and that at the end of scan assists, and in this way the inductance becomes high at the beginning of scan and decreased towards the end. This assumes that the drive to the circuit continues the voltage droop required to ensure that the damper cuts off.

One desirable feature of this arrangement is that the load line for the driver can be made to follow the bottomed line in which case all that is required for the drive is a simple square wave, provided precautions are taken to ensure that the screen dissipation is not exceeded. This makes the behaviour of the circuit very insensitive to drive waveform.

For scanning a wide angle flat face tube the current waveform normally should be slightly S-shaped, i.e. the rate of change should be greatest at mid-scan. This can be arranged by adjusting the boost capacitor. In this way the total available voltage across the transformer is maximum at mid-scan when the rate of change of current is required to be at maximum.

It is well to draw attention to the fact that the inherent linearity of these circuits is within about 15 per cent. without any correction whatever.

The design of transformers for voltage boost circuits becomes extremely complex and many of the characteristics are best found by trial and error. There are, however, several very important factors to be taken into consideration.

The first is that the natural period of the coil and transformer assembly with wiring and valve stray capacities shall not exceed twice the period allowed for flyback. The tendency with values of α which approach 1 is to load the circuit with a high effective value of L_c, which tends to lengthen this period. Practically, it is desirable that capacity should be saved at every possible point in the circuit particularly at the higher potential points

In particular where E.H.T. is derived from the line transformer, the E.H.T. winding capacity should be kept as low as possible and wiring to the rectifier as short as possible.

Leakage inductance tends to appear as an effective series inductance in the coil circuit and therefore causes loss of output. In the case of a multi-wound transformer for use in the circuit shown in Fig. 5 leakages of the order of 1 per cent. of mutual occur. The optimum arrangement is such that the inductance of the winding driving the deflector coils should be ten times the coil inductance. The shunt and series components are then both 10 per cent., giving a 20 per cent. loss of the calculated value of *VA*.

However, probably the worst effect of leakage inductance is to introduce damped oscillations in various uncoupled portions of the circuit resulting in velocity modulation of the raster. This problem is an interesting one, and worthy of a detailed examination.

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* Emlyn Jones "Scanning and E.H.T. circuits for wide-angle picture tubes," *J.Brit.I.R.E.*, 12, No. 1, January 1952, pp. 23-48.

Figure 14 shows the equivalent circuit of a three-winding transformer.* Terminal 1 is regarded as connected to the anode of the driver, 2 to the damper tube and 3 to the coils. During the early part of the scan 1 is connected to the anode capacity of the driver valve which is not conducting, and 2 is shunted by the 80 or so ohms of the damper. T_{12} of ratio r_{12} and T_{13} of ratio r_{13} are perfect transformers which give the required transformation ratios. The flyback transient excites the resonant circuit formed by the leakage inductances L_1 and L_2, resistance R_B, and the driver anode capacity C_P which produces a damped oscillation. These oscillatory currents can be of equal order to that of the coil currents and since they pass through R_B and L_2, a comparatively large voltage appears at the junction of the three leakage inductances, and therefore across the deflector coils. This results in a degree of velocity modulation decaying from left to right of the picture. The author has used the term "primary ring" to distinguish this form from the other two possibilities. Another circuit which can be excited by the fly-back transient is that consisting of the stray capacity in the deflector coil circuit in conjunction with L_2 and L_3. This one has been termed the "secondary ring." The third possibility is the same as the primary ring, but is caused by the leakage inductance of the E.H.T. winding, when used, in conjunction with the stray capacities of the E.H.T. system. Damping cannot be used to eliminate these oscillations as it degenerates the value of α.

The auto transformer circuit as shown in Fig. 4, generally produces higher frequency oscillations in all these circuits and since the deflector-coil inductance presents a higher impedance the results are less serious, but it must be pointed out that fundamentally it does not necessarily offer a better solution.

If the damper resistance could effectively be arranged to shunt the coil circuit the intercoupling between the three possible circuits can be considerably reduced, and this is the very strong argument for using a coil impedance which is sufficiently high to be connected directly across the damper winding of the transformer.

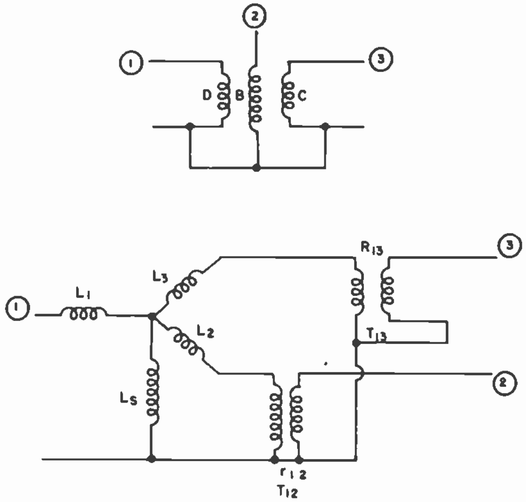

Fig. 14.—Equivalent circuit of 3-winding transformer.

The "secondary ring" should then be non-existent and the "primary ring" and E.H.T. ring are coupled in by the 80 or so ohms mutual resistance of the damper circuit. The damper resistance, however, although small, is quite significant, and it was with some disgust that it was realized that it was by no means a complete solution. Further, as was pointed out earlier, a very high voltage appears across the deflector coils during the fly-back (of the order of 4 kV). Another possibility is that individual windings of the deflector coil assembly, break up into separate resonant circuits and produce complex oscillations. These complex oscillations take more time to die away when the natural resonance frequency is lower, and are more likely to occur when using high impedance coils.

In connection with the transformer design, a very interesting fact emerged. Theoretically, it can be shown that in a three-winding transformer one of the leakage inductances can be made zero. Sandeman's results are as follows (see Appendix):

$$L_s = \frac{K_{13}\,K_{12}}{K_{23}}\,L_{11}$$

$$L_1 = L_{11}\left(1 - \frac{K_{13}\,K_{12}}{K_{23}}\right)$$

$$L_2 = L_{11}\left\{\left(\frac{K_{13}}{K_{23}}\right)^2 - \frac{K_{13}\,K_{12}}{K_{23}}\right\}$$

$$L_3 = L_{11}\left\{\left(\frac{K_{12}}{K_{23}}\right)^2 - \frac{K_{12}\,K_{13}}{K_{23}}\right\}$$

---

* E. K. Sandeman, English Electric Co., Ltd. Unpublished communication.

$$r_{12} = \frac{K_{12}}{K_{23}} \sqrt{\frac{L_{11}}{L_{33}}}$$

$$r_{12} = \frac{K_{13}}{K_{23}} \sqrt{\frac{L_{11}}{L_{22}}}$$

$L_1 = 0$ if $K_{23} = K_{13}\,K_{12}$, $L_2 = 0$ if $K_{13} = K_{12}\,K_{23}$ and $L_3 = 0$ if $K_{12} = K_{13}\,K_{23}$

where L_s is the apparent shunt inductance common to all windings
L_{11} is total inductance of winding (1)
L_{22} is the total inductance of winding (2)
L_{33} is the total inductance of winding (3)
L_1 is the leakage inductance of winding (1)
L_2 is the leakage inductance of winding (2) referred to winding (1)
L_3 is the leakage inductance of winding (3) referred to winding (1)
r_{12} is the ratio of the perfect transformer feeding term (2)
r_{13} is the ratio of the perfect transformer feeding term (3)
K_{12} is the coefficient of coupling (1) to (2)
K_{23} is the coefficient of coupling (2) to (3)
K_{13} is the coefficient of coupling (1) to (3)

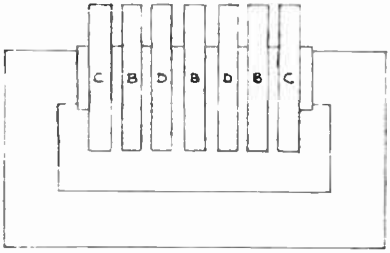

Fig. 15.—Sectionalized winding arrangement for a 3-winding transformer.

This fact accounted for the success of the winding arrangements shown in Fig. 15, which had been tried early on in the experimental work. This arrangement consisted of wave wound pi's, the driver winding consisting of the pi's marked D, the damper winding those marked B, and the coil winding those marked C. The leakage inductance of each winding to each other was measured and by simultaneous equations leakage L_2 proved to be of the order of 10 per cent. of the others. This transformer, however, showed symptoms of secondary ring. The frequency of this ring, however, can be made as high as desired because it is caused by the actual leakage inductance of winding C of the coil circuit capacity. By using 200 μH deflector coils and arranging the transformer ratio to the deflector-coil circuit accordingly a very tolerable result was achieved. The secondary ring was still present but owing to its high frequency was lost in the back porch. The primary ring was just discernible. Fig. 16 shows a slightly simpler arrangement of transformer winding which exhibited the same tendency. It might be emphasized here that the three winding arrangement removes the difficulties encountered in heating the diode which are present in the auto transformer case.

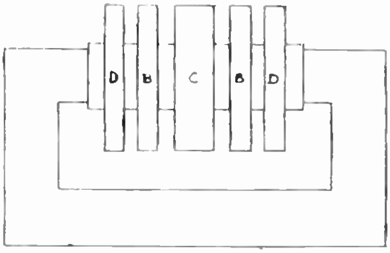

Fig. 16.—Simpler arrangement slightly less effective than Fig. 15.

A further improvement in the leakage inductance of winding B can be effected by distributing some turns of C beside the driver winding D but wound in the opposite direction to those of the main winding C. In this way the leakage of winding B can be made negative and a small neutralizing, variable inductance can be connected in series.

However, nothing can be done about the mutual resistance of the damper tube so that all these adjustments can only minimize the presence of these rings.

If, however, the circuit is worked under the $AB_{100/100}$ condition and the driver valve is made to have a low output resistance, either by bottoming the stage or alternatively using a form of feedback circuit from the primary winding of the transformer, the primary ring can be killed.

So far, only a three-winding transformer has been considered from this aspect, and with the addition of a fourth winding for E.H.T. generation the theoretical analysis becomes very complex and cumbersome.

At the moment it would appear that the best solution is to operate the stage under the $AB_{100/100}$ condition, when both driver and damper windings are effectively shunted by low resistances, and treat the transformer as a three-winding one with the driver and damper as a combined winding, with the coil and E.H.T. windings as the other two.

A good way of testing transformers for this quality is to short the appropriate windings and inject, from a signal generator, a frequency of the order of the anticipated ring into the winding likely to cause trouble and measure the output voltage across the coil winding; the coupling can then be assessed accurately.

Figure 16 shows a winding arrangement which has proved to be very satisfactory in practice, though by no means perfect, and Fig. 17 one with a section E denoting the E.H.T. winding.

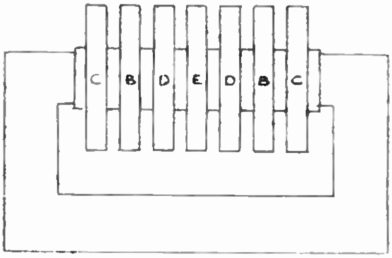

Fig. 17.—Suitable arrangement for including E.H.T. winding.

One further point which has been noticed in connection with oscillations is that the discontinuity in the damper current when it ceases to conduct can cause a noticeable E.H.T. ring at the end of the scan.

It might be mentioned that since these oscillations occur and are either dissipated without contributing to the scan current or are killed by the driver valve, they probably constitute a loss and probably account for the fact that circuits behave as though α is less than the measured value. One further point in connection with losses is that the heating of the E.H.T. rectifier (which is usually affected by a small auxiliary winding on the line transformer) and the supply of energy to the E.H.T. circuit constitute an appreciable loss which further reduces the effective value of α.

Windings of the type discussed are obviously expensive and somewhat tedious to make, and must at least be oil immersed. The voltage distribution is extremely bad because the damper section voltage is in antiphase to that of the driver winding and has to be placed close to it. Voltages of the order of 6 kV or so appear between pi's and therefore between end connections. Oil as a filling has the advantage that in any region where the stress is high, the heating effect causes the oil to circulate, which reduces the risk of dielectric deterioration and consequent breakdown. It is desirable that the sleeving used to insulate the end connections should have a high dielectric constant so as to improve the voltage gradient in the immediate vicinity of the conductor, and to avoid the excessively high stress that would exist next to the small diameter conductor.

The tendency which can therefore be expected is towards the auto transformer circuit shown in Fig. 4 and to accept the difficulties of heating the diode when pulses of the order of 4 kV appear on it. The method generally adopted is to supply the heater from the secondary of a mains transformer which has a low capacity to earth and other windings. Since this point is at a comparatively high impedance, capacity affects the resonant frequency and therefore the fly-back period quite appreciably. A diode has now been developed to withstand cathode–heater and cathode–anode voltages of 7 kV.

In the case of the auto transformer, the tendency is to layer-wind at least the whole of the driver winding and to wave-wind the E.H.T. section on top as shown in Fig. 18. This type of winding is excellent from the voltage point of view because it is automatically graded across the winding. However, it suffers from the disadvantage of having a higher self-capacity than those previously mentioned. In several cases the resonant frequency of the system is lower than that permitted by the time available for fly-back, particularly when considering the use of a 625-line 50-cycles or 525-line 60-cycles interlaced scan system.

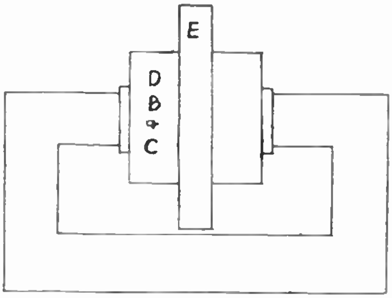

Fig. 18.—Winding arrangement of an auto-transformer.

Some of the transformers of this type tried show quite a serious tendency to produce E.H.T. ring and where the circuit is operated under the B condition also slight primary ring.

However, a compromise winding arrangement shown in Fig. 19 might prove satisfactory. It consists of a common driver and damper winding tapped at a suitable point for the damper tap and arranged as an auto winding in the circuit of Fig. 4.

Here an attempt is made to use the combined driver and damper winding as a screen between the E.H.T. and coil windings and at least ease the problem of voltage distribution. It has of course the disadvantage that its leakage inductances will be higher than those of an auto transformer but at least the driver to damper coupling will be extremely tight, and the winding capacities will be kept low.

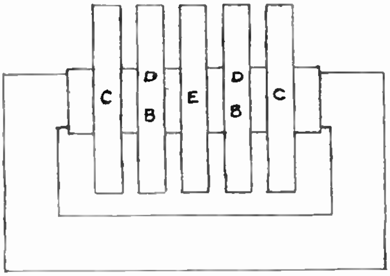

Fig. 19.—Alternative arrangement with separate deflector coil winding.

In all the previous circuits discussed one is faced with the fact that since the losses in coil and transformer assembly affect the performance considerably, if the transformer could be dispensed with, a considerable improvement in possible output could be expected. Further, it seems likely that the transformer in any high-grade circuit is liable to be expensive.

With this in mind, R.C.A. have developed the circuit which is basically shown in Fig. 20. In this case the deflector coils L_c were connected directly into the anode circuit of the driver valve with damper valve across them.

Going back to Fig. 6 it will be seen that normally the recoverable current is always less than the driven current unless a transformer is used. If therefore L_e in Fig. 20 is neglected, the circuit, if started must inevitably "run down" and current would only flow straight through the damper and driver valves. The only possible way the circuit could work would be if $\alpha = 1$.

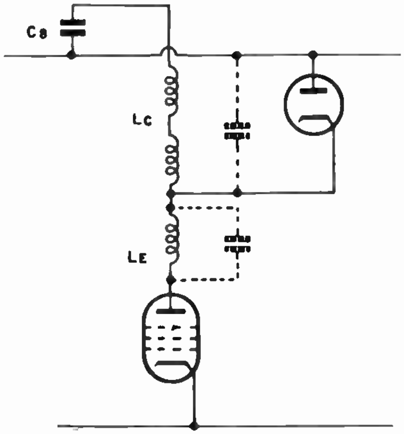

Fig. 20.—Transformerless energy recovery circuit.

By considering the effect of L_E it is extremely interesting to note that α can in fact apparently exceed unity. Fig. 21 shows the equivalent circuit where C_p is the anode capacity of the driver. This will be familiar to all as a capacity-coupled bandpass circuit. If L_E and its associated shunt capacity is tuned correctly in the region of the resonant frequency of L_C it can be shown that, if the circuit is allowed to oscillate freely after cut-off, the energy established in L_E can start transferring to L_C to augment the energy already established there, with the result that the amplitude of the second half-cycle in L_C can exceed that of the first.

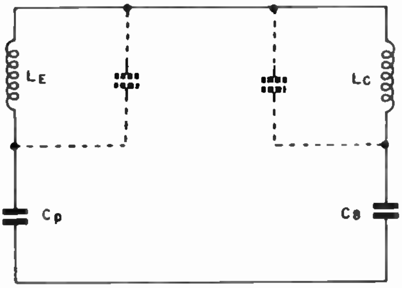

Fig. 21.—Equivalent circuit illustrating operation of Fig. 20.

Figure 22 shows the current waveforms after cut-off which occur in such a circuit with the damper tube disconnected. Since it is only the first half-cycle of current swing which is of interest, the recoverable portion of current can

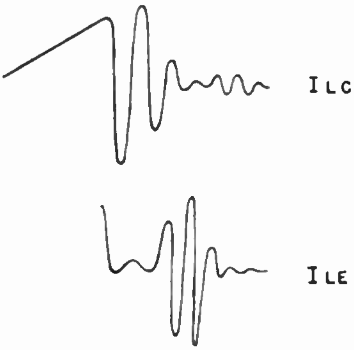

Fig. 22.—Waveforms illustrating mode of operation of circuit in Fig. 20.

exceed the driven portion, with the consequence that the circuit "builds up" until a limit is reached. L_E can be part of an air-cored auto transformer for E.H.T. generation.

The difficulty with such a circuit is again the very high voltages which are developed across the deflector coils with the consequent risk of breakdown, and also the deflector coil circuit has a habit of breaking up into separate resonant circuits resulting in complex oscillation. Very little data is available except that it is capable of supplying very large outputs, certainly in excess of those available from any of the transformer circuits so far developed.

Acknowledgments

The author would like to thank Marconi's Wireless Telegraph Co., Ltd., for the facilities for carrying out the experimental work, also Mr. L. H. Bedford for his encouragement and help, and Messrs. A. N. Heightman and G. A. Thorogood for their considerable assistance.

Appendix

L_{11}	inductance of winding (1).
L_{22}	inductance of winding (2).
L_{33}	inductance of winding (3).
L_s	apparent common shunt inductance referred to winding (1).
L_{12}	mutual inductance between windings (1) and (2).
L_{13}	mutual inductance between windings (1) and (3).
L_{23}	mutual inductance between windings (2) and (3).
K_{12}	coupling coefficient between windings (1) and (2).
K_{13}	coupling coefficient between windings (1) and (3).
K_{23}	coupling coefficient between windings (2) and (3).
r_{12}	ratio of perfect transformer feeding terminal (2).
r_{13}	ratio of perfect transformer feeding terminal (3).

The equivalent circuit shown in Fig. 14 represents the effective shunt inductance and three leakage inductances referred to winding (1), with two perfect transformers feeding the loads on the other two windings.

$$L_s + L_1 = L_{11} \quad \ldots\ldots (1)$$

$$L_s + L_2 = r^2_{12} L_{22} \quad \ldots\ldots (2)$$

$$L_s + L_3 = r^2_{13} L_{33} \quad \ldots\ldots (3)$$

$$L_s = L_{12}\, r_{12} \quad \ldots\ldots (4)$$

$$= L_{13}\, r_{13} \quad \ldots\ldots (5)$$

$$= r_{13}\, r_{12}\, L_{23} \quad \ldots\ldots (6)$$

from (4) and (6)

$$r_{12} L_{12} = r_{12}\, r_{13}\, L_{23}$$

$$\text{i.e.,} \quad r_{13} = \frac{L_{12}}{L_{23}} \quad \ldots\ldots (7)$$

$$= \frac{K_{12}}{K_{23}} \sqrt{\frac{L_{11}}{L_{33}}} \quad \ldots\ldots (8)$$

$$\text{similarly} \quad r_{12} = \frac{K_{13}}{K_{23}} \sqrt{\frac{L_{11}}{L_{22}}} \quad \ldots\ldots (9)$$

from (5)

$$r_{13} = \frac{L_s}{L_{13}}$$

combining (5) and (7)

$$\frac{L_s}{L_{13}} = \frac{L_{12}}{L_{23}}$$

$$L_s = \frac{L_{12}\, L_{13}}{L_{23}}$$

substituting for L_{12} L_{13} and L_{23}

$$L_s = \frac{K_{12}\sqrt{L_{11}L_{22}}\; K_{13}\sqrt{L_{11}L_{33}}}{K_{23}\sqrt{L_{22}\, L_{33}}}$$

$$= \frac{K_{12}\, K_{13}}{K_{23}} L_{11} \quad \ldots\ldots (10)$$

$$L_1 = L_{11} - L_s$$

$$= L_{11}\left(1 - \frac{K_{12}\, K_{13}}{K_{23}}\right) \ldots\ldots (11)$$

from (2) and (10)

$$\frac{K_{12}K_{13}}{K_{23}}L_{11} + L_2 = r^2{}_{12}L_{22}$$

$$L_2 = r^2{}_{12}L_{22} - \frac{K_{12}K_{13}}{K_{23}}L_{11}$$

substituting for r_{12} from (9)

$$L_2 = \left(\frac{K_{13}}{K_{23}}\right)^2 \frac{L_{11}}{L_{22}} L_{22} - \frac{K_{1}K_{13}}{K_{23}}L_{11}$$

$$L_2 = \left[\left(\frac{K_{13}}{K_{23}}\right)^2 - \frac{K_{12}K_{13}}{K_{23}}\right] L_{11}$$

$$= \left(\frac{K_{13}^2 - K_{12}K_{13}K_{23}}{K_{23}^2}\right)L_{11} \qquad (12)$$

similarly

$$L_3 = \left(\frac{K_{12}^2 - K_{12}K_{13}K_{23}}{K_{23}}\right)L_{11} \qquad (13)$$

$L_1 = 0$ when $K_{23} = K_{12}K_{13}$

$L_2 = 0$ when $K_{13} = K_{12}K_{23}$

$L_3 = 0$ when $K_{12} = K_{13}K_{23}$

DISCUSSION

Otto H. Schade (*Communicated*): I would like to make some comments with respect to the operation of the linearity control in circuit of Fig. 12. The waveform shown in Fig. 13(*a*) assumes a high Q-value for the linearity transformer and thus accounts for the inability to produce a sharper sawtooth-shaped voltage than shown in Fig. 13(*c*). Actually the Q-value is reduced to such a low value that the driver current does produce a barely oscillatory transient voltage which decays to zero *within* the scanning time. This permits the shortening of the period of oscillation, gives a steep slope after the retrace time and the desired sharper peak at the end of scanning which cuts off the diode. The damping of the linearity circuit can be adjusted by proper impedance choice or by a shunt resistor across the transformer. I do not, therefore, agree with the author's conclusions.

A. B. Starks-Field (*in reply*): I agree entirely with Mr. Schade's suggestion. Unfortunately I have not yet been able to do any exhaustive work on the subject, but I would point out that by increasing the damping, more energy is drawn from the driver cycle which results in an increased loss of power. It is also true that any effective additional resistance which appears in the cathode circuit of the damper valve requires an additional linearity correction.

However, these effects may not be serious. Both systems cause loss of output and in our experiment we achieved a greater degree of success with the saturated inductor method.

JOURNAL OF THE BRITISH INSTITUTION OF RADIO ENGINEERS

SPEECH INPUT SYSTEMS FOR BROADCASTING TRANSMITTERS*

by

S. Hill, M.Eng.†

A Paper presented at the Sixth Session of the 1951 *Radio Convention on September 6th at Earls Court, London*

SUMMARY

The paper discusses the technical and economic factors involved in the selection and design of the audio-frequency equipment used in broadcasting transmitters.

After first stating the basic technical requirements, considerations of layout and switching are reviewed. Microphones, amplifiers, level indicators and faders and mixers are dealt with from the point of view of both studio and outside broadcasts, and the paper concludes with a discussion of recording requirements.

1. Introduction

By speech input equipment we mean all the low-frequency apparatus needed to create, and to organize, the programmes delivered to a broadcast transmitter for ultimate radiation by high-frequency technique to the listening public. It can be grouped under many headings: pick-up, control, programme-building, monitoring, recording, etc., but is perhaps most tidily conceived as one or more main amplifying chains from a number of microphones, or other inlets, to a line leading to the broadcast transmitter, and a number of offshoots serving the purpose of monitoring and control.

The building which houses the speech input equipment is sited, and in part designed, to facilitate the administrative as well as the technical work of programme assembly. The same intimate admixture of administrative (or artistic) and technical problems is a constant feature of the whole system and it is, therefore, to be expected that the most successful installations will be those whose planners have a broad appreciation of both aspects of the whole conception. For the same reason it is not to be expected that any completely standardized system can be laid down for major undertakings. Where a broadcasting authority is weak in experience and is constrained to hand over the problem *in toto* to a commercial firm it is likely that the resulting solution will bear a strong family likeness to other systems within that firm's experience, but it is more usual to find that the authority has its own ideas as to organization, and possibly as to the broad lines of the technical solution, and it then becomes the function of the commercial organization convoked to adapt its standard apparatus, elements, and technical ideas, to realize in detail the conception offered by its customer. In this way every new project is to some extent a "custom built" job.

2. Basic Technical Requirements

Before we consider some of the decisions to which this co-operative planning may lead, let us review briefly the basic technical requirements. These differ only in detail from the requirements one would lay down for almost any communication system, since what we called the main chain exhibits the fundamental features of a transmission system, viz. transduction, amplification, transmission and fidelity.

The gain of the system is determined by the type of microphone proposed and the level which one is allowed to transmit by land-line to the broadcast transmitter. The microphone level may be of the order of -80 dbm, for quiet speaking, and the line level perhaps $+15$ dbm, so that an overall gain of some 100 db has to be available. Variations in level from moment to moment are very wide, but must be restricted to a maximum practical dynamic range to avoid overload on the one hand and noise masking on the other. Studies by Civian, Dunne and White

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* Manuscript received August 17th, 1951.

† Standard Telephones and Cables, Ltd.

U.D.C. No. 534. 861 + 621. 395.6

and other workers indicate that an ideally faithful system should offer a dynamic range, i.e. ratio of loudest to quietest passages, of some 80 db. Fortunately few listeners have the desire and fewer have the means to hear programmes reproduced over such a volume-spread. Most programmes are therefore confined without complaint to a normal spread of 30 db with an occasional extension to 40 db. Since technical improvements react on each other it seems possible that a demand for a greater range will arise with improving fidelity. With the quieter background promised by F.M. broadcasting it may be possible to increase the dynamic range by a few decibels and this would undoubtedly add to the realism of music reproduction. One wonders indeed if we are not already a little too cautious in this matter as one can think of some outstanding disc recordings which give a remarkable impression—possibly illusory—of wide dynamic range, and a gramophone would seem to be in worse case in this respect than a broadcasting chain.

Since avoidance of transmitter overloading, except perhaps for a few milliseconds at a time, is a *sine-qua-non*, the limiting factor is of course noise. Noise sources are perhaps worth classifying. They are: (*a*) unavoidable thermal agitation in the microphone and first valves of the system; (*b*) hum, which can theoretically be brought down below the largest unavoidable source; (*c*) carrier noise; (*d*) receiver noise. The last two are beyond the control of the speech-input engineer, and it is perhaps fortunate for him that the last mentioned together with background noise in the listener's room will probably swamp the others in the majority of cases. Two minor sources, not nowadays important, are studio background (due to extraneous unexcluded noises, ventilation plant noises, etc.), and microphone hiss.

The frequency response of a system has been much discussed of late. In America there seems to be some evidence that most listeners are satisfied with a range known to be inadequate for high-fidelity reproduction and the same tendency, though less marked, has been observed here. It is, however, difficult to isolate frequency response from other categories and it would be unsafe to restrict the range below, say, 30 to 10,000 c/s. It may be doubted however, whether the present tendency to push response to 15 kc/s is justified. For a long time frequency distortion was given too prominent a place in our thoughts because it was more easily measured than other forms, particularly at the loudspeaker, and it would probably be wiser to concentrate on reducing cross-modulation before considering an extended frequency range.

3. Layout and Switching

We now review some of the requirements which need considering when planning a particular system.

Because of the piecemeal nature of speech input apparatus, the problem of centralization versus dispersion has to be settled at the outset. In the past, the centralized system has offered advantages which have seemed to be over-riding. All amplifiers and other panel elements are concentrated in a central control room where they are under immediate supervision and where a faulty element can be instantly removed and a spare patched in. This is clearly convenient, and economical in panels, but it leads to cabling schemes which are inelegant and costly. Thus a studio microphone may have to be extended to the control room to pick up a microphone amplifier, return to the studio (or its annexe) to join other inlets at an announcer's fader, thence return again to reach the main amplifier, and so forth. Two considerations lead away from the centralized scheme, viz (*a*) the very low maintenance rate possible with well-established amplifier types, and (*b*) the notion of continuity working. This has been described in the *B.B.C. Quarterly* and need not be reviewed here. It leads to the conception of the self-contained studio suite where all essential controls are situated and where it is, therefore, desirable to have at least all the smaller amplifying elements. It is still possible of course to concentrate some of the units in a central location, i.e., where input lines and output lines are gathered on a central board.

The other main controversial question is that of switching. In the earliest systems this required little more than cord-patching by an operator sitting in front of his amplifier, but led naturally to the notion of control desks located a little apart from the amplifier array and generally using keys instead of a jack-field. A notable advance came with the I.N.R. studios in Brussels where the size and bilingual nature of the programmes suggested grouping the elements into input units (alphas) and output groups (lambdas). Programme assembly was then effected by dialling-up the particular alphas and lambdas required. This type of system gives the maximum flexibility and will probably be widely adopted. It has to meet the following requirements: (*a*) the switching system must be of good reliability; (*b*) comprehensive means must be used to deal with busy conditions; (*c*) clear indications must be given that the selectors have in fact seized the required input or output unit including the signalling and other facilities auxiliary to the main signal channel.

Studios are not always considered to be part of the speech input equipment but they are certainly a main technical problem for the planning engineers and there are now commercial organizations who will undertake their design as part of their service to their customers. The problems of design cannot be adequately discussed in a short lecture but it is worth noting that there are no cut and dried solutions even from the purely technical angle, and when it is remembered that studios have to meet artistic as well as acoustic requirements, it will be seen that their planning is a matter of great difficulty. It is especially difficult to bring studio design within the scope of commercial tendering, partly because, in the present state of the art, work has to proceed, in part, in a cut and try manner, and partly that it is practically impossible to find an agreed basis of acceptance. It is nearly useless to check reverberation time against a previously imposed specification as this leaves out of account reverberation *effect*. On the other hand judgment of results by ear is a process so clearly liable to abuse that a contractor would be unlikely to agree to it. The only safe plan seems to be to place the design in the hands of the authority which is going to use the studios and for the contracting engineers to act as acoustic consultants. The studios will then be roughed out, allowing the maximum flexibility of adjustment and aiming at the greatest possible rigidity of construction. Finally, work will proceed under close engineering supervision and measurements be taken at each stage. If unexpected features show themselves the authority will have to face the cost of modification, judging each case on its merits. The B.B.C. has done admirable pioneer work on these problems and it is to be hoped that one day it may be possible to reduce the technique entirely to forward-looking calculations. There is of course no ideal reverberation time for a studio; each has to be treated on its merits bearing in mind its purpose, size, and the need or otherwise to admit an audience. Generally there will be many studios with widely divergent characteristics. No single studio will be sufficiently flexible—even with mechanically retractable walls and other such devices—for the needs of drama, and it will be necessary to use various modifying devices such as the echo room. This is usually a reverberant room with microphone and loudspeaker and associated with means of mixing the output with the normal (unreverberant) channel. While this technique is usually considered sufficient, it is certainly capable of considerable development. Thus a French engineer demonstrated some years ago that by including variable filters in the echo and non-echo channels, a variety of interesting effects could be obtained. Sometimes tape recorders or acoustic delay lines are substituted for the echo room. These need careful design to avoid flutter effects and acoustic lines require careful equalization—though an echo line does not need to be efficient in the higher registers.

4. Apparatus

While it is not possible to discuss the design of all the elements in a system, it will be well to consider the main amplifying chain, roughly in the order of progression of the signal from studio to outgoing line. Perhaps the most important element in this chain is the microphone.

The wide variety of programme sources in modern broadcasting needs microphones of several directional pick-up patterns to give satisfactory reproduction. They are provided by (1) the pressure microphone, which responds to the pressure component of a sound wave and has therefore no sense of direction; (2) the pressure gradient microphone which responds to the pressure gradient of a wave train and has therefore zero output in a direction parallel to the isobars of a sound field, with equal outputs in either direction at right angles to this. This type is sometimes called the velocity microphone; (3) the unidirectional microphone which has a response in the forward hemisphere greater than that in the rear hemisphere.

The response of types 2 and 3 to random sound is 10 db less than that of type 1, and they may thus be used about three times further away from the sound source than type 1 for equal outputs of background noise. This explains why they are often preferred for studio work where a large sound source, such as an orchestra, has to be reproduced with suitable balance between all the instruments. The unidirectional microphone has an obvious application in a transmission from a theatre or studio with an audience, when it helps in subduing the audience noises which can be so distracting. For outdoor events the microphone must be able to operate in all sorts of weather conditions from a gale on the sub-arctic coasts of Norway to exposure in the sun in Egypt or India. The moving-coil type of pressure microphone is particularly suitable for these conditions.

In Germany the condenser microphone has been developed for all three classes but in the rest of the world the disadvantages of having to supply polarizing voltages to the microphone and head-amplifier have restricted its use largely to laboratories where its stability is attractive. Electrodynamic microphones of the moving-coil and ribbon types are respectively of type 1 and type 2 and, having an impedance in the range 20 to 300 ohms, can be separated by long distances—half a mile or more—from their associated amplifiers. This allows complete freedom for locating all amplifiers at any point in even the largest studio centres. A combination of pressure plus pressure-gradient in the same microphone results in unidirectional pick-up. The application of an acoustic phase changing impedance to one side of the diaphragm of a pressure gradient microphone can also give a unidirectional pattern but usually not equally at all frequencies.

It is important that the frequency response characteristics shall be the same shape for all angles of incidence; in other words the polar directional characteristics should be the same for all frequencies. To achieve this the maximum dimension of the diaphragm or ribbon should be smaller than the wavelength of the highest frequency (about 1 in at 10,000 c/s), in order that phase cancellation shall not be appreciable for incidence at shallow angles to the diaphragm surface.

It is possible to shape diaphragms of such a small size that they move like a piston at all frequencies, and the response curves of good microphones do not therefore show the sharp peaks and troughs that, in a loudspeaker, are associated with complex modes of vibration of the cone. Transient distortion is likewise small compared to that of the loudspeaker.

The uniform coverage of a wide frequency range, 30 to 10,000 c/s leads inevitably to low sensitivity and the self-noise of all types (or that of the loading resistance in the case of the condenser microphone) is dangerously near the minimum sound level of some programmes. The softest passages of a solo instrument in a quiet studio may be below 30 phons compared to 18 phons self noise for a pressure gradient, 20 phons for a condenser and 12 phons for a moving coil pressure microphone. We need 6 to 10 db greater sensitivity in our microphones to make electrical background noises unnoticeable on a high quality transmission.

As long as microphones remain at their present efficiencies there will be none too much clearance between signal and noise for quiet passages and it will be undesirable to introduce any losses into a microphone circuit until its level has been raised by at least 10 db. Where several microphones have to be combined into a single channel it is desirable that each be associated with a microphone amplifier. This is a nuisance in a centralized system as it means cabling back to the control room, but if it is accepted that the microphone amplifier be mounted near the microphone (as of course it must be for a condenser microphone), and if the amplifier can be made small and relatively cheap, it will be wise to perform no operations at all on a microphone before amplification. An exception might be made, for economy reasons, when fading only is contemplated in the input circuits, provided that the fading circuit is of the type where loss is introduced to fade out and is completely removed when a microphone is faded in. This is possible if microphone mixing is avoided, but is not useful to administrations that insist on having a large number of specially sited microphones for each programme, in the search for the elusive quality called balance. The microphone amplifier is in some ways the most difficult amplifying element on account of the need to keep down hum, microphonicity, and shot-noise. There is certainly a case for running the heaters of the first (and perhaps the second) valve from rectified a.c. but the increased bulk and cost make it highly desirable to find a quiet a.c. heated tube. This usually involves a process of selection, but if the valve manufacturer will perform this function, and adequate spares are provided, there is probably no objection to this. The input transformer is also a possible source of trouble and should be shielded with one or possibly two layers of a high permeability alloy. The noise problem is made much easier if the input transformer is given the highest possible step up, say up to at least 1/4 MΩ. It is difficult to avoid loss at high audio frequencies with such a lift, but provided the greatest care is taken to achieve uniformity, and that the input capacity of the valve is not allowed to vary appreciably, the loss can be dealt with by equalization and an overall frequency characteristic maintained flat to within 0·5 db over a range of 30 to 10,000 or 15,000 c/s. The resistors in anode and cathode are a prolific source of noise and need to be of the first grade, while electrolytic cathode condensers are to be avoided if possible. Generally speaking gain controls are to be avoided in microphone amplifiers, but if fitted should introduce no loss in their position of maximum gain.

The next most important element is the main studio amplifier. Since it will accept microphone level in the absence of microphone amplifiers, or if there is a microphone fader of considerable basic loss, the input circuits must be designed with the same care as for the microphone amplifier. These amplifiers however can afford to be somewhat bulkier and rectified supplies for the heaters are worth considering. Alternatively heaters can be operated at say 20 kc/s. This scheme is very attractive but does not yet seem to be in very general use. The best place for a gain control is probably after the first valve but it is difficult to maintain an equally flat frequency characteristic over the whole of a wide range control when variations of 0·1 db may be held significant. There is thus a case for making a fixed gain amplifier, or perhaps a two-gain amplifier, and using it with fixed pads at the input and output. Such an amplifier will need considerable output power to avoid overloading and consideration should therefore be given to making an amplifier whose input circuit is quiet enough to work from a microphone and whose output power is large enough to feed a line, so that the number of amplifier types is reduced.

Usually the studio amplifier will raise the level to a point where the main volume control of the system may be inserted. This is normally a manually controlled potentiometer of rotary or lever type. There has been much discussion on the use of manual versus automatic volume control. Undoubtedly it would be possible to leave the question of volume to the unfettered judgment of the orchestra and to employ automatic means of compressing the programme within an agreed dynamic range. The result would sound mechanical and dead. At the other extreme lies the proposal to have a musician operate the manual controls, a procedure found to lead to frequent transgressions beyond the assigned range. A compromise sometimes used on the Continent is to have partial automatic compression and to require the orchestral conductor to conduct by listening to the reproduced output, isolating him from the live sound by a thick glass screen. This has the great disadvantage that the system has to be abandoned for guest conductors who will not accommodate themselves to the scheme. We are left with manual control by engineers, the plan most normally used, and one that works well if the engineer acts mainly as a limiter to prevent programme level rising too high or falling below noise level while leaving the interpretation between extreme limits to the orchestra. The main difficulty is to avoid sudden overload due to a failure of the control engineer to anticipate, and here the use of an automatic limiter is of great value as it allows the programme to have more life, while protecting the system against excessive peaks. A limiter of this sort may be used as a safeguard of whose presence the control engineer need not be aware, or as a means of radiating a higher average level, the engineer being instructed to keep a watch on an indicator lamp, showing when limiting is taking place, and not to allow the lamp to flash more than two or three times a minute.

Associated with the volume control is another important and controversial element, the programme level indicator. In its simplest form this need be no more than a rectifying voltmeter with suitable dynamic properties. Such an instrument is very simple and it is claimed that an operator who is used to it can achieve a satisfactory control, at least if he is protected against peaks by a suitable limiter. Most European authorities however prefer a peak operated device since it shows the particular aspect of the programme which interests the control engineer. An instrument of this kind responds to peaks if they last more than about 3 milliseconds (shorter peaks are generally innocuous). A peak once registered is held long enough to read and is then slowly released. The release time has to be chosen with care. Too short a time leads to fatigue since the needle, or light spot, is in continuous rapid movement, and gives inaccurate indications of peaks since these may have decayed appreciably before even a fairly rapid meter has time to register them. Too long a time obscures troughs and intermediate peaks. Best results are secured if any peak is held without much decay for perhaps 100 milliseconds and then allowed to release fairly rapidly in say 200 milliseconds.

The programme engineer, supplemented by limiters, controls the programme visually by operating the gain control potentiometer and observing the programme indicator. In addition, monitoring amplifiers of high input bridging impedances are connected across the line and provide either head-receiver or loudspeaker monitoring as an overall check. These amplifiers are of conventional design and need no special comment. They may be supplemented by high-power monitors which constitute, in effect, a public address system whereby the outgoing audio programme may be distributed to suitable listeners throughout the building. Radio sets may also be installed and so switched that these listeners may rapidly compare the quality of the outgoing audio programme with that received through the ether. For this purpose it is desirable to install a listening room whose acoustics simulate the average living-room.

Faders and mixers are an important part of programme building. Though both are essentially groups of potentiometers their functions are to be distinguished. Faders can be installed at microphone level if necessary, since once the programme is faded in or out they need play no part in adding noise to the system, whereas mixers are intended to produce a balanced admixture of various sources. They must therefore only be inserted at a reasonably high-level part of the circuit and must of course be made as noiseless as possible. Various arrangements are possible, of which perhaps the simplest is to put all mixer potentiometers in series and feed the combined output into a high impedance source. This avoids interaction between the different sources but has some obvious disadvantages and it is therefore often preferred to use them with blocking amplifiers. A complete system may include many faders since one may wish to combine the outputs of several microphones in one studio, the outputs of several studios, or the outputs of various groups of studios. This is particularly so in dramatic control where a single complex programme may be built up from many sources by a special controller seated at a dramatic-control desk. In a centralized system where the amplifying elements are located in a control room and the faders scattered throughout the studios this leads to much complication of cabling, and it is sometimes preferred to mount all fading elements in the control room and to locate the fader or mixer knobs by considerations of convenience. This calls for a system of remote control which may be mechanical or electrical, i.e. through groups of rectifiers or thermistor bridges whose biases are remotely controlled. It is thus possible to envisage a single mixing point immediately before the main gain control, or even including it, each source being faded in to the desired level by a system of remotely controlled d.c. biases.

Beyond the gain control it is necessary to add a line amplifier to lift the level to that suitable for transmission to a line and thence to the transmitter. The level chosen depends on the needs of the transmitter and on any regulations which may apply if the line is owned by another authority. An amplifier which is to be applicable to all cases should have an output of, say, +15 dbm to line. Quite often shortish but unequalized lines are provided which become usable without treatment if they are fed from a low-impedance source to compensate for their falling sending-impedance at high frequencies. The line amplifier is therefore given a low impedance by using feedback, or in some other way, so that it will tolerate a large mismatch at its output terminals without loss or distortion. The output stage has therefore to be heavier than if feeding into a simple 600-Ω circuit, i.e. it may have to be designed to deliver say + 30 dbm although only a few milliwatts of power are actually transmitted.

When a number of outgoing lines have to be supplied it is sometimes the practice to use a line amplifier with an output impedance of a few ohms but it is usually considered better to use several separator amplifiers, one per line, having substantially zero gain and with their inputs connected in parallel. Their design is conventional and poses no special problems.

5. Outside Activities

In our review so far we have considered the large equipment housed in a broadcasting house, but great importance attaches in any broadcasting organization to "extra-mural" activities, among the most important of which is the outside broadcast. The special problems here are portability, flexibility, and robustness. Most organizations possess, for this purpose, a mobile control room in the form of a van laid out with all the essential elements of the fixed studio equipment and with microphones which can be run out on long cables. There must also be portable amplifier units which can be taken out by individuals and rapidly plugged together to make an amplifying chain. The essential elements are a mixer or fader for three or four microphone channels, an amplifier capable of raising the level from that of the microphone to a suitable line level, some form of monitor, if only by headphone, and a programme meter. The whole of this apparatus can be built into a single unit if required but considerations of weight may cause it to be split up. The units must be capable of drawing their power from mains for the more stable installations or from car batteries for the more out-of-the-way locations. There must also be auxiliary equipment for keeping in telephonic communication with the main studio location.

Microphones for outside broadcast work have to be robust and as free as possible from wind noises hence the moving-coil is a very popular type. There are also special types not generally used in studios. Thus the "machine-gun" microphone has sometimes been used to good effect. This is a moving-coil type, fitted with an array of tubes of varying length whose function is to ensure that sounds coming from any other than the straight-ahead direction arrive at the diaphragm in various phases which secure virtual cancellation. The machine-gun microphone is very susceptible to wind noise but on favourable occasions it can isolate a favoured item from a jumble of other unwanted sounds. A commentator's microphone must also be provided. It may take the form of a ribbon but is preferably of a more robust type given the characteristics of a ribbon microphone by the use of acoustic networks. The frequency characteristic is tilted upwards so that it is insensitive to much of the middle- and lower-register sound arriving from a distance. Close talking by the commentator compensates for the tilt by a well-known effect depending on the difference between spherical and plane waves.

The problem of bringing O.B. material to the main speech input equipment by land line is one for specialists. Probably we, in this compact and highly populated country, are better off than many others. Most "O.B.s" are not far from a telephone exchange or a repeater station from which good equalized lines are probably available to headquarters. Some administrations however may find it essential to use one or more channels in a commercial carrier system having a restricted frequency range. For these cases a "split band" equipment is most useful. Two channels are hired for the occasion and the frequency band of say 50 to 6,000 c/s is split into two, 50 to 3,000 and 3,000 to 6,000. Modulation processes are then used to fit both bands into the pass range of the given channels and at the other end the wider range is re-established. No additional cost for channels is incurred in this scheme since no control line is needed, urgent telephone messages during a programme being passed along the high frequency channel at the expense of a temporary loss of quality.

Intermediate in complexity between the outside broadcast van and the full speech input equipment is the auxiliary studio equipment. This type of equipment is perhaps commoner abroad than here, since we do not have a host of private broadcasters attempting to reach the largest public with the simplest equipment. For such systems several commercial concerns have devised the speech input console. This is a large desk which contains on its surface all the controls, and in its interior all the amplifiers, necessary for a complete broadcast unit. The design of such consoles has led to improvements in the art because, to be feasible at all, the elements have to be small, inexpensive, and quickly replaceable. Power supplies are concentrated in a single compact unit—sometimes mounted on the wall outside the console—so that hum pick-up problems are reduced to a minimum. The cabling and keying of course lead to acute problems of stability and crosstalk, but these are solved once and for all and a standard unit offered instead of a custom-built array.

There is a growth throughout the communications industry of unattended stations. This has long been feasible for the broadcast transmitter, but a speech input equipment has seemed to be so much a matter of control and adjustment that remote working has not seemed possible. The introduction by the B.B.C. of an automatic monitoring apparatus is therefore a notable contribution which will certainly make unattended equipments possible in some circumstances. This apparatus, which is described in the literature, makes a continuous and automatic check on the level, the harmonic content, and the noise of a programme and takes appropriate action if these fall below a fixed standard.

6. Recording and Reproducing

Whatever may be said about the desirability of "live" programmes there are many occasions where the use of "dead" material is unavoidable. Recording and broadcast technique have advanced at about the same rate, so that it has almost always been possible to say that reproduced programmes at their best are nearly indistinguishable from the directly broadcast material when heard on the listener's set. It must be admitted however that the hazards of recording often result in offerings which fall below the best standards, and listeners who probably accept quite inferior gramophone reproduction in their own homes are quick to criticize anything that they can detect as a recording. Among the various systems which have given good service we need only notice the two which now dominate the field, viz. disc and tape. There is little to choose between their best technical performances but they persist side by side because they fulfil different roles.

The success of disc recording depends very much on the excellence of the mechanical design of the recorder since flutter and "wow" are detectable down to 0·1 per cent on a sustained note. The use of heavy rim driven turntables, which are replacing gear and belt drives, contributes to the reduction of speed irregularities, but unless the resiliency of the driving wheel be chosen correctly and wear avoided the result can be worse rather than better. Bearings have to be accurate to a few hundred-thousands of an inch, particularly as rim drives involve a side thrust and any slight bearing knock is quickly exaggerated. There are many sources of wow—main bearings, drive bearings, motor alignment, turntable unbalance, etc.—and these may adventitiously balance out in a particular machine much as spurious hum cancellation may occur in an amplifier, so that it is a common experience to improve one source and make the total result worse. Type approval is therefore difficult unless one has several samples or unless a lengthy statistical analysis of the different variances is undertaken. The B.B.C. type D is a fine example of a really advanced design which shows, over and above attention to accuracy in detail, the other *sine-qua-non* of a first-class recorder, fool-proof operability. Just as a first-rate photograph can often be obtained from a simple box camera, an unexceptionable recording can be made on a cheap machine provided only that it runs smoothly. Nevertheless good recordings under all circumstances can only be obtained if it is made impossible to spoil the result by a slip, such as over-running or dropping the head. Swarf, however carefully brushed away, is a source of danger and the best machines must remove it by blowing or suction (or both) as it is formed at the point of the stylus. This calls for acetate discs (we are not here considering wax) which do not have troublesome and irregular electrostatic attractions—or for a fluid lubricant which neutralizes them. Fortunately the quality of discs in this respect, and also in respect of uniformity, freedom from blemish, etc., is constantly improving. Electrically, it is essential to have a recording amplifier with a capacity of 10 or 20 times the nominal power taken by the head, particularly if radius compensation is used (as it must be for speeds less than 78). A limiter is also almost a necessity as overloading on a disc is intolerable. Fortunately a broadcasting organization plays back the discs it records and it has therefore more freedom of action in choosing a recording characteristic than the maker of commercial discs, and can use what pre-emphasis of high notes it considers will give useful noise suppression and can cut the base to give a good dynamic range without groove break-through. This of course involves the use of various reproducer equalizers suitable for its own discs and discs made to other standards.

The reproducer is essentially a simpler machine but the requirements of smoothness are the same. Since one of the advantages of disc reproduction is the ease with which snippets can be edited into a programme, a reliable groove selecting device is an essential auxiliary. Most devices are content to select a given groove, but even if the selection is accurate there is a probable error of about one word so that skill is needed to make an undetectable selection. At least one machine however, by means of a synchronous commutator and a well-developed indicator system, enables a semi-skilled operator to select to an accuracy of 0·1 of a groove. The additional circumferential selection, however, does not help, as such, with long-playing records which remain something of a problem; the longer the record the more important it becomes to isolate a given portion, and, for a given diameter, the more difficult.

The pick-up itself is of course the most important detail but the most difficult to discuss in a non-specialist way, as there is an immense variety of types. Most broadcast pick-ups will use a sapphire tipped stylus but it is a mistake to suppose that this confers immortality. Diamond tips, though very much more expensive, are worth while if permanency is really required. Where there is any fear of accidents, however, a sapphire stylus which can be replaced quickly is possibly better. Lightness of weight and smallness of inertia are of course necessary and vertical compliance is desirable, though this calls for moving parts weighing only a few milligrams. There seems little to choose in principle between moving-coil and moving-iron.

Tape reproduction is a relatively new acquisition for most broadcast organizations but some admirable machines already exist. The problems involved in securing a flutterless movement of the tape are similar to those encountered in disc recording, but there are of course no needle problems. Hum was troublesome in early machines but better first valves and better shielding have overcome this. Basic noise with good tape is very low in spite of the considerable equalization needed to keep a flat overall frequency characteristic. The chief defect of tape is also one of its chief virtues, viz. the long playing time which makes it difficult to produce individual snippets to order. The inconvenience may perhaps be reduced if a system of automatic cueing, with cueing marks on an auxiliary track along the edge of the tape, is developed in conjunction with very rapid rewinds. Such a system would take the place of a groove indicator and would probably increase the use of tape at the expense of disc.

7. Conclusions

It will be seen how wide a range of technical activity is covered by the term speech input equipment. We have here considered these matters only discursively but each heading might easily be the subject of a separate lecture. However, it is sometimes desirable to step back and review the subject in broad outline. Nor have we been exhaustive, as a glance at the complete schematic of a broadcasting equipment will show. In particular, signalling, talk back, and similar cueing adjuncts, so necessary to the smooth running of a programme have not been mentioned.

THE RADIO TRADES EXAMINATION BOARD

formed by

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

RADIO SERVICING CERTIFICATE EXAMINATION—MAY 1952

Of the 301 candidates who sat the examination which took place in May of this year, 133 candidates satisfied the examiners in both the written and practical parts; 69 candidates passed the written examination but were referred in the practical test, and 19 candidates completed the examination, having previously been referred in the practical test in the 1951 examination.

PASS LIST

The following candidates satisfied the examiners in the entire examination:

Acarnley, Leslie. *Manchester*
Alderson, Ronald William. *Coventry*
Aldridge, Reginald John William. *London, W.1*
Alexander, John. *Southampton*
Andre, Reginald John. *Westcliff-on-Sea, Essex*
Appleby, Peter William. *St. Albans, Hertfordshire*
Appleton, Roy Charles. *Alresford, Hants.*
Baigent, Jack. *Torquay, Devon*
Bailey, Leslie. *Morecambe, Lancashire*
Bain, Malcolm M. *Wolverhampton*
Bate, David Ronald. *Bristol*
Bell, Jack Robert. *Croydon, Surrey*
Binnall, Arthur Edward. *Blackpool*
Black, Wallace John. *Goodmayes, Essex*
Blake, Henry Reuben. *Romford, Essex*
Blakely, John. *Glasgow*
Brand, Leonard Richard. *Morden, Surrey*
Brennan, Peter. *Glasgow.*
Brewer, Keith. *Farncombe, Surrey*
Brook, Leonard. *Mirfield, Yorkshire*
Brown, Allan. *Leeds*
Brown, John Cyril. *London, E.13*
Cann, David Michael. *Leigh-on-Sea, Essex*
Caunt, Barry. *Leicester*
Chapman, Alfred Henry. *Bristol*
Clark, Kenneth Charles. *London, S.E.12*
Connor, William George. *Leeds*
Cooke, Frederick Roy. *Mickleover, Derbyshire*
Cooper, Harold Arthur. *Brentwood, Essex*
Croshaw, David William. *Leicester*
Crossland, George Henry. *Wakefield*
Cuthbertson, John. *Glasgow*
Day, Ronald George. *London, S.E.6*
Dean, Trevor E. *Bristol*
Dickinson, Bernard. *Preston*
Don, Robert Cathcart. *Ayr*
Duffy, Arthur J. *Tillicoultry, Clackmannanshire*
Eastwood, Frederick Roy. *Leicester*
Ellett, Ernest John. *Thornton Heath, Surrey*
Farmer, Donald Stephen. *Birmingham*
Felgate, Victor. *Redcar, Yorkshire*
Forsyth, Hugh Barr. *Glasgow*
France, Peter. *Surbiton, Surrey*
Gale, Henry Charles. *Epsom, Surrey*
Gallon, Arthur Anderson. *Skegby, Nottinghamshire*
Gardner, Ian Walter. *Darlington*
Gledhill, Peter. *Leeds*
Goddard, Frederick Edward. *Glossop, Derbyshire*
Goodall, Leonard. *Southampton*
Graham, Robert Hunter. *Blythe, Northumberland*
Greenhill, Gerald Henry. *Birmingham*
Griffiths, Thomas Arthur. *Tamworth, Staffordshire*
Hannah, Raymond Alexander. *London, S.W.4*
Hart, Raymond Leonard George. *Morden, Surrey*
Hately, John Norman. *Paisley*
Hauxwell, Peter. *Wakefield*
Hill, Frank Philip. *Stockport, Cheshire*
Hing, Leslie Charles. *Beckenham, Kent*
Hopkins, Bernard. *Manchester*
Horne, Denis. *Manchester*
Humphrey, Raymond Robert. *Beckenham, Kent*
Jackson, Jack. *Glasgow*
Jeffery, Falga Terence. *Newmarket, Cambridgeshire*
Kell, Ronald. *Gateshead*
Knight, David Richard Joseph. *Salisbury*
Knight, Ronald Harry. *Lancing, Sussex*
Knox, Andrew. *Glasgow*
Lindsley, Thomas Legender. *Durham*
MacDonald, Archibald. *Glasgow*
MacGregor, John. *Glasgow*
MacIver, John M. *Stornoway, Isle of Lewis*
McNamara, Edward. *Halifax*
Mantell, Basil Clarence. *Sutton, Surrey*
Marshall, Matthew. *Blairgowrie, Perthshire*
Mason, Eric Boyle. *Stockport, Cheshire*
Maton, Ronald William. *Kettering, Northants.*
Medd, Reginald A. P. *Cambridge*
Metcalf, A. W. R. *Skegness, Lincolnshire*
Millar, William. *Ayr*
Moore, John Derek. *Southwick, Sussex*
Moores, Harold. *Droylsden, Lancashire*
Munro, Ronald. *Gateshead*
Osborn, Gerald. *Huddersfield*
Palmer, Albert Edward. *Southampton*
Pankhurst, Richard Alwyn. *Leicester*
Pledge, John Roland. *Leicester*
Podlaski, Jan. *Manchester*
Porter, James Anthony. *Londonderry*
Poustie, Alan. *Meigle, Perthshire*
Price, Douglas Gordon. *Cheltenham*
Pridell, James Albert. *London, S.W.2*
Priestley, Charles. *Oldham, Lancashire*
Proctor, Wilfred. *Nottingham*
Quinn, Francis. *Edinburgh*
Ranson, Derek Percy. *Cambridge*
Rayner, Frank. *Barnsley*
Reeves, Leonard W. *Birmingham*
Roberts, Peter John. *Leigh-on-Sea, Essex*
Roche, John. *London, S.W.11*
Rule, Robert James. *Chessington, Surrey*
Scott, James Simon. *York*
Sherwood, George Grafton. *Hayes, Middlesex*
Shurman, Stanley David. *Coulsdon, Surrey*
Smith, Haddon Ernest. *Kirklangley, Derbyshire*
Smith, Peter Leyland. *Liverpool*
Spence, James M. *Surbiton, Surrey*
Squires, Walter Arthur John. *London, S.E.2*
Stafford, Derrick. *Leicester*
Stewart, Geoffrey. *Mirfield, Yorkshire*
Stewart, John. *Strathaven, Lanarkshire*
Stiglitz, Ronald. *Wallington, Surrey*
Stroud, John Philip. *Solihull, Warwickshire*
Sutherland, Peter Sidney. *Doncaster*
Taylor, Alan. *Ely, Cambridgeshire*
Terras, Robert Thomson. *Ayr*
Thomas, George Ernest. *Leicester*
Thompson, Ernest William. *Wallsend, Northumberland*
Tibbles, Raymond. *Leicester*
Tupper, Derek Arnold. *Surbiton, Surrey*
Turner, John Alfred. *Smethwick, Staffordshire*
Turski, Stefan. *Dundee*
Vinall, William Henry. *Yeovil, Somerset*
Wadsworth, Alan. *Manchester*
Walker, John Govan. *Glasgow*
Ward, R. T. *Exmouth, Devon*
Watson, Reginald Arthur. *Spalding, Lincolnshire*
Waud, George. *Leeds*
Whalley, Benjamin Allen. *London, E.5*
Wharfe, Stanley. *Bedford*
White, Harold David. *Southend-on-Sea, Essex*
Wills, Alfred. *Rushden, Northants.*
Wilson, Thomas. *Glasgow*
Wood, Richard Robert. *Leicester*

The following candidates who were referred in the practical test in May, 1951, now qualify for the Certificate:

Anderson, Ronald V. *Birkenhead*

Baker, John E. *London, N.*19

Catt, William John. *Bradford*
Crossby, Victor G. *London, N.W.*5

Hart, Charles Edward. *Middlesbrough*
Herbert, Peter Reginald. *Reading*
Humphriss, Ernest Lawton. *Liverpool*

Knox, William Lockhart. *Edinburgh*

McColl, Duncan. *Bearsden, Dumbartonshire*
Monoghan, Thomas. *Bradford*

Reback, Bernard. *London, E.*17
Reilly, James Vincent. *Liverpool*

Sword, William. *Coupar-Angus, Perthshire*

Waddingham, Brian Vickery, *Brixham, Devon*
White, John George. *Norwich*
Whiteley, Robert. *Halifax*
Whittaker, Albert John. *Birmingham*
Wilson, Ian Meikle. *Ayr*

Zdrojewski, Zygmunt. *Glasgow*

The following candidates satisfactorily passed the written papers but were referred in the practical test:

Abrahams, Thomas George. *Bristol*
Aitken, Thomas. *Barrhead, Renfrewshire*
Andrews, Ronald George. *Birmingham*

Balson, Charles Frederick. *Poole, Dorset*
Beasley, William Edward. *London, N.*17
Bishop, John Charles. *Martock, Somerset*
Bond, George Frederick. *London, S.W.*9
Bruton, Paul Alfred William. *Bristol*
Butlin, Frank Herbert. *Riddings, Derbyshire*

Chandler, Francis James Stewart. *Birmingham*
Clancy, Francis R. P. *Southend-on-Sea, Essex*
Clark, Horace Ernest. *Birmingham*
Clarke, George Harold. *Leeds*
Cross, Albert. *Chilwell, Nottinghamshire*
Crowder, Charles Donovan. *Birmingham*

Douglas, George Gilbert. *Bexley, Kent*

Edwards, Robert E. *London, S.E.*6
Eyre, Charles Thomas. *London, S.E.*4

Fellowes, John. *Dudley, Worcestershire*
Flower, Wilfred. *Grimsby*
Foster, Peter. *Southport, Lancashire*
Friend, Alan Walter. *London, W.*12

Gardner, Edward Francis. *Thundersley, Essex*
Gilbert, John. *Slough, Bucks.*
Gill, Michael Arthur Ford *Nottingham*
Greenham, Leslie Crosby. *Bournemouth*
Greenwood, Samuel James. *Blackpool*

Harrison, Raymond Colin. *Hebburn-on-Tyne, Co. Durham*
Hellicar, George Edward. *Mitcham, Surrey*
Hocken, Alfred Roy. *Plymouth*

Jehan, David. *Cowplain, Hants.*
Jessop, Joseph E. *Liverpool*

Kaletta, Kazimierz. *London, W.*11
Keeling, Jeffrey Frank A. *Hucknall, Nottinghamshire*
Kitching, Terence. *Leeds*

Landon, Edwin John. *London, S.E.*13
Layer, Ronald Alexander. *Croydon, Surrey*
Lees, Kenneth. *Bristol*
Lines, Derek Edward. *Sutton Coldfield, Warwickshire*
Linsey, David John. *London, N.*20

McMahon, Francis. *Blantyre, Lanarkshire*
McMeekin, Frederick Newell. *Belfast*
Mapplebeck, Raymond. *Leeds*
Maszewski, Artur Edward. *Edinburgh*
Miller, William Aikman. *Edinburgh*
Morris, James. *Brighton*
Mullis, Neville Raymond. *Birmingham*

Newell, Albert James. *London, S.E.*4

Oldfield, Percy. *Wallasey, Cheshire*

Paterson, George Raymond. *London, S.W.*1
Payne, Sidney Alfred. *London, E.*17
Purdon, Matthew. *Glasgow*

Reece, Raymond Dennis. *Gosport, Hants.*
Ruskin, James. *London, N.W.*4

Slater, Raymond Charles. *Birmingham*
Smith, Andrew R. *Edinburgh*
Smith, John Hugh. *Ripley, Surrey*
Spencer, Charles Henry. *London, S.E.*12
Stark, Thomas Ernest. *Kingsthorpe, Northants.*
Storey, Sidney Ernest. *London, S.E.*18

Taylder, Joseph Leslie. *Newcastle-upon-Tyne*
Tipping, Albert. *Birmingham*

Wager, James Henry. *Birmingham*
Webb, William Robert. *Glasgow*
Webb, Walter Thomas Patrick. *Watford, Hertfordshire*
Webley, Edward John. *Wimborne, Dorset*
Wilson, Charles. *Gatley, Cheshire*
Winckle, George Albert. *Ilford, Essex*
Wood, John. *Liverpool*

The results of the 1952 Television Servicing Certificate examination will be published in the November *Journal.*

Radio Servicing Certificate Examination 1953

The next examination will be held on April 28th, April 30th and May 16th, 1953.

Entries must be submitted before February 1st.

Television Servicing Certificate Examination 1953

The next examination will be held on May 4th, May 6th and June 20th, 1953.

The closing date for entries is January 15th.

TECHNICAL REPORTS AND STANDARDS

E.R.A. Report

The Electrical Research Association has asked the Institution to draw the attention of members to the following report:—

Report Ref. N/T61 "Stainless Steel Magnetic Recording Wire" by Prof. W. Sucksmith, F.R.S.

This is a report of an investigation into the magnetic properties of stainless steel recording wire in the light of the theories of Stoner and Wohlfarth on the one hand and Neel on the other, on the shape anisotropy mechanism of hysteresis in heterogeneous magnetic alloys. The variation of coercive force and J_{REM}/J_{SAT} with time of heat treatment at 450 deg C., 500 deg C. and 550 deg C. were required.

Limited supplies of the report are available from the Association at Thorncroft Manor, Dorking Road, Leatherhead, Surrey, price 6s., postage 3d.

New British Standards

The British Standards Institution has recently published the following new and revised Standards. Copies may be obtained from the B.S.I., 24 Victoria Street, London, W.C.1.

B.S.1872 : 1952. Electroplated Coatings of Tin. Price 2s. 6d.

This is a further publication in the series covering electroplated coatings of various metals. It provides for coating of this metal on fabricated articles of iron, steel, copper and copper alloys and covers five classes of coating according to the use to which the coating is to be put. It also provides details of samplings, finish, solderability, thickness, adhesion, and heat treatment, together with the necessary methods of test.

B.S.1885 : 1952. Synthetic-Resin Bonded Paper Insulating Tubes (Rectangular Cross Section) for Electrical Power Circuits up to 1,000 V. Price 2s. 6d.

The standard is an addition to the published series dealing with insulating material and, apart from the voltage limitation, is complementary to B.S.1314 (1946) which covered circular tubes of similar material. It deals with two types of rectangular tube intended for electrical insulating purposes with direct current, and with alternating current up to 100 c/s.

B.S.899 : 1952. Rolled Copper Sheet and Strip for General Purposes. Price 2s. 6d.

In this revised standard, which includes provisions for annealed, half-hard and hard conditions, the mechanical properties have been modified and elongation requirements have been added, as well as an embrittlement test for deoxidized material. Other minor amendments have been made in order to bring the standard as far as possible into line with the revised edition of B.S.1432, "Copper for electrical purposes (sheet and strip)" which will be issued shortly.

B.S.'s 1035-40, 1172-4 and 1961 : 1952. Standards for Raw Copper. Price 4s.

The following 10 standards for raw copper have just been issued in one booklet:—

B.S.1035—Cathode copper.

B.S.1036—Electrolytic tough-pitch high-conductivity copper.

B.S.1037—Fire-refined tough-pitch high-conductivity copper.

B.S.1038—99·85 per cent tough-pitch copper (conductivity not specified).

B.S.1039—99·75 per cent tough-pitch copper (conductivity not specified).

B.S.1040—99·50 per cent tough-pitch copper (conductivity not specified).

B.S.1172—Phosphorus deoxidized non-arsenical copper.

B.S.1173—Tough-pitch arsenical copper.

B.S.1174—Phosphorus deoxidized arsenical copper.

B.S.1861—Oxygen-free high-conductivity copper.

R.I.C. Specifications

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

RIC/111—Resistors, Fixed Wirewound, Non-Insulated. Section 3. Price 5s.

RIC/122—Resistors, Rotary Variable, Composition Track. Section 3—complete version. Price 1s. 6d.

RIC/133—Capacitors, Fixed, Ceramic Dielectric, Grade I. Section 3. Price 3s.

It should be noted that the charge for Sections 1 and 2 of these Specifications did not include the cost of Section 3. Hence these will *not* be supplied automatically to the holders of the Specifications but should be ordered from the R.I.C., 59 Russell Square, London, W.C.1.