ELECTRONIC ENGINEERING

VOL. XXVI No. 321

NOVEMBER 1954

Commentary

AMONG the principal celebrations to mark the Jubilee of the thermionic valve which occurs on the 16th of this month is that organized by the Institution of Electrical Engineers. On this occasion the proceedings will be opened by the Lord President of the Council, the Marquess of Salisbury, and there will follow papers by Sir Edward Appleton, Professor G. W. O. Howe and Dr. J. Thomson, which together will trace the history and development of the thermionic valve since its inception fifty years ago.

The celebrations commemorate the application on 16 November, 1904, by Sir Ambrose Fleming for his British patent to cover the rectifying properties of a device which both he and Edison had, in fact, independently discovered some years previously in connexion with their investigations of the carbon filament lamp. At the time Ambrose Fleming was Professor of Electrical Engineering at University College, London, and it is therefore appropriate that the Jubilee celebrations should include a conversazione at the College where so much of his work was done.

An appreciation of the work of Ambrose Fleming is to be found elsewhere in this issue and a fuller account of his activities was published in 1949 on the occasion of the centenary of his birth*, so that to deal in these columns with the events as they occurred at the time would be merely repetitive.

The growth of electronics has, of course, been phenomenal, particularly in the post-war years and so rapidly does the progress continue that any forecast or prophecy of the state of development when the centenary of the valve is celebrated would be very wide of the mark. To attempt to look ahead fifty years we have only to turn back by the same time interval to realize how far we have come. Certainly, fifty years ago Ambrose Fleming could not have foreseen the enormous revolution the valve was to bring about. Both he and Edison had already observed the unidirectional flow of current across the space between the filament and the " plate " of the early carbon lamp and what we are, in fact, commemorating this month is no more than an inspiration on Fleming's part when he applied this simple rectifying device to a wireless receiver while acting as a consultant for the newly-formed Marconi Company. He could not have realized that that simple experiment, taking no longer than an afternoon to carry out, had ushered in the electronic age that was destined to speed up enormously the tempo of our lives and to contribute inestimably to our well-being. To many of us fifty years ago is not a fading memory but a matter of history and we can have no intimate knowledge of those spacious leisurely days of 1904.

We are accustomed as from birth to these modern miracles that were absent then, and we take for granted the fact that from the telephone at our side we can speak to the ends of the earth and that a mere turn of a knob on a radio set carries us from continent to continent. It is no longer a wonder to us that from the comfort of our homes we can see events as they occur hundreds of miles away and that daily our range of vision is increasing. These are now the everyday occurrences that are part and parcel of what we call our improved standard of living.

Yet it is perhaps in the scientific world that the thermionic valve is making its greatest impact for, by its aid, many of nature's mysteries which hitherto had baffled us, have now been forced to yield their secrets. It is true to say that there are few physical phenomena which cannot be measured and displayed by electronic methods and that, as a result, our knowledge has increased enormously. In no period of our history has scientific progress proceeded at such a pace as during the last fifty years, and it is due very largely to the thermionic valve.

* * *

An event of considerable importance to the economic well-being of Scotland took place last month when His Royal Highness the Duke of Edinburgh opened the new electronic research laboratories of Ferranti Ltd., at Edinburgh.

For some years concern has been felt at the continued drift of industry to the south, and the Scottish Council (Development and Industry) has been much occupied in arresting this trend and devising ways and means of producing a more balanced industrial economy for Scotland.

The manufacture of many new light engineering products such as aero engines, office machinery, clocks and watches has been added to the range of Scottish production, but several of the newer and more important branches of engineering industry have not developed to any great extent and electronic engineering is the most prominent example.

The inadequate growth of this industry in Scotland—country of world renowned engineering tradition—has meant that not only has it not shared fully in a major and growing source of employment, but that the basis from which will come the more important products of the future has not been established there.

Some five years ago, therefore, the Scottish Council set out to introduce electronic engineering into Scotland on a wide front and instituted discussions with the Ministry of Supply, the Admiralty and several Scottish firms. At that time, Ferranti Ltd., were the only firm in Scotland with research laboratories of worthwhile size and they agreed to act as a channel through which some Government electronic contracts might flow.

They also undertook to train engineers from Scottish firms in their laboratories to acquire the new techniques and to act as a seedbed from which young electronic teams could be transplanted in due course to other firms.

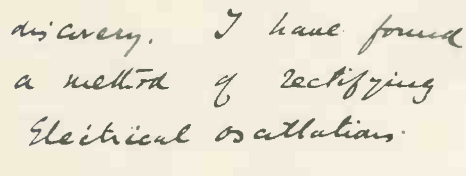
This scheme has been operating for some time past, although on a restricted scale due to space limitations, but now the Ministry of Supply has provided a new laboratory to accommodate not only Ferranti's own research staff, but a nucleus of 40 engineers from other firms. The opening of these new laboratories is an excellent example of co-operation between Government Departments, the Scottish Universities, Technical Colleges and industry, and it will prepare the way for the development in Scotland of a new major industry.

* MacGregor-Morris, J. T. Birth Centenary of Sir Ambrose Fleming. *Electronic Engng. 21*, 442 (1949).

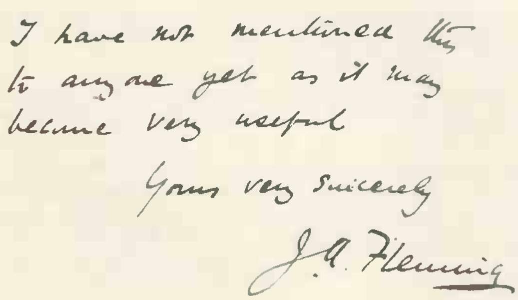
FIFTIETH ANNIVERSARY OF THE VALVE

An appreciation of the work of Sir John Ambrose Fleming, M.A., D.Sc., F.R.S.

By W. J. Baker*


discovery. I have found
a method of rectifying
Electrical oscillations.

Facsimile of part of a letter written by Fleming to Marconi (circa 1904), announcing his discovery of the "Oscillation Valve."


I have not mentioned this
to anyone yet as it may
become very useful

Yours very sincerely

J. A. Fleming

FIFTY years ago, on 16 November, 1904, an insignificant-looking sheaf of papers was handed in at the Patents Office in London, to be filed, in due course, with the thousands of its predecessors. There is not the slightest suggestion that those documents caused even the lift of an eyebrow in that temple of inventive aspirations; yet, had they but known it, the clerks were holding in their hands a conception that was destined to affect, to a profound degree, the future of the entire human race.

The papers described an apparatus termed by its inventor an "Oscillation Valve". The applicant for a patent was John Ambrose (later, Sir Ambrose) Fleming.

But even the most imaginative official in the Patents Office might well be forgiven for failing to appreciate the possibilities of Fleming's idea. Indeed, in that heyday of the Machine Age the apparatus must have presented a woefully improbable appearance to the lay eye; for here was no intricate piece of machinery to quicken the brain and promote visions of power. The entire equipment, it seemed, consisted merely of an Edison, or Swan, type of electric lamp to which had been added, inside the glass bulb, a few square centimetres of metal plate.

Even Fleming himself could have had no idea, at the time, of the far-reaching consequences of his patent. That he had solved the problem of providing a sensitive and reliable rectifier for the high-frequency currents of wireless telegraphy he well knew; but that he was, at the same time, witnessing the birth of the electronics industry he could have had no inkling. This is evident when, in his capacity as consultant to Marconi's Wireless Telegraphy Company he writes a personal account of his experiments to Marconi, and concludes by saying: "I have not mentioned this (oscillation valve) to anyone yet, as it may become very useful."

Fleming lived to see his words become a classic of

* *Marconi's Wireless Telegraph Co., Ltd.*

conservative understatement. Less than fifteen years later, R. D. Bangay, in his text book "The Oscillation Valve" could say, in preface: "The invention and improvement of the Oscillation Valve has led to important and far-reaching developments in the art of Wireless Telegraphy. The new fields of possibility opened by the invention have as yet been only partially explored, but already the perfection of the wireless telephone and of the wireless compass are directly due to its agency."

Today, with a fifty-year span to review, those remarks are as apposite as when they were written in 1919. The intervening years have undoubtedly unfolded a multiplicity of applications for the thermionic valve. To the "wireless telephone" and "wireless compass" one could add a detailed list to stretch far beyond the bounds of this article. Broadcasting, television, radio communication, radar, diathermy, ultrasonics, guided missiles, airborne and ground navigational equipment, radio facsimile, radio-thermics, sound amplification (from public address systems to deaf-aids)—all these, and more, can be added to the quota. And all of them stemming directly from Fleming's apparatus.

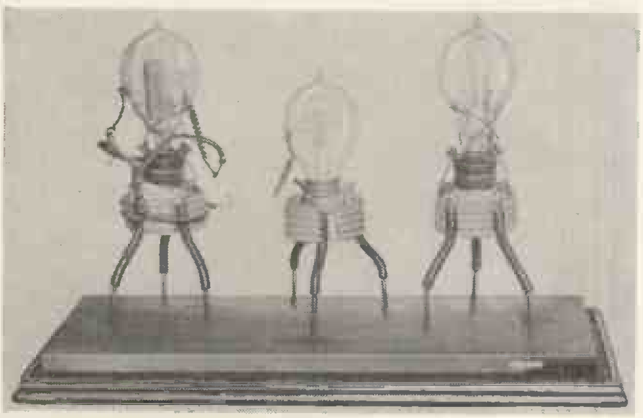
Almost daily, fresh applications confront us. The broad classifications given above are splitting, amoeba-like, into sub-divisions, each tending to become a specialist industry in its own right. Radar, for instance, which began existence as a desperate expedient for giving advance warning of the approach of hostile aircraft, has developed in innumerable directions, and today only the most basic of first principles can give a common denominator between a C.H. radar station and, say, the proximity fuse.

To quote only one more example—television, which began solely as a means of entertainment, has more recently expanded its aims to include applications in industry. Prophecies are always dangerous, but it seems not unreasonable to suppose that in the course of time the manufacture of industrial television equipment may become the senior partner of the two.

All of which is a far cry from 1904, but it is beyond dispute that the valves of the mighty transmitters of today are in direct line of descent from that first thermionic valve patented by Fleming. But although it is this particular anniversary we are commemorating now, it would be grossly unfair to forget that, had Fleming never invented his "Oscillation Valve", his many other achievements in the field would still have rendered his place secure in the Hall of Radio Pioneers.

John Ambrose Fleming was born on 29 November, 1849, near Lancaster. Five years later his parents moved to the London area, where young Fleming was to spend many years. It would seem that from his earliest days he was possessed of that blend of patience coupled with an inability to take things for granted, which is one of the hall-marks of the inventor.

Sir Ambrose Fleming's original experimental thermionic valves, the forerunners of all modern wireless valves (1904).



Early Marconi production models of the Fleming diode, forerunner of all thermionic valves.

At the age of fourteen he was sent to University College School, where his bent for engineering became even more apparent. Three years later, his parents being unable to afford the expense of an engineering apprenticeship—the premium demanded in those days was quite considerable—young Fleming got a situation on the clerical staff of the Stock Exchange, and continued his studies at home, under the University of London External Scheme. Before he was twenty-one he had taken his B.Sc. degree, First Class, there being but one other to do so in that year.

Fleming's restless, inquiring nature seems to have made him somewhat of a rolling-stone for some time. He obtained a post as Science Master at Rossall College, but remained there for only eighteen months. There followed a lengthier spell at the Science Schools, South Kensington, where he studied under Dr. Frankland. His most notable activity here was the part he played in the founding of the Physical Society; the first paper ever read to that body was, in fact, Fleming's.

Soon, however, he was on the move again, for a brief sojourn as a science master at Cheltenham College, but in 1877 he resigned the post, having won himself a Scholarship to St. John's College, Cambridge. This was indeed a great day for Fleming, for it meant the fulfilment of a cherished ambition—the opportunity to study under the great Clerk Maxwell.

Maxwell's death in November, 1879, filled Fleming with a deep sense of personal loss. Shortly afterwards he left Cambridge to take the post of Professor of Physics and Mathematics at Nottingham's University College. But, hardly had he unpacked his belongings there, when an offer arrived which called upon him to make what transpired to be one of the most momentous decisions of his career.

The proposition emanated from the Edison Electric Light Company of London. Fleming became electrical adviser to that company and so began research work on behalf of the Wizard of Menlo Park. It was during the course of this that he made his first acquaintance with the phenomenon known as the Edison Effect. To quote Fleming's own words:—

"In 1882, as Electrical Adviser to the Edison Electric Light Company of London, I was brought into close touch with the many problems of incandescent lamps and I began to study the physical phenomena with all the scientific means at my disposal. Like everyone else, I noticed that the filaments broke at the slightest shock, and when the lamps burned out the glass became discoloured. The discoloration of the glass was generally accepted as a matter of course. It seemed too trifling to notice. *But in science it is the trifling things that count. The little things of today may develop into the great things of tomorrow. . . .*"

The immediate objective, however, was to prolong the life of the filaments and to prevent the carbon deposit. Edison himself was also working on the problem in America, and tried various expedients to cure the trouble. He agreed with Fleming's findings, namely, that the deposit consisted of an accumulation of carbon atoms shot from the overheated point on the filament, and in one experiment introduced a coating of tinfoil inside the bulb, with the object of applying a counter-charge of electricity to off-set the bombardment. To Edison's surprise, when the foil was connected, through a galvanometer, to the positive leg of the filament, a small direct current registered on the instrument. Connexion to the negative leg produced no reading at all. Such, then, was the "Edison Effect".

This, to Edison, was a sidetrack (albeit a fascinating one) to his main line of investigation, and he did not pursue it to the point of offering an explanation. Fleming, however, spent much time in research on the matter, and subsequently gave lectures on his findings. These aroused a certain amount of interest in scientific circles, but caused no furore, as there appeared to be no practical application for the phenomenon.

For a time Fleming suspended his investigations, having been appointed Professor of Electrical Engineering at University College, London. He also subsequently became exceptionally occupied in another direction, having undertaken, in 1899, the duties of technical consultant to Marconi's Wireless Telegraph Company.

One of his first assignments with Marconi's was a collaboration with Marconi himself over the design of the transmitter for Poldhu. This was *terra incognita* with a vengeance, for all of Marconi's previous experiments had been conducted with laboratory-type apparatus, whereas the Trans-Atlantic project called for an engineered transmitter of high power. No previous data was therefore available, but the success of the design was headlined in December 1901, when the Poldhu signals were picked up in Newfoundland. Wireless had spanned the Atlantic—a feat which many of the eminent scientists of the time had declared to be impossible. Fleming's part in the project is suitably commemorated on the Poldhu memorial.

Wireless telegraphy of those days however, was handicapped by one weak link. The most practicable detector known was the coherer, a form of relay which was, at best, a temperamental and erratic performer. True, in 1902, the Marconi magnetic detector appeared, and did sterling service for many years, but this had certain disadvantages, not the least of which was a strong tendency to be affected by static discharges. Many workers, among them Fleming, were seeking a sensitive and reliable means of direct rectification of the high-frequency signals.

Fleming first approached the problem by experimenting with chemical rectifiers, with no striking success. Then, in October 1904, he recalled his experiments with the Edison lamps. Here was a device which, when the metal plate was given a positive potential with respect to the filament, would pass current, but would not do so when the plate was made negative. Might it not rectify wireless signals?

Hastily fitting up a small spark transmitter at one end of his laboratory, Fleming resurrected one of his experimental lamps and wired it to a receiver in conjunction with a mirror galvanometer. Said Fleming, describing the occasion:—

"It was about five o'clock in the evening when the apparatus was completed. I was, of course, most anxious to test it without loss of time. We set the two circuits some distance apart in the laboratory and I started the oscillations in the primary circuit.

"To my delight I saw that the galvanometer indicated a steady direct current passing through, and found that we had in this peculiar kind of electric lamp a solution to the problem of rectifying high-frequency wireless currents. The missing link in wireless was found—and it was an electric lamp!"

Fleming at once set to work improving the crude construction of his apparatus by making the metal plate into a cylinder which enclosed the whole filament. The patent, filed on 16 November, 1904, described the apparatus subsequently termed an "Oscillation Valve"; by this, of course, Fleming meant that it was a non-return valve for rectifying oscillations.

Marconi, to whom Fleming wrote telling of his discovery, immediately foresaw at least some of its possibilities. The Fleming valve was put into production by Marconi's, and proved to be an unqualified success.

De Forest, in America, who had been closely following Fleming's work, conceived the idea of inserting a "grid" between filament and plate, whereby the electron flow might be controlled. He found that under suitable conditions of operation small variations in P.D. between the grid and filament produced large changes in the current flowing between filament and plate; in short, amplification of a signal could be effected.

De Forest's patent for this was at once challenged in the U.S.A. by Marconi and in several important legal actions it was established that the principle involved in the Fleming patent was fundamental, that it had priority and that the grid was merely an improvement upon the basic idea.

Fleming was to live to see much of the fruits of his labours, and to receive due honours, among them the Gold Albert Medal—the ultimate award of the Royal Society of Arts—the Faraday Medal of the Institution of Electrical Engineers, the Kelvin Medal and the Franklin Medal. In 1929 he was knighted for his valuable service in science and industry. Far from resting on his laurels after 1904, he was active almost to the last—investigating, inventing, writing, lecturing. In his capacity as Professor of Electrical Engineering at University College, many hundreds of radio engineers were trained by him, while his lectures achieved international fame. Many still remember his Marconi Memorial lecture to the R.S.A. in 1937 (given when he was 88), as a truly remarkable *tour de force*. His books, too, were classics of their kind. To mention only two: "The Principles of Electric Wave Telegraphy" (1906) was a standard work of reference to innumerable wireless engineers for many years after, while his "Fifty Years of Electricity" (1921) makes fascinating reading, and serves to give some idea of the ramifications of Fleming's genius.

On the writer's desk is a letter written by Sir Ambrose in 1943. The handwriting is bold and vigorous, the mind behind it obviously crystal-clear. In the course of the letter he says regretfully:—"... all the pioneers are dead (Sir Ambrose was referring to the original engineers of the Marconi Company)—Marconi, Jameson Davis, Kemp, Bradfield and possibly Paget. I am ninety-four years old and have outlived them all, or nearly all ..." He then proceeds to write twenty-two pages of foolscap, which details, with dates, various phases of the history of wireless telegraphy from his own personal angle of scientific adviser to the company! Nothing could be more characteristic of the enthusiasm and capacity for painstaking detail which he carried with him throughout his life.

Two years later, on 18 April, 1945, Sir Ambrose Fleming died, being in his ninety-sixth year. So passed one of the giants of the Radio Age. Memorials to his fame are in almost every home in this country, and, indeed, throughout the world—the thermionic valves, which now form part of our everyday life, and of which Fleming made the first.

A Pulse-Interval Meter

for Measuring Pulse Repetition Frequency

(Part 1)

By A. M. Andrew*, B.Sc., and T. D. M. Roberts*, B.Sc., Ph.D.

The type of counting-rate meter commonly used with Geiger counters is not suitable for indicating pulse repetition frequency when the P.R.F. *is changing rapidly and the indication is required to follow the variations accurately. Its limitations are serious in neurophysiological applications. An instrument is described which measures each pulse interval and provides an output voltage which is a linear function of the reciprocal of interval duration. The output voltage of the instrument at any instant is determined either by the duration of the preceding pulse interval, or by the duration which the current interval has already attained, whichever is the longer. In this way the instrument gives a continuous indication of* P.R.F. *and responds to a change as rapidly as is physically possible.*

PULSE repetition frequency (P.R.F.) can be indicated continuously by a counting-rate meter of the type frequently used in conjunction with Geiger counters. Circuit techniques used in such meters have been reviewed by Smith[1]. For some purposes, however, such meters are not satisfactory, for they incorporate an integrating circuit whose time-constant is long compared with the durations of the intervals between pulses. They are therefore sluggish in their response to any change in P.R.F. which occurs in a time which is not extremely long compared with the pulse intervals.

In studying the discharges in nerve-fibres it is convenient to have an instrument which indicates and records the P.R.F. continuously. In this application the limitations of the counting-rate meter are serious, for the P.R.F. may be quite low and may change abruptly. We have therefore developed an instrument for indicating P.R.F. which responds immediately to a change in P.R.F. and yet gives a smooth output when the P.R.F. is steady.

Messages are conveyed in nerves in the form of a succession of "impulses". Each impulse consists of a cycle of activity lasting about 1 millisecond. It is accompanied by an electrical disturbance which can be detected through suitable electrodes and recorded. The impulses travel along the nerve-fibres at a velocity of a few metres per second. The interpretation by one part of the body of a message carried by a nerve from another part depends on the arrival of impulses, on which nerve-fibres carry the impulses, and on how rapidly successive impulses follow one another.

A portion of a typical oscillograph record of impulses in a nerve-fibre is shown in Fig. 1. This particular record was obtained from the nerve serving a sense-organ in the knee-joint of a cat. This sense-organ generates nerve-impulses at a repetition frequency which has been found to depend on the angular position of the joint[2]. The second trace in this record is used to indicate the angle of the joint; the sloping portion of this trace shows that the joint was moved during this part of the record. The change in P.R.F. is clearly shown.

Most sense-organs which have been studied give rise to discharges of nerve impulses in a somewhat similar fashion. One difference between sense-organs which is of interest lies in the differing way in which the P.R.F. of the discharge changes with changing conditions of stimulation of the sense-organ.

The instrument to be described has been developed to facilitate the analysis of such changes in P.R.F. in the discharges from sense-organs and for studying discharges in other nerves. It may also prove to have applications in other fields.

The frequency range covered by the instrument is from zero to 100 pulses/second, which is sufficient for most neurophysiological applications. No serious difficulty is anticipated in building a similar instrument to cover a greater range.

Principle of Operation

Each interval between pulses is measured electronically and determines an output voltage. The output voltage is an approximately linear function of the reciprocal of the interval duration. Hence an oscilloscope or moving-coil meter connected to the output of the pulse-interval meter gives an indication of frequency on an approximately linear scale.

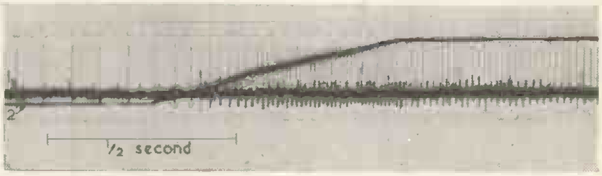


Fig. 1. Oscillograph record of impulses in a nerve-fibre coming from a sense-organ in the knee-joint of a cat. *Trace 1 shows the impulses. Trace 2 is a simultaneous record of the angular position of the joint. The sloping portion indicates that the joint is being moved at this stage in the record*

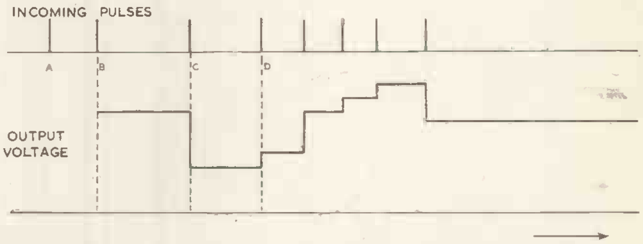


Fig. 2. Incoming pulses and resulting output voltage where the output voltage at any instant is determined by the duration of the previous pulse-interval

The series of output voltages determined by successive intervals has to be combined to give a continuous indication of frequency. A way in which this might have been done is illustrated in Fig. 2. The instrument could have been designed so that the output voltage determined by each interval was given as output during the succeeding interval. In Fig. 2 the interval AB is short and therefore corresponds to a high frequency; hence the output voltage is high during the interval BC. The interval BC is longer and corresponds to a lower frequency, so the output voltage is lower during CD, and so on. This mode of operation may be described by saying that the output at any instant is determined by the duration of the preceding pulse interval.

A serious disadvantage of an instrument operating as

* *Institute of Physiology, University of Glasgow.*

described above would be that if the P.R.F. fell to zero the instrument would not give an indication of zero frequency, but would continue indefinitely to indicate the frequency corresponding to the duration of the interval between the last two pulses. This property is illustrated at the right-hand end of Fig. 2.

The mode of operation actually employed is slightly different. The output voltage at any instant is determined either by the duration of the preceding pulse-interval or by the duration which the current interval has already attained; whichever is the longer. This mode of operation is illustrated in Fig. 3. When the P.R.F. becomes zero the output voltage falls asymptotically towards the value corresponding to zero frequency.

Definition of Frequency

When pulses are occurring somewhat irregularly, the most practical definition of frequency appears to be as the reciprocal of the interval between two successive pulses. Using this definition, the instrument responds to a change in frequency as rapidly as is physically possible. If an interval is shorter than the preceding one the higher value for the frequency is indicated as soon as the interval is completed. If an interval is longer than the preceding one the instrument does not wait until the end of the interval before indicating a reduction in frequency. For instance, in Fig. 3 the indication begins to fall away at B′, where BB′ = AB.

Arrangement of the Instrument

Fig. 4 shows a block diagram of the instrument, with associated waveforms. The incoming pulses are applied to an amplitude discriminator, which is triggered only by pulses of greater than a certain amplitude. Pulses from the discriminator then reach a gate circuit, which is closed to further pulses for a time after a pulse has passed through. The moment of reopening of the gate is controlled from further on in the circuit. Its purpose will be discussed later.

The timing of the pulse intervals is done by two timing units which come into play alternately. To produce the alternate operation, pulses which come through the gate are made to operate a "changeover circuit" which consists of an Eccles-Jordan trigger circuit or bistable multivibrator[3,4]. Of the two outputs which are taken from this circuit one is always positive and one negative, and they change over every time a pulse comes through the gate.

Each timing unit has two possible states during any pulse-interval; it may operate to "measure" the pulse-interval or it may hold the capacitor charge which represents a measure of the duration of the previous interval. During each interval a capacitor is charged in whichever timing unit is operative, and the voltage which it reaches depends on the duration of the interval. The capacitor is charged in such a way that, except during the first 1/100sec of the interval, the voltage at any instant differs from a certain fixed voltage by an amount which is inversely proportional to the time which has elapsed since the start of the interval. Thus if V is the voltage reached, and the last pulse occurred at time $t = 0$:

$$V_0 - V = k/t \text{ for } t > 1/100 \quad \text{.......} \quad (1)$$

where k and V_0 are constants.

It is clear that the charging process cannot conform to equation (1) from $t = 0$, for when $t = 0$, V would have to take the value of minus infinity. Instead, the capacitor is not allowed to start charging until a time of just over 7msec has elapsed since the occurrence of a pulse. For values of t greater than 10msec the charging process conforms to equation (1).

The delay of approximately 7msec is adjusted to the correct value by a procedure which will be described. The delay is introduced by the two circuits termed "delay phantastron" and "resetter phantastron," of which the delay phantastron introduces about 1msec delay and the resetter phantastron the remainder.

Each timing unit includes a means of charging its capacitor in the manner described and also a means of discharging it. The timing units are connected to the changeover circuit in such a way that charging and discharging can occur only in that timing unit which is currently operative in measuring a pulse-interval. Furthermore, discharging can occur only while the resetter phantastron is in its quasi-stable state.

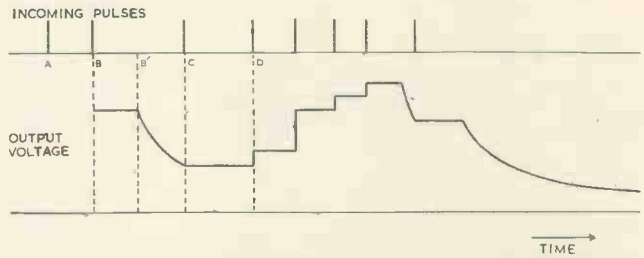


Fig. 3. Incoming pulses and resulting output voltage of the pulse-interval meter

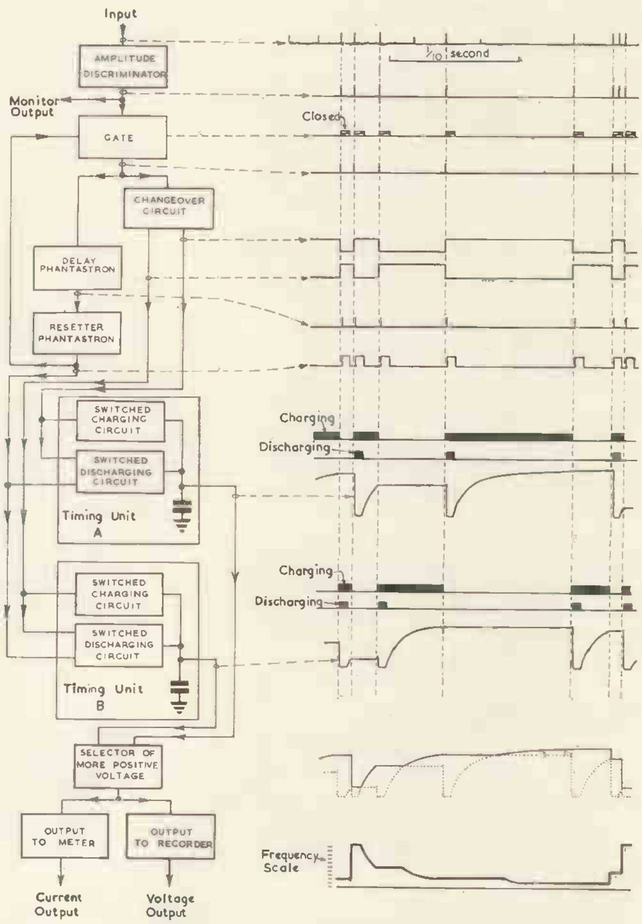


Fig. 4. Block diagram with associated waveforms

The cycle of operations in the timing units may be seen from the waveforms of Fig. 4. At the occurrence of a pulse, that timing unit which was previously in the "holding" state changes over. Charging of the capacitor commences, but only proceeds for 1msec before the resetter phantastron is flipped and discharging takes place. The capacitor is held discharged until the resetter phantastron flops and the capacitor is then charged as described above. The initial rise of voltage during the 1msec delay time is an undesired effect, but it is not serious as the rise is slight.

When the timing unit changes over to the "holding" state, charging of the capacitor ceases, and the capacitor neither gains nor loses charge during the next pulse interval.

The voltages developed across the capacitors of the timing units are combined to give the output voltage of the instrument by the circuit termed "selector of more positive voltage". This arrangement gives the mode of operation illustrated in Fig. 3. Had it been desired to make an instrument operating as illustrated in Fig. 2, the selector of more positive voltage would have been replaced by an electronic switch so arranged that the output voltage was derived from whichever of the timing units was in the "holding" state. The output voltage of the selector of more positive voltage is effectively the output voltage of the instrument.

The output voltage becomes more positive with increasing interval-duration and hence more negative with increasing frequency. The inverted waveform at the foot of Fig. 4, where the frequency-scale increases in an upward direction, does not occur in the instrument, but the output is normally connected to a pen-recorder amplifier in such a way that an increase in pulse-frequency causes upward deflexion of the pen.

Purpose of Delay Phantastron

The delay phantastron is included for two reasons. It is necessary that the changeover circuit should have changed over before the discharging process is initiated by the resetter phantastron, otherwise the wrong timing capacitor may be partially discharged. The inclusion of the delay phantastron ensures that the changeover definitely precedes the discharging.

The second reason for including the delay phantastron is that it and the gate ensure that the resetter phantastron can never under any circumstances be triggered until at least 1msec has elapsed since it flopped to its stable state after the previous operation. The gate does not open, and hence the delay phantastron cannot be triggered, until the resetter phantastron returns to its stable state. The phantastron, like all trigger circuits, requires a certain recovery time between operations. If it is not given sufficient time in which to recover, the duration of its stay in the quasi-stable state is reduced.

Purpose of the Gate

The gate ensures that neither the delay phantastron nor the resetter phantastron is re-triggered until it has had an adequate recovery time. The arrangement is such that these two phantastrons are triggered alternately, and each always has a recovery time which is at least equal to the duration of the quasi-stable state of the other. The gate also ensures that only those pulses which are effective in triggering the two phantastrons get through to the changeover circuit.

The gate has no effect on the operation of the instrument except when two incoming pulses are separated by less than about 7msec. If the gate were not included it would be difficult to predict the response of the instrument under these conditions, because the phantastrons might be triggered after an insufficient recovery time, and the changeover circuit might be changed over although the resetter phantastron was not ready for re-triggering. With the arrangement used, the second pulse is rejected by the gate, and an overload of the instrument by too high an input frequency leads simply to frequency division, which starts to occur at about 140p/s. An input frequency of 150p/s leads to an output voltage corresponding to 75p/s.

Circuit Details

The complete circuit is shown in Figs. 5, 6 and 8.

Amplitude Discriminator

The incoming pulses are amplified by V_1, the anode of which is connected through an *RC* coupling to the grid of the cathode-follower V_{2a}. The cathode of V_{2a} goes to V_3, which is connected as a Schmitt trigger circuit, or cathode-coupled bistable multivibrator.[4] This acts as a squaring circuit whose output is differentiated, and the resulting negative pulses are applied to V_{2b} and to V_5, which is part of the gate circuit.

When the polarity selector switch is in the positive pulse position, the grid leak R_1 is taken to a standing voltage such that the mean potential of V_{2a} cathode is more positive than the critical voltage range of the Schmitt trigger. Thus to operate the Schmitt trigger, a negative pulse is required at the anode of V_1. With the switch in this position, therefore, the instrument responds to positive pulses at the grid of V_1. Conversely, when the polarity selector switch is in the negative pulse position, the grid leak R_2 is taken to a standing voltage such that the mean potential of V_{2a} cathode is more negative than the critical voltage range of the Schmitt trigger. The instrument then responds to negative pulses at the grid of V_1. The central test position of the polarity selector switch is only used when adjusting the preset variable resistor VR_1, as described later.

The cathode-follower V_{2a} is included to ensure that the coupling capacitor does not receive charge when V_{3a} passes grid current. R_3 is included to limit the grid current of V_{3a}, since without this stopper resistor the grid current can be so large as to interfere with the action of the Schmitt trigger. The speeding-up capacitor C_1 is of a very small value, for with larger values the Schmitt trigger circuit can go into oscillation when V_{3a} grid voltage falls in a certain range. This oscillation would not matter if the input always consisted of short pulses, but it could be troublesome when calibrating with a low-frequency sinusoidal input.

The "accepted pulses" from the amplitude discriminator go through the cathode-follower V_{2b} to the monitor output. This is usually connected to a headphone or through an amplifier to a loudspeaker, and it is then useful when adjusting the gain control so that the Schmitt trigger is triggered only by the wanted pulses.

Gate

The gate is required to remain closed, after a pulse has passed through it, until the resetter phantastron flops from its quasi-stable state back to its stable state. The gate circuit includes V_5, V_6 and V_7. V_5 and V_7 form a flip-flop or monostable multivibrator in which V_5 is normally conducting and V_7 normally cut off. A negative pulse applied to g_3 of V_5 flips the circuit to the quasi-stable state wherein V_7 conducts and V_5 is cut off. Differentiating circuits are connected to anode and screen of V_7, so the commencement of current in V_7 gives rise to negative output pulses which trigger the delay phantastron and the changeover circuit. While the gate circuit remains in its quasi-stable state no further pulses can come from it; the gate is closed. After a millisecond the resetter phantastron is flipped to its quasi-stable state and V_6 starts to conduct. The voltage drop across the common anode load of V_5 and V_6 cuts off V_7. V_7 cannot conduct until the resetter phantastron flops back to its stable state. As soon as the resetter phantastron flops back, V_6 becomes cut off and the gate is immediately ready to respond to the next incoming pulse from the amplitude discriminator.

The time-constant R_4C_2 plays no part in timing the above cycle of events, for the monostable multivibrator formed by V_5 and V_7 is not allowed to flop to its stable state of its own accord. It is made to return to it when V_6 conducts. The circuit would work if R_4 and C_2 were replaced by a direct coupling, so that V_5 and V_7 formed a bistable multivibrator. With the bistable arrangement, however, the circuit might, on switching on, go into the state where V_7 conducts and V_5 is cut off, and it would remain that way indefinitely, with no pulses passing through the gate. The monostable circuit is therefore preferred.

Delay and Resetter Phantastrons

Miller-transitron circuits, or monostable screen-coupled phantastrons[5] have been used, because this type of circuit

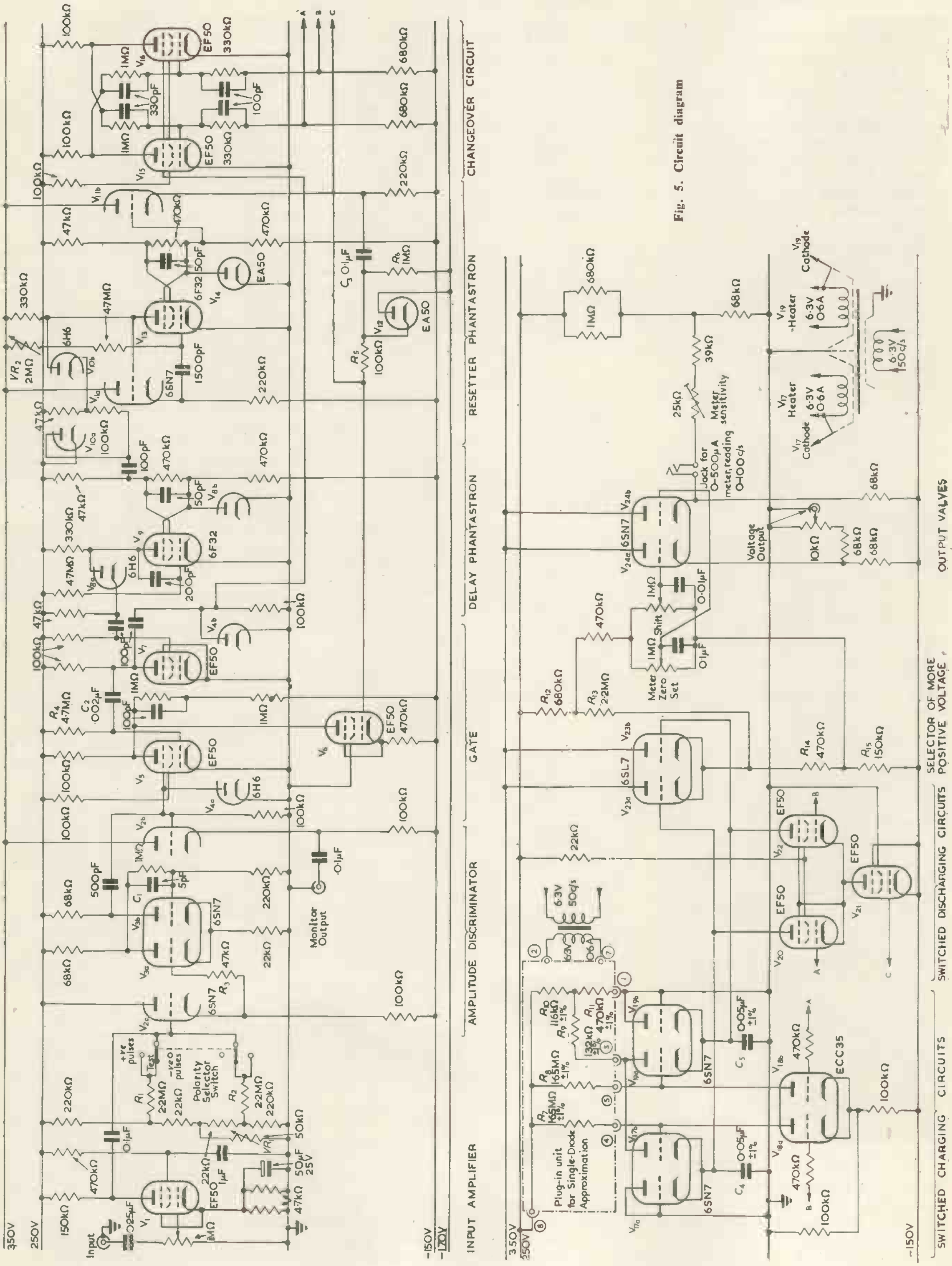


Fig. 5. Circuit diagram

is noted for the stability of its timing. The delay phantastron is triggered by a negative pulse applied through V_{8a}, and the delayed negative output pulse is obtained by differentiating the waveform at the screen of V_9. The arrangement of two diodes V_{10a} and V_{10b} is needed to eliminate the positive pulse produced when the phantastron is triggered.

The negative pulse from the delay phantastron triggers the resetter phantastron V_{13}. The duration of the quasi-stable state of the resetter is adjustable by the preset resistor VR_2. A cathode-follower V_{11a} is incorporated to ensure that the resetter is ready for re-triggering after a short recovery time (see reference 5). This refinement is not needed in the delay phantastron, where the recovery is always several times the duration of the quasi-stable state.

The waveform on the suppressor of V_{13} is a positive-going rectangle. It is coupled to the grids of V_6 and V_{21}, so that these valves, which are normally cut off, conduct during the quasi-stable state of the resetter. The waveform at the suppressor is preferred to that at the screen because it has a flatter top, being clipped by V_{14}. The cathode-follower V_{11b} is inserted to isolate V_{13} from effects of current in V_{12} or grid current in V_6 and V_{21}. C_3 and R_6 couple the cathode of V_{11b} to the grids of V_6 and V_{21}. V_{12} acts as a D.C. restorer and R_5 is included to limit grid current in V_6 and V_{21}.

Changeover Circuit

This has two stable states, one with V_{15} conducting and V_{16} cut off, and the other with V_{15} cut off and V_{16} conducting. The application of a short negative pulse to the suppressors causes the circuit to change from whichever state it is in to the other. The mechanism of the changeover is fully described by Puckle[3]. The two outputs of the circuit are labelled A and B. When V_{15} conducts and V_{16} is cut off, A is positive and B negative with respect to their mean potential, and *vice versa* when V_{15} is cut off and V_{16} conducts.

Timing Units

The two timing units are not, in fact, completely independent as shown in the block diagram (Fig. 4). The two capacitors are C_4 and C_5. Consider first the charging and discharging of C_4. It is charged by the combined anode and grid currents of V_{17b}. The charging occurs only when V_{18a} is cut off, for when V_{18a} conducts, V_{17b} is cut off. C_4 is discharged when V_{20} and V_{21} conduct, and then V_{17a} connected as a diode, prevents the live side of the capacitor from being taken below earth potential.

When A is positive and B negative, the left-hand timing unit (incorporating C_4) is operative in "measuring" a pulse-interval, for V_{17b} is conducting, and V_{20} is also ready to conduct during the time when V_{21} conducts. The right-hand timing unit is then holding the charge on C_5, for V_{19a} and V_{22} are both non-conducting. When B is positive and A negative the conditions are reversed.

The instrument is designed to indicate frequency on an approximately linear scale over the range 0 to 100p/s. It is therefore necessary that the voltage of the capacitor in the operative timing unit should conform closely to equation (1) after the first 1/100sec of the interval. In the practical instrument $V_0 = 250$ volts, for the capacitor charges towards the 250 volt H.T. line. The circuit is so designed and adjusted (by adjustment of VR_3) that when $t = 1/100$sec, $V = 50$ volts. Thus equation (1) becomes:

$$250 - V = 2/t \qquad (2)$$

and the charging process must approximate to this for $t > 1/100$.

A rough approximation to the required charging law can be made by using the circuit of Fig. 7(a). When the switch S is opened the capacitor will be charged through both R_7 and R_9, until the voltage across it reaches a value V_c given by:

$$V_c = V_0 R_{11}/(R_{10} + R_{11}) \qquad (3)$$

Once this voltage is reached, no more charge is received through R_9, and the capacitor is charged only through R_7. The charging curve is made up of two exponential curves, one of which is followed from $V = 0$ to $V = V_c$, and the other from $V = V_c$ to $V = V_0$. By a suitable choice of resistance values, the composite curve can be made to approximate the curve represented by equation (2), (see Appendix A). The timing units of the pulse-interval meter

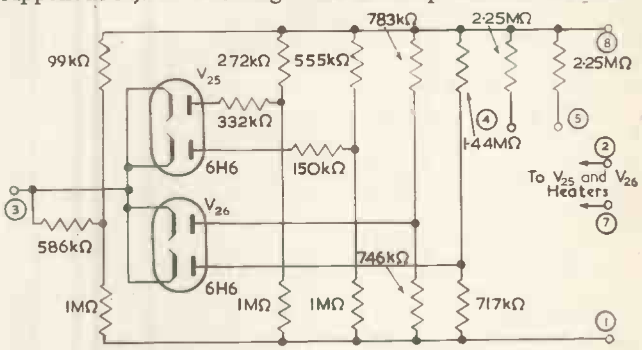


Fig. 6. Plug-in unit for the 5-diode approximation to the required charging law. *All resistance values are plus or minus 1 per cent*

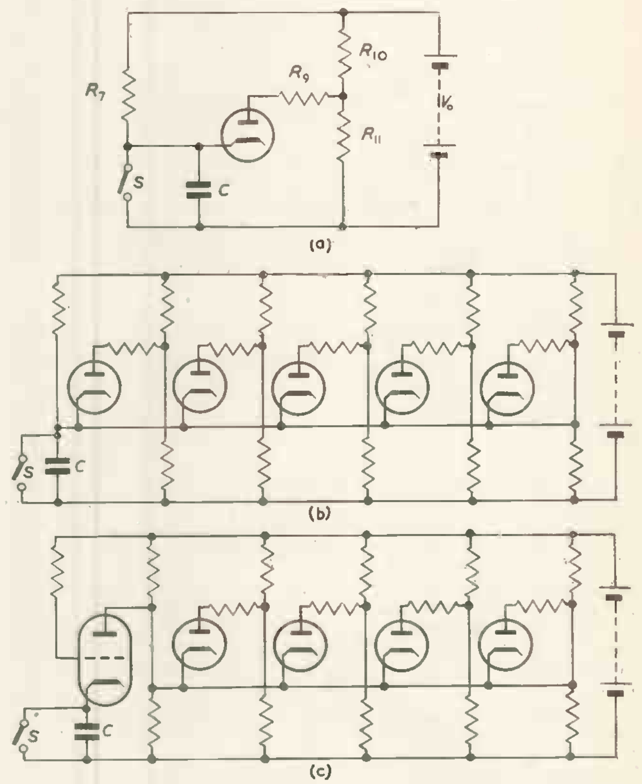


Fig. 7(a). Circuit giving single-diode approximation to the required charging law
(b) Circuit giving 5-diode approximation
(c) Practical circuit giving 5-diode approximation

incorporate an arrangement which is effectively that of Fig. 7(a). In the left-hand timing unit the triode V_{17b} takes the place of the diode in Fig. 7(a). Resistors R_9, R_{10} and R_{11} are common to the two timing units. R_7, instead of being connected directly to the capacitor, goes to the grid of V_{17b}.

The arrangement shown in Fig. 5 and operating as described above gives what is termed a single-diode approximation to the required charging law. A closer approximation can be obtained by using more diodes, as shown in Fig. 7(b), with resistance values chosen so that the diode currents are successively cut off at different voltages. A practical circuit for our purpose is shown in Fig. 7(c) and is considered in greater detail in Appendix B. The plug-in unit shown in Fig. 5 can be replaced by the more complex unit shown in Fig. 6, to give a five-diode approximation to the required law.

The pulse-interval meter is normally operated with this more complex plug-in unit. The relationship between output voltage and applied pulse-frequency is then very nearly linear. The simpler plug-in unit is shown in Fig. 5 for simplicity, and also because its closeness of approximation to the required law is remarkably good, considering its simplicity. (See Figs. 14(a) and 14(b)).

Alternative plug-in units can be devised to give non-linear frequency scales, if required. (See Appendix C).

SELECTOR OF MORE POSITIVE VOLTAGE

This consists of the two cathode-follower valves V_{23a} and V_{23b} with a common cathode resistor. The cathode potential is determined almost entirely by the more positive grid. When the difference in grid potentials is more than a few volts, the more negative grid has no effect whatever, since the valve to which it belongs is cut off. When the grid potentials are closer the more negative one has some effect, but it can only alter the cathode potential by a fraction of a volt at the most.

OUTPUT STAGES

The voltage variations at V_{23} cathode constitute the output of the instrument. A fraction of the variation is tapped off at the junction of R_{12} and R_{13}, and the same fraction at R_{14}-R_{15} junction, so that shift controls can be introduced. The shift control for the current output is termed " meter zero set " and is used for that purpose.

V_{24a} and V_{24b} are cathode-follower output valves for the voltage and current outputs respectively. The current output is of suitable magnitude for connexion to a 0 to 500μA meter. The excursion of output voltage for the frequency range of 0 to 100p/s, with the output voltage control turned right up, is just over 6 volts, and it can be adjusted to swing equal amounts positive and negative with respect to earth.

REFERENCES

1. SMITH G. D. Counting-rate Meters. *Electronic Engng. 24*, 14](1952).
2. BOYD, I. A., ROBERTS, T. D. M. Proprioceptive Discharges from Stretch-Receptors in the Knee-Joint of the Cat. *J. Physiology 122*, 38 (1953).
3. PUCKLE, O. S. Time Bases, 2nd Ed., p. 76 (London, Chapman & Hall Ltd., 1952).
4. CHANCE, B., HUGHES, V. W., MACNICHOL, E. F., SAYRE, D., WILLIAMS, F. C. Waveforms p. 164. (New York, McGraw-Hill Book Co., Inc., 1949).
5. CHANCE, B. *et al.* Waveforms, p. 197.

(To be continued)

New G.E.C. Laboratories for Semiconductor Research and Development

A NEW two-storey extension has recently been added to the General Electric Company's research laboratories and will be given over to semiconductor research and development. Future plans provide for still further expansion in this field of research. A brief outline of the work on which the various departments are engaged is given below.

Basic Research in Solid Physics

Known semiconductors such as germanium and silicon have physical properties (such as energy gap and charge carrier mobilities) which are not ideally balanced for use in some devices. It is possible to envisage materials with more desirable properties and which would be neither so rare nor difficult to prepare as the semiconductors used at present. The laboratories are making and investigating the properties of such materials, including a new group of compounds with a crystal structure closely related to that of silicon and germanium. Known as chalcopyrite type materials, they have already been shown to possess interesting semiconducting properties. For example, copper indium selenide ($CuInSe_2$) has shown point contact rectification with peak inverse voltages of about 400 volts.

The second purpose of research into new materials is to give greater insight into the physical properties of semiconductors. This field is relatively undeveloped but already many unusual effects, thermal, optical and magnetic, as well as electrical, have been discovered. An investigation into the thermo-electric effects in semiconductors is just one part of a programme to elucidate some of these unusual properties. The magnitude of the effect is, however, very small if conventional metals are used. Some semiconductors show a far more favourable combination of properties and it was possible to choose, out of the large number recently prepared, the particular material which would be expected on theoretical grounds to give the best performance. The junction of the metal bismuth and the new semiconductor bismuth telluride can be used to produce a temperature difference of 26°C, and work on other materials is proceeding with a view to obtaining even greater effects.

Fundamental studies have shown that a knowledge of the bulk properties is not sufficient for solving application problems. Every specimen is necessarily limited by a surface which, in an actual device, may be exposed to atmosphere or joined to another surface. The phenomena occurring at the surface of a semiconductor are in fact radically different from those in the bulk material. Even with silicon and germanium, the present understanding of the surface phenomena is incomplete, and this is even truer of the new semiconductors.

The effect of various surface treatments on the electrical properties of these materials is being studied. For example, the bombardment of a silicon surface with ions of various gases accelerated by an applied potential of 30 000 volts produces a drastic change in the electrical properties. A comparison between the current-voltage characteristics of the treated and untreated materials shows that the ion bombardment produces a permanent improvement in the rectifying effect.

Semiconductor Materials

The problems concerned in the preparation of suitable semiconductor materials can perhaps best be illustrated by reference to germanium. The material used by British manufacturers of crystal valves is obtained from the dust and soot which collects in the flues of gas-works, particularly where coals from Northumberland and Durham are used. The G.E.C. research laboratories carried out an extensive search for an indigenous source of germanium several years ago and as a result a substantial annual tonnage of germanium-bearing flue-dust is now available. The semiconductor, once so rare as to be considered a chemical curiosity, is usually present at 0·5-1·0 per cent by weight in the better flue-dusts and can now be obtained in quantities of the order of hundredweights.

After its extraction from the flue-dust, germanium is given elaborate chemical purification and is supplied to the laboratories as germanium dioxide, which is then reduced by high temperature treatment with hydrogen. The metal thus obtained is fused and cast into an ingot, which has about one part of impurity to every 10 million parts of germanium. Although very pure by chemical standards, this is still almost a hundred times as impure as required for semiconductor devices.

The necessary further purification is accomplished by means of a directional freezing technique known as zone refining. Only a small region of the ingot is melted at any one time, but the heat source is moved so that the molten zone also moves and slowly traverses the length of the bar. During the process impurities, when at the junction of liquid and solid, are concentrating preferentially in the liquid zone. By repeatedly traversing the bar, therefore, the impurities are ultimately swept to one end of the ingot, which is then sawn off.

Having obtained germanium of suitable purity, it then becomes necessary to prepare it in the form of a single crystal so as to give the required electrical properties. The metal is again melted, this time in a crucible, and a minute controlled amount of the element which determines the electrical properties is added. A small "seed" of monocrystalline germanium is dipped into the molten mixture and, with very precise temperature control, the germanium begins to deposit in solid form on the "seed". By withdrawing the growing crystal at a predetermined rate, the entire contents of the crucible can be made to solidify in the form of a monocrystalline ingot.

Semiconductor Devices

With the materials available, the device designer has to develop new circuit elements that will meet the needs of industry. The early work on the design and production of point contact silicon crystal diodes for high-frequency mixer work is well known. Now, after a period in which the main emphasis has been on germanium devices, attention is again being focused on the use of silicon. Preliminary studies have indicated that silicon p-n junction diodes have several useful characteristics including the ability to operate at considerably higher ambient temperatures than their germanium counterparts, very low inverse currents and a large rectification ratio between forward and reverse currents. To prepare silicon p-n junctions donor and acceptor type electrodes are attached to a homogeneous silicon crystal of either type by heating the crystal and then bringing it into contact with metals to which it will alloy. A junction with p-type silicon, for instance, is made with a donor metal or an alloy containing a donor element such as antimony, phosphorus or arsenic. The junction is grown by deposition from the molten alloy when cooled and is situated between the unmelted silicon and the metal solid solution. An ohmic or base contact can be formed in the same way except that, on p-type silicon for example, an acceptor element such as aluminium or indium is used. By careful control of the heating and cooling cycle, and the selection of suitable metals and alloys, both the junction and the base contact can be formed simultaneously.

Purification of germanium by zone refining. The germanium ingot is placed in a graphite crucible and the zone is melted by eddy current heating

In one of the techniques being used, a gold-antimony alloy wire forms a p-n junction on p-type silicon and an aluminium wire provides the base contact. With n-type silicon these roles would be reversed, but no changes would be required in the manufacturing technique.

One of the rectifiers now being developed has a fairly massive copper base to remove heat dissipated in the device. When the p-n junction has been made, an enclosing copper cap is hermetically sealed to this base by a cold pressure welding technique. The success of this sealing method is such that these units have withstood long periods of storage under severe "jungle" conditions without change of characteristics.

Typical characteristics of one of the present designs of rectifier are 10A at 0·5V, and 1mA at −30V and 10mA at −160V.

Semiconductor Electronics

The main uses of the present semiconductor devices are in electronic equipments where small size, light weight, long life, ruggedness, reliability and low power consumption are important considerations. Much work is therefore being done in the design of suitable circuits for use with crystal valves and on the determination of the basic principles of their operation.

Crystal valves are at present limited in their range of application by their maximum frequency of operation and their power output, readily available types being usable only up to frequencies of about 500kc/s with output powers of a fraction of a watt. These limits are, however, being rapidly extended by improvements in design and the development of new types. Experimental types have already been established which are capable of operating up to 10 or 20Mc/s as amplifiers and up to 100Mc/s as oscillators, while others working in the audio frequency range are capable of giving several watts output.

The most immediate and most significant of applications for crystal valves are likely to fall in the telecommunications field, where their special properties provide the solutions to existing problems in equipment design and open up quite new possibilities for the future. For example, crystal valves are likely in future to be found at many points in telephone

This weather-dependent alarm clock is being developed as an illustration of the uses to which semi-conductor devices can be put. It incorporates a light-sensitive germanium junction photocell with two point-contact transistors as amplifiers. The alarm sounds only if a pre-set brightness level is obtained.

systems; in exchanges, repeaters and subscribers' equipment. Many of the circuit problems involved are common also to computors and calculating machines, so that the establishment of a sound design for the elementary "bricks" of the system will lay a foundation for a far wider range of application.

As far as domestic radio and television receivers are concerned, the earliest use of crystal valves is likely to be in personal or small portable radio receivers, which will give performances equal to present valve receivers but will require only 1/10th the power.

At the present state of development the study of device application falls naturally into three stages:—

(a) The measurement and study of the characteristics of devices under development in order to provide detailed information and specifications to users.

(b) The study of the basic problems inherent in designing electric circuits round the devices.

(c) The application of the devices to actual equipment problems.

Differential Width Control for Television Line Scanning Circuits

By K. G. Beauchamp*, A.M.Brit.I.R.E.

Methods of width control in television receiver scanning circuits are discussed and design techniques evolved for a differential type of width control. Particular consideration is given to reduction of the variation in E.H.T. *developed by the scanning circuit as the picture width is varied. The causes of these variations are investigated and means suggested for overcoming them.*

THE literature appertaining to television line scanning circuits is fairly extensive and in particular the mode and theory of operation of resonant return or efficiency diode circuits has been fully dealt with elsewhere[1,2,3,4]. However, as far as the author is aware, no detailed attempts have been made to analyse the methods by which the amplitude of the sawtooth current waveform generated can be made to vary without at the same time unduly affecting the E.H.T., which, in the majority of domestic television receivers, is derived from the line scanning circuit.

Methods of Varying the Scan Amplitude

A typical line scanning circuit is shown in Fig. 1(a). Here V_1 with T_1 and associated circuits form a blocking oscillator supplying a positive-going sawtooth voltage to the grid of V_2. The amplitude of this waveform is such as to render V_2 non-conductive during almost half the total scanning period, while the efficiency diode V_3 is conducting. The action of these two valves can be loosely considered as a push-pull arrangement supplying a sawtooth of current to the scanning coils L_y via a coupling transformer T_2.

A high potential pulse voltage is present across the autotransformer during the retrace period and may be increased in value by an additional winding 5-6. The amplified pulse voltage may, after rectification by V_4, be applied to the cathode-ray tube anode terminal as accelerating potential (E.H.T.).

This is a simplified circuit with such components as grid stoppers, linearity controls, etc., omitted for clarity.

Study of this circuit will reveal a number of ways in which the sawtooth current, *i*, may be varied. Several of these are shown in Fig. 1(b) and will now be examined in the light of their effect on the magnitude of the voltage pulse (*v*), appearing at V_2 anode during the retrace period.

This potential has been given elsewhere[4] as:

$$v = e^{-0.83/Q_r} \; . \; I \; . \; \sqrt{(L/C)} \text{ volts} \quad \ldots\ldots\ldots\ldots \quad (1)$$

where:

Q_r = Q of resonant circuit during retrace period.

I = Maximum value of V_2 anode current.

L = Total inductance at anode of V_2.

C = Total capacitance at V_2 anode.

Any control of the input waveform supplied to V_2 grid by variation of C or R_1 will vary the pentode anode current and hence *v*. In addition, variation of the charging capacitor C, will have the undesirable effect of varying the operating frequency of the oscillator V_1. Similarly, variation of screen-grid potential by R_2 or cathode bias by R_3 (with or without negative feedback by choice of C_1 value) will affect V_2 anode current and hence peak potential *v*. Alteration of the H.T. supply by R_5 or boosted H.T. by R_4, will also exert control over I, but will have an advantage over the preceding four methods in that the linearity of the scanning waveform is less likely to be affected with changes of picture width.

All the preceding methods, however, give a poor ratio of scan variation to E.H.T. change, as reference to equation

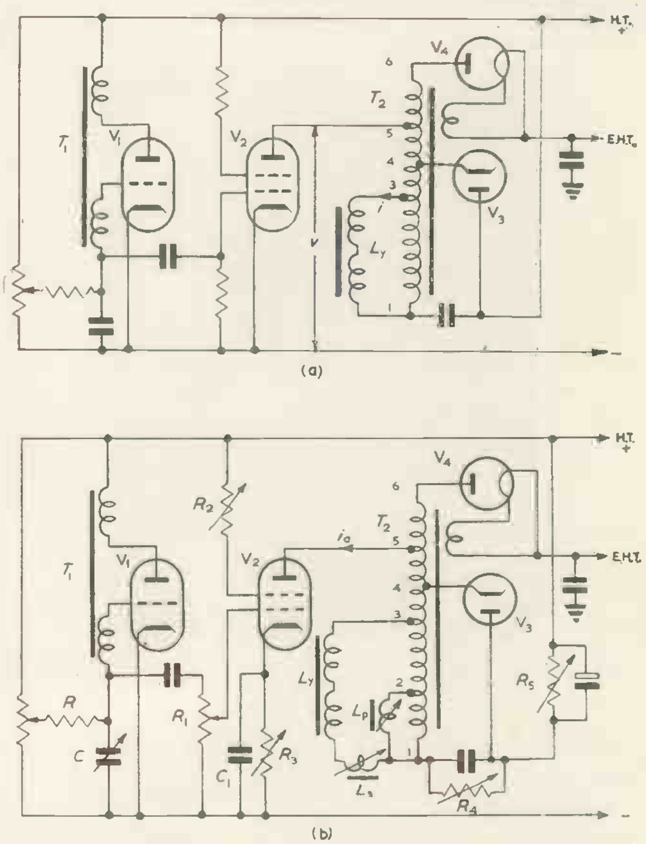


Fig. 1(a). Simplified line scanning circuit. (b) As (a) with possible width controls added

(1) will show the E.H.T. changes linearly with change of peak anode current I.

An improved method is to vary the matching of the scanning coils L_y to that of the output valve V_2. This can be achieved by either a series inductance L_s, or an inductance L_p in parallel with part of the transformer winding.

Both these methods can be shown to be equivalent to variation of L_y and hence the total inductance L of equation (1). The effect of the E.H.T. generated is, however, less as *v* is proportional to the square root of L. One disadvantage of varying L_y is that in doing so the transformer efficiency may be considerably reduced. An expression for

* *G.E.C. Development Laboratories, Coventry.*

this is given by Friend[1] in terms of deflexion factor F_d:

$$F_d = \frac{k}{1 + L_y/L_{1-3}}$$

$$= \frac{\text{Yoke ampere-turns for a practical transformer}}{\text{Yoke ampere-turns for an ideal transformer}} \quad \ldots\ldots\ldots\ldots (2)$$

where L_{1-3} = Inductance of transformer scanning coil winding 1-3.

k = Transformer coupling factor.

Reduction in transformer efficiency due to this cause results in an increase in i_a and anode dissipation for V_2, both of which limit the maximum power that may be safely handled by this valve.

It is possible, however, to use a combination of the two inductive methods of scan control by arranging that as L_s is increased in value, so L_p is decreased; the rates of inductance change in both cases being such that the total inductance across the transformer windings 1-3 remains constant. Thus only the sensitivity of the scanning coils is affected, allowing L in equation (1) to remain constant.

This method is known as the differential method of width control and the remainder of this article will deal with the calculation and design of suitable systems of this type and an evaluation of their relative performance.

Criterion of Performance

In assessing the performance of a width control system one is interested in obtaining an adequate variation of picture width to compensate for changes occuring both during the life of the receiver, and by the manufacturer, to cover expected production tolerances. A figure of ±10 per cent variation about the mean scan width is generally desirable and should give sufficient compensation. Also, as has been previously mentioned, as little variation of E.H.T. as possible is required during the adjustment of picture width.

Consequently one can establish a figure of merit for a width control system as:

$$K = \frac{\text{Maximum change of scan width}}{\text{Minimum change of E.H.T.}} \quad \ldots\ldots (3)$$

It is also desirable that K remain constant throughout the entire range of the control.

Obtaining Maximum Change of Scan Width

The simplest arrangement for the width coils is to use a long solenoid through which passes an adjustable core. An approximate inductance formula for such a coil is given as:

$$L = \frac{4\pi n^2 A \mu}{10^9 l} \text{ Henries} \quad \ldots\ldots\ldots\ldots (4)$$

where A = cross-sectional area of coil, cm²

l = length of coil, cm

μ = permeability of core.

Therefore a long solenoid of small cross-sectional area is necessary with an adjustable core of high permeability material. In practice it will be found that the coil length will be controlled by the length of the core chosen; no advantage being derived from using a coil of greater length than the core.

A suitable diameter for the coils used lies around 0·25in. This enables a long coil of suitable inductance to be wound and readily available core materials used.

Using two such solenoids L_p L_s wound on the same former as shown in Fig. 2 it is possible, by movement of core C, to arrange that their inductances will have the inverse relationship required in a differential width system.

Choice of Core Material

The factor mainly required from the core material used is high incremental permeability at the band of frequencies associated with the line scanning circuit (approximately 10 to 100kc/s). As will be seen later, eddy current and hysteresis losses play some part in the performance of the width coil as it is desirable to keep the Q of the coil relatively constant.

Three types of core material appear possible:

(1) A laminated silicon iron core (i.e. a bundle of iron wires bonded together with an insulating medium).

(2) An Iron-dust core.

(3) A Ferrite core.

The core losses with the laminated iron at the frequencies involved render it unattractive for this purpose and a practical choice lies between iron-dust and ferrite core materials.

Due to the small size of the dust-iron particles (< 50 microns diameter) and the relatively large mass of insulating medium surrounding them, incremental permeabilities of only about 4 to 6 are possible, although core losses are very small.

Using ferrite cores[5] the losses are negligible and due to its homogenous nature incremental permeabilities of 7 to 10 may be realized. Rods of ferrite material are available in extruded form and prove very useful for this application.

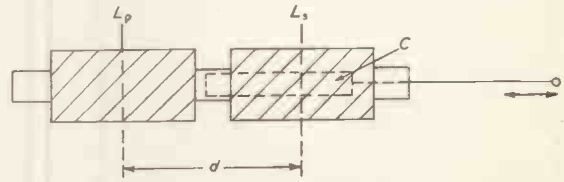


Fig. 2. Coil arrangement of a differential width system

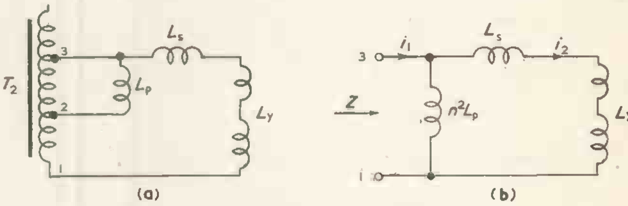


Fig. 3. Circuit arrangement

Design of a Differential System

The part of the line scanning circuit involving the width system is shown in Fig. 3(a). L_s is shown as the series section and L_p as the shunt section of the composite coil. The scanning coils are shown as L_y with the appropriate transformer connexions numbered to correspond with Fig. 1(a).

An equivalent circuit is shown in Fig. 3(b) where the shunt inductance is transformed across the scanning coil terminals 1-3. Thus the total inductance between these terminals is given as:

$$L_{1-3} = \frac{n^2 L_p (L_s + L_y)}{n^2 L_p + L_s + L_y} \quad \ldots\ldots\ldots\ldots (5)$$

Now L_{1-3} is required to remain constant with suitable changes of inductances L_p, L_s, as previously described. To simplify design of the line scanning circuit it is convenient to make L_{1-3} equal to the scanning coil inductance L_y. Then the inclusion of the width coils into the scanning coil circuit will have little effect on the overall performance.

Hence making $L_{1-3} = L_y$ in equation (5) gives:

$$L_p = L_y/n^2 + (L_y/n)^2 \cdot 1/L_s \quad \ldots\ldots\ldots\ldots (6)$$

Now with the coils adjusted for maximum picture width, (L_s a minimum and L_p a maximum) some fixed fraction of the scanning current will be absorbed by the system and before these values can be inserted into equation (6) it is necessary to decide how much attenuation is allowable in a given circuit.

An approximate calculation of this initial scan loss can be made from Fig. 3(b) which assumes an infinite Q for all coils involved. The assumption is also made that the scan width is proportional to the amplitude of sawtooth current through L_y. This is, however, permissible for the small changes of scan we are dealing with.

The percentage of the maximum scan possible to that obtainable in the "maximum width" position is given by:

$$\frac{\text{actual scan}}{\text{maximum scan}} \cdot 100 = i_2/i_1 \, . \, 100 = \frac{n^2 L_p' \, . \, 100}{n^2 L_p' + L_s' + L_y}$$

$$= \frac{100}{1 + (L_s' + L_y / n^2 L_p')} \text{ per cent} \qquad \ldots\ldots\ldots\ldots (7)$$

where L_p' = Maximum value of shunt inductance.
L_s' = Minimum value of series inductance.
and all inductance values in millihenries.

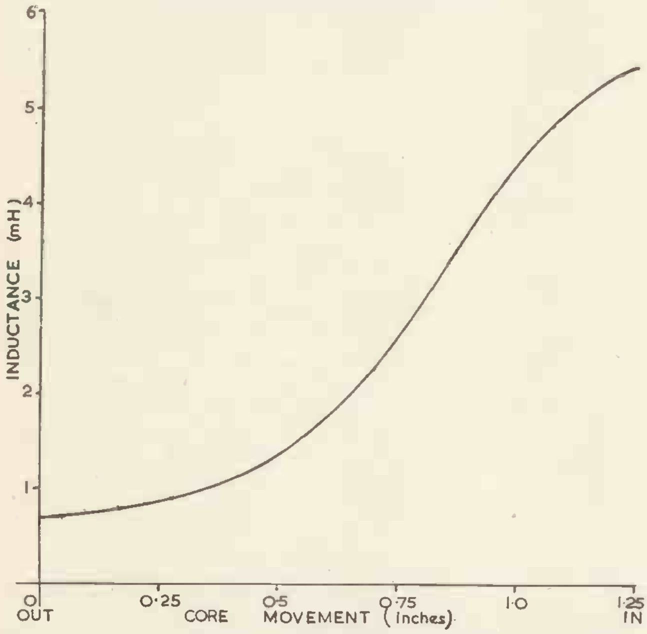


Fig. 4. Variation of inductance with core movement for a long solenoid

The position has now been reached where the design of a practical system can be commenced. An inductance figure for the line scanning coils which is rapidly becoming a standard for domestic television receivers is 10mH. Taking this figure for L_y and assuming a ratio of 10:1 for n, an initial figure for L_s' can be chosen, say 0·4mH, which may be substituted in equation (6) to give:

$$L_p' = 0{\cdot}1 + (1/0{\cdot}4) = 2{\cdot}6\text{mH}$$

and from (7):

$$\text{percentage of maximum scan} = \frac{100}{1 + 10{\cdot}4/260} = 96 \text{ per cent,}$$

i.e.: 4 per cent scan reduction.

Taking this figure, for the moment, as an acceptable one, these limit figures for L_s' and L_p' will be used to derive the minimum scan condition. Using a ferrite core an inductance change of around 8 should be obtainable, giving figures of 3·2mH for L_s (max) and 0·33mH for L_p (min), the greatest scan reduction of:

$$\text{percentage of maximum scan} = \frac{100}{1 + 13{\cdot}2/33}$$

$$= 100/1{\cdot}4 = 71{\cdot}5$$

i.e.: a total inductance change of $96 - 71{\cdot}5 = 24{\cdot}5$ per cent.

This means that if the line scanning circuit is designed to give full scan plus 16 per cent then the width system should give a control $\pm$ 12 per cent over the nominal picture width.

Determination of the Series and Shunt Core Movement—Inductance Laws

Up to now only the extreme positions of the width control have been considered. In order to ensure that K of equation (3) remains constant over the entire range of the control it is necessary to investigate a little more closely the manner in which L_s and L_p vary as the position of the core is altered.

A typical curve showing inductance variation against movement of the ferrite core is given in Fig. 4. It will be seen that over the major portion of core movement the inductance change will be a linear one.

If we take this curve to show the manner of inductance

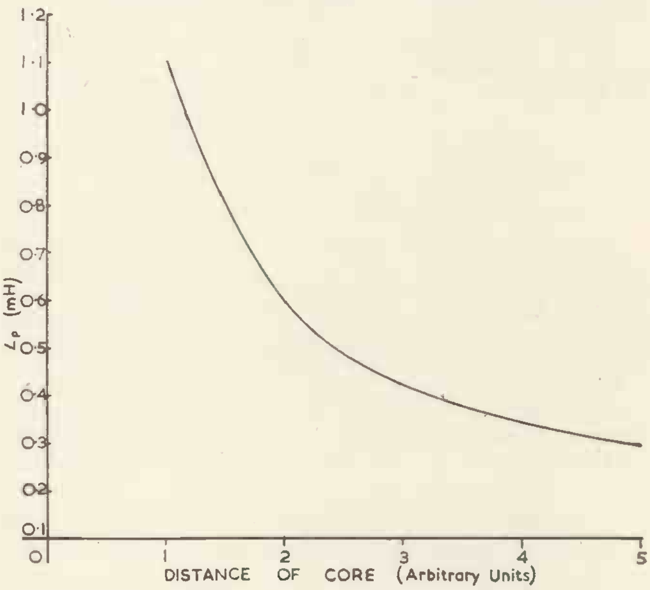


Fig. 5. Required inductance variation for L_p to maintain $L_{1\text{-}3}$ a constant

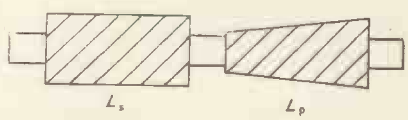


Fig. 6. Suggested tapered winding for L_p to obtain correct shunt law

variation for L_s and substitute these values in equation (6) a graph is obtained showing the required variation for L_p during the same core movement (Fig. 5) and this is the law of inductance change needed if K is to remain constant over the full range of the control.

Obtaining Correct Shunt Law

One method of obtaining this relationship is to use a tapered winding for L_p (Fig. 6). The amount of tapering required is determined by experiment to give the closest approach to the theoretical desideratum. Fairly close approximation can be obtained as is shown by the curves of Fig. 7, but the coil is not easy to wind and is certainly not suitable for factory mass-production in this form.

A simpler method is to adjust the spacing d (Fig. 2) between coil centres so as to use the shunt coil over the curved section of its characteristic. This also is best done empirically, and a series of curves is shown in Fig. 8 for

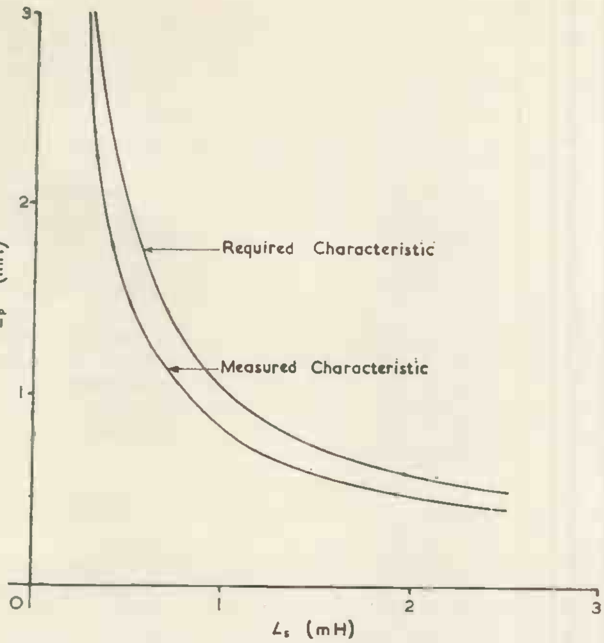


Fig. 7. Use of tapered shunt coil

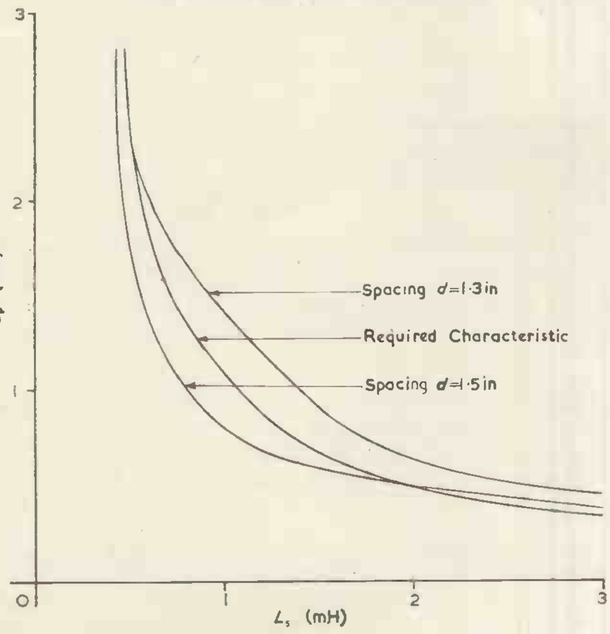
various coil spacings. In this particular example a spacing of 1·4in would appear to give the closest approach to the desired law.

Performance of a Differential Width System

A pair of coils were designed in accordance with the procedure given above and with the distance between coil centres adjusted to optimum the following figures were obtained:

L_s (min) = 0·36mH	L_s (max) = 2·84mH
L_p (max) = 3·48mH	L_p (min) = 0·46mH
L_y = 10mH	n = 10
d = 1·3in	Ferrite core = 1·25in long.

Fig. 8. Effect of varying coil spacing



Calculated minimum scan reduction:

$$= 100 - \frac{100}{1 + 10{\cdot}36/348} = 3 \text{ per cent}$$

Actual minimum scan reduction = 3·85 per cent.

Calculated maximum scan reduction:

$$= 100 - \frac{100}{1 + 12{\cdot}84/45} = 22 \text{ per cent}$$

Actual maximum scan reduction = 27·5 per cent.
The actual scan variation being:
+ 13·6 per cent − 10·0 per cent.

While the total E.H.T. variation measured = 5·5 per cent.

It will be seen from these results that some E.H.T. variation does, in fact, occur, as the scan width is adjusted.

Fig. 9. Equivalent circuit for differential width circuit including coil resistances

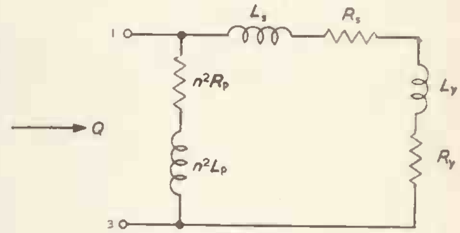
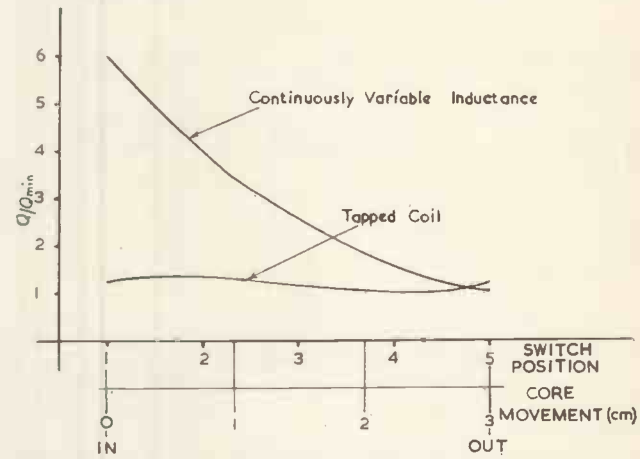


Fig. 10. Comparison between a continuously variable inductance and a switched tapped coil



Although the amount of variation is quite small, it is interesting to see why a variation should now occur.

Effect of Width Coil Resistance

One factor that has, so far, been omitted from the preceding calculations has been the Q-factor of the coils. This will, of course, vary as the coil inductance is altered and as is seen from equation (1) will have an effect on the overall Q factor of the scanning coil resonant circuit.

The complete circuit then, is as shown in Fig. 9, and if values are given to L_y, R_y, n, and the coil resistances R_p and R_s, an approximate expression for the overall Q of the complete circuit can be shown to be*:

$$Q_r = \frac{250 + 80Q_p + 270Q_p^2 + 160Q_s}{400 + 60Q_p^2} \quad \ldots\ldots (8)$$

For the case when:

$L_y = 10$mH	$R_y = 16\Omega$
frequency = 1 000c/s	$R = 4\Omega = R_p = R_s$

and Q_s = Q of series coil
Q_p = Q of shunt coil.

Taking an extreme case of variation in Q factor for the

* *See Appendix A.*

two coils from 1·0 to 10·0 then substitution in equation (8) will yield overall Q factors of 1·65 to 4·35. From equation (1) the E.H.T. variation will be found to be of the order of 23 per cent all other factors remaining constant.

Consequently if the Q factor of the width coils could be made constant over the range of control required, then a truly constant E.H.T. with change of picture width may be obtained.

Constant Q Coils

No simple way of obtaining a continuously variable inductance of this type, having a constant Q factor seems possible; but an alternative lies in the use of a tapped coil. This may be wound with different gauges of wire so that

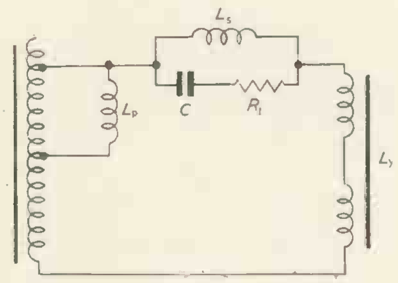


Fig. 11. Damping circuit across L_s

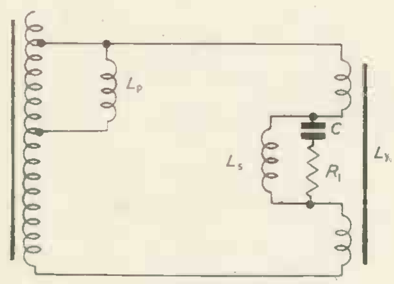


Fig. 12. Alternative position for L_s

the resistance increases from tap to tap in a manner proportional to the inductance change. Curves for a coil of this nature are shown in Fig. 10 for comparison with a continuously variable inductance of the type previously discussed.

Using two such coils in the series and shunt positions, a differential width system was constructed using a double-pole 5-way switch to adjust the picture width.

This arrangement gave a scan variation of ± 11 per cent for a total E.H.T. variation of less than 3 per cent. This is probably the best performance that can be obtained with such an ideal system, although the improvement over the continuously variable system hardly merits the additional complication of coil taps and switching.

"Ringing" of Series Coil

No treatment of inductive width systems would be complete without mention of the phenomenon of ringing or velocity modulation of the scanning waveform due to the presence of a coil in series with the scanning coils.

Any practical series width coil used will possess a certain amount of self-capacitance, which, together with the inductance, forms a tuned circuit with a resonant frequency in the order of 200 to 600kc/s. When this circuit is subjected to rapid changes of current during the retrace period, it resonates and an exponentially decaying sinusoidal waveform is developed across it. The duration of this oscillation persists during the scan period and results in a modulation of the steady potential across the scanning coils.

The resulting velocity modulation of the scan is shown on the screen as a series of light and dark vertical lines extending from the extreme left-hand side of the screen towards the centre, with diminishing intensity. The same effect may be present due to the scanning coils and may be obviated by tuning one-half of the coils[6]. In this latter case, however, the frequency is rather lower and the two sets of ringing can be readily distinguished.

To reduce this shock excitation of the series coil, a damping resistor may be connected across the coil. This increases the decrement of the tuned circuit and the oscillations are prevented from extending into the scan period. The exact value for this resistor is dependent on the coil used and is determined by experiment.

The value of resistance required to sufficiently reduce the amplitude of ringing will usually be such that an appreciable amount of energy is dissipated within the resistor. This has the effect of reducing the overall Q of the scanning coil circuit and consequently the E.H.T. generated.

A better arrangement is to shunt L_s by a series combination of R and C as is shown in Fig. 11. It can be shown* that if the relationship:

$$L_s = C \cdot R_1^2 \quad \ldots\ldots (9)$$

is maintained then the circuit may be made non-resonant and "ringing" will not occur.

In practice as L_s is made variable, a new value of R_1 is required for each setting of the width control. A variable control for R_1 could be fitted, but as the amplitude of ringing is inversely proportional to frequency it is sufficient to adjust R_1 with L_s at the maximum value of inductance (minimum scan position.)

Although the width circuit of Fig. 11 has now been rendered non-resonant it will behave as a capacitance at frequencies of the order of 500kc/s. This capacitance in series with the leakage reactance of the line scanning transformer can form a tuned circuit having this order of resonant frequency. Consequently ringing of this series tuned circuit may be possible and produce unwanted velocity modulation.

A solution to this problem lies in placing the series section of the width coil, together with the damping circuit, between the two line scanning coils as is shown in Fig. 12. The transformer leakage inductance is now no longer directly associated with L_s and this source of ringing obviated.

Appendix A

To derive an expression for the overall Q of the circuit of Fig. 9 given certain practical values, viz:

$$L_y = 10\text{mH} \quad R_y = 15\Omega$$
$$\text{frequency} = 1\,000\text{c/s} \quad n = 10$$
$$\text{and let } R = R_s = R_p$$

Now the impedance of the circuit, looking from the transformer is:

$$Z = \frac{n^2 (R_p + j\omega l_p)(R_y + R_s + j\omega l_s + j\omega l_y)}{n^2 R_p + n^2 j\omega L_p + R_y + R_s + j\omega L_s + j\omega L_y} \quad \ldots\ldots (i)$$

Expanding this and substituting $Q_p R_p$ for ωL_p and $Q_s R_s$ for ωL_s together with values given above:

$$Z = \frac{(15R - 62{\cdot}8 Q_p R - Q_s Q_p R^2) + j(Q_p R 15 + 62{\cdot}8 R + Q_s R^2)}{(R + 0{\cdot}15) + j(Q_p R + Q_s R/100 + 0{\cdot}628)} \quad \ldots\ldots (ii)$$

Neglecting term $Q_s R/100$ as very small, this expression may be rationalized to give:

$$Z = (15R^2 + 42R + 15Q_p^2 R + 0{\cdot}63 Q_s R + 0{\cdot}15 Q_s Q_p^2 R) + j((63R + Q_p 42 + Q_s R^2 (1 + Q_p^2) + R(0{\cdot}15 Q_p R^2 + 63 Q_p^2)) \quad \ldots\ldots (iii)$$

Now substituting a figure of, say, 4Ω for R—a practical value that can be achieved, a Q factor is obtained for this

* *See Appendix B.*

impedance of:

$$Q = \frac{250 + Q_p 42 + Q_s 16 + Q_p^2 16 + 0{\cdot}6Q_s + 40Q_p + 252Q_p^2}{408 + 60Q_p^2 + 2{\cdot}5Q_s + 0{\cdot}6Q_sQ_p^2}$$

which reduces to:

$$Q = \frac{250 + 80Q_p + 270Q_p^2 + 16Q_s}{400 + 60Q_p^2} \quad \ldots\ldots\ldots\ldots \quad (8)$$

Appendix B

Taking the circuit of Fig. 11 and including a resistance R_2 in series with L_s to represent its distributed resistance then the admittance of this circuit is given by:

$$1/Z = \frac{1}{R_2 + j\omega L_s} + \frac{1}{R_1 + 1/j\omega C} \quad \ldots\ldots\ldots\ldots \quad \text{(i)}$$

rationalizing each term:

$$1/Z = \left\{\frac{R_1}{R_1^2 + 1/\omega^2C^2} + \frac{R_2}{R_2^2 + \omega^2 L_s^2}\right\} + j\left\{\frac{1/\omega C}{R_1^2 + 1/\omega^2C^2} - \frac{\omega L_s}{R_2^2 + \omega^2 L_s^2}\right\} \quad \ldots\ldots \quad \text{(ii)}$$

at resonance the j terms are equal to zero, i.e.:

$$\frac{1/\omega C}{R_1^2 + 1/\omega^2C^2} = \frac{\omega L_s}{R_2^2 + \omega^2 L_s^2} \quad \ldots\ldots \quad \text{(iii)}$$

which gives by rearrangement:

$$\omega^2 = 1/L_sC \,.\, \frac{L_s - CR_2^2}{L_s - CR_1^2} \quad \ldots\ldots\ldots\ldots \quad \text{(iv)}$$

Now R_2 will usually be very small and for practical values of L_s and C, CR_2^2 can be neglected as very small compared with L_s.

Thus equation (iv) simplifies to:

$$\omega^2 = 1/L_sC \left\{\frac{1}{1 - CR_1^2/L_s}\right\} \quad \ldots\ldots\ldots \quad \text{(v)}$$

and if:

$$L_s = CR_1^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

then ω^2 is equal to infinity, i.e.: the circuit will be non-resonant.

REFERENCES

1. FRIEND, A. W. Television Deflection Circuits. *RCA Rev. 8*, 98 (1947).
2. SCHADE, O. H. Magnetic Deflection Circuits for Cathode-ray Tubes. *RCA Rev. 8*, 506 (1947).
3. SCHADE, O. H. Characteristics of High Efficiency Deflection and High-voltage Supply Systems for Kinescopes. *RCA Rev. 11*, 5 (1950).
4. JONES, E. Scanning and E.H.T. Circuits for Wide-angle Picture Tubes. *J. Brit. Instn. Radio Engrs. 12*, 25 (1952).
5. SNOEK, J. L. Non-metallic Magnetic Materials for High Frequencies. *Phillips Tech. Rev. 8*, 359 (1946).
6. COCKING, W. T. Simple Line Scan Circuit. *Wireless World, 43*, 308 (1952).

Industrial Radiography

Two new types of high voltage X-ray generator units have recently been designed by the High Voltage Engineering Corporation of Cambridge, Massachusetts. They are for the radiographic examination of heavy castings and forgings and of welded structures.

The first is the Model JR one million volt generator and is designed for continuous operation at its rated output. The exposure time is less than one minute for a thickness of steel of 1½in rising to 30 minutes for thicknesses of 4½in.

The voltage generator unit is mounted in a steel cylinder 36in diameter and 50in length and consists of a Van de Graaff generator with its associated power supplies, belt driven motor and charging unit. The whole unit is pressurized up to 200lb/in² with nitrogen and carbon dioxide in equal amounts.

The multiple sectioned X-ray tube is of new design and can be kept in operation by an automatic titanium adsorber mounted in the base of the generator.

The principal characteristics of the Model JR are as follows:—

- Voltage—1 million, constant potential.
- Target current—0·01 to 0·25mA.
- Radiation output—8 Roentgens per minute at 100cm in forward direction.
- Focal spot size—1mm.
- Half-value layer—0·6in steel.
- Field coverage—50° in forward directed cone with intensity variation of less than 10 per cent.

The unit can be suspended with a two hook sling and to provide greater flexibility in operation and transport a fork lift truck can be used.

For permanent installations the unit can be suspended from an overhead gantry which permits a lifting range of 16ft, tilt from vertical to horizontal and a full 360° rotation.

The larger unit is the model AR two million volt generator and is capable of radiographic examination of steel up to 10in with an exposure time of less than one minute for steel not exceeding 5in thick.

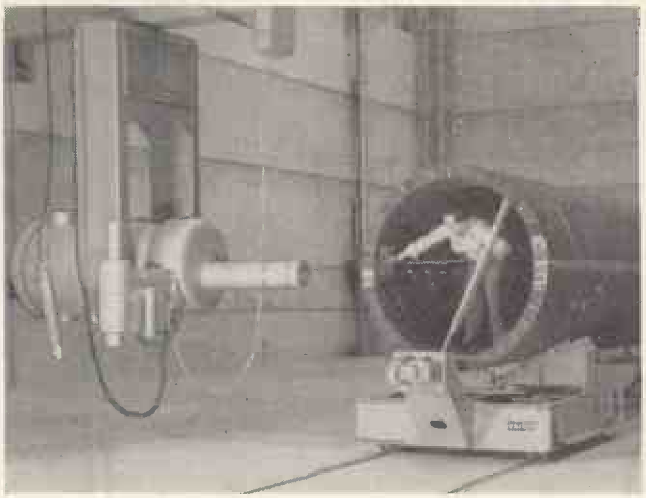
The voltage generator is a Van de Graaff generator in a steel cylinder in which is also mounted the multi-sectioned X-ray tube. The vacuum pumping system for the X-ray tube consists of a high speed mercury diffusion pump, cold trap, mechanical pre-vacuum pump, vacuum gauge and protective circuits. The whole unit is mounted at the generator base on a swivel joint so that the unit remains vertical irrespective of the generator position.

A desk type console contains the necessary operating controls and monitoring facilities for generator voltage, target current, focusing current exposure time. The principal characteristics of the Model AR are:

- Voltage—Two millions electronically stabilized.
- Target current—0·01 to 0·25mA.
- Radiation output—75 Roentgens per minute at 100cm measured in forward direction.
- Focal spot size—½mm.
- Half value layer—0·83in steel

The generator is supported on two trunnions which are attached to a yoke containing the motor drives for tilting the unit and rotating the yoke assembly. Where a high lift is required a double set of telescopic box members are provided to which the yoke can be attached assuring a rigid sway-free mounting.

The model AR two million volt generator in use at the Foster Wheeler Corporation.



An Even-Harmonic Magnetic Amplifier

and Some Applications to Measurement and Control

By P. D. Atkinson†, M.A., A.M.I.E.E., and A. V. Hemingway*, B.Sc., A.M.I.E.E.

The even-harmonic magnetic amplifier described has a zero stability of better than 10^{-11} watts input power and in this respect represents a significant improvement on conventional magnetic amplifiers. Its application to multi-stage magnetic amplifiers for the automatic control of street lighting and the measurement and control of temperature are described.

MAGNETIC amplifiers are used in increasing numbers in industry to amplify the electrical output of sensitive detecting elements (e.g. photocells, resistance strain gauges, thermocouples) and to operate relays or indicating or recording instruments[1]. The power level of the electrical signal from such detectors is often so low that zero drift in the magnetic amplifier sets a limit to the accuracy which can be achieved.

Using conventional balanced magnetic amplifier circuits the zero error over long periods can generally be made less than the zero shift produced by an input power of 10^{-8} to 10^{-9} watts. Normal variations in supply voltage and frequency, and drift in rectifier characteristics make it difficult to improve on this. However, even-harmonic magnetic modulators[2] used with electronic amplifiers are known to have considerably better zero stability; figures for zero drift ranging from 10^{-14} to 10^{-17} watts input power are quoted depending on the mode of operation of the modulator and on the design of the electronic amplifier and oscillator[3,4]. The amplifier to be described in this article has been developed to meet a need for a simple robust device with a zero stability appreciably better than can be achieved using conventional magnetic amplifier techniques[5]. A long term zero stability of better than 10^{-11} watts input power can be obtained with no more care than is required to achieve a figure of 10^{-8} watts using conventional methods.

The use of even-harmonic magnetic amplifiers has made possible reliable static apparatus for a number of applications which are outside the range of conventional techniques. Two such applications are discussed in some detail in the latter part of this article.

The Basic Circuit

The even-harmonic amplifier is an adaption of the even-harmonic modulator which is used as a D.C. to A.C. convertor for an electronic amplifier[6]. The design and mode of operation, however, are such that it will give a useful power output. Typical performance figures are: power gain 1 000, power output 1mW. It will operate satisfactorily over a fairly wide range of supply voltage and frequency and is suitable for connexion to the 50c/s mains supply; a stabilized supply or an electronic oscillator is not required.

Description of Circuit

The circuit is shown in Fig. 1. Windings a and a' carry an alternating excitation current supplied from a mains transformer through a limiting resistor R. Windings b and b' carry the input or control current; they are connected in series opposition with respect to the excitation windings so that if the cores and windings are identical no voltage at the supply frequency can appear at the input terminals. The output windings c and c' are connected in the same way as the control windings. One pair of windings could be used for both purposes, but it is usually convenient to isolate the input and output circuits.

When the control current is zero no voltage can appear at the output terminals xx'. If a direct current flows in the control windings a voltage containing only even-harmonics of the supply frequency will appear at xx'. The choke L is included in the input circuit to prevent the

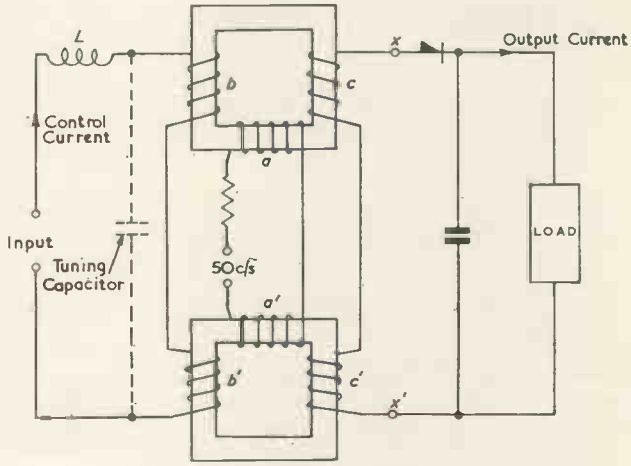


Fig. 1. Even-harmonic magnetic amplifier

control circuit from presenting an inductively coupled short-circuit across the output terminals. The alternating output voltage is rectified and smoothed to give a direct current output. Thus a direct current flowing in the control circuit causes a direct current to flow in the load circuit.

Characteristics

An arrangement of this type may be expected to have a good inherent zero stability. For, with a balanced pair of cores, the output is zero if the input is zero and this condition is independent of the voltage and frequency of the excitation. The sensitivity, or current amplification is, in general, dependent on supply voltage (Fig. 2(a)). However, over a fairly wide range the sensitivity is almost independent of supply voltage and frequency and the relationship between control current and output current is approximately linear.

The excitation voltage in the working range is of the order of three times that required to produce saturation. The cores are therefore both saturated for the greater part

* *Elliott Brothers (London), Limited.*
† *Now at British Tabulating Machine Co., Ltd.*

of each half cycle of the supply voltage and the voltage at xx'. consists of short pulses generated at each reversal of the excitation current (Fig. 3). The polarity of these pulses is determined by the polarity of the control current. Within the working range an increase in supply voltage produces both an increase in amplitude and a decrease in length of the output pulses. Thus the charge transferred to the smoothing capacitor by each pulse is nearly independent of the supply voltage. (A detailed analysis of this mechanism is given in Ref. 6.)

Both input and output impedances may be arranged to have any value up to about 3kΩ.

TUNING OF THE CONTROL WINDING

An increase of about 2 : 1 in the current sensitivity of the amplifier can be obtained by tuning the output wind-

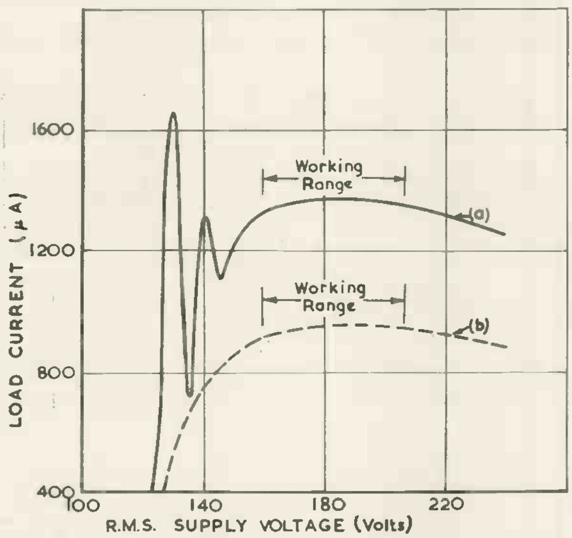


Fig. 2. Typical regulation curves for even-harmonic magnetic amplifier. Control current 50 μA.
(a) *With tuning*
(b) *Without tuning*

ings. This is usually done by connecting a capacitor across the control windings as indicated in Fig. 1. The natural period of the tuned circuit formed by the winding inductance and the capacitor should be somewhat less than the total length of the output pulse, T in Fig. 3(b). In addition to increasing the current sensitivity, the tuning capacitor causes a damped oscillation in the output circuit (Fig. 3(c)) and modifies the regulation curve (Fig. 2(b)).

CONSTRUCTION

The considerations governing the assembly of the magnetic circuits and the arrangement of the windings are the same as in the case of ordinary magnetic amplifiers. Identical construction and winding techniques are used and the only physical difference between an even-harmonic and a conventional magnetic amplifier is in the details of the winding design and in the circuit connexions.

The even-harmonic amplifiers used in the applications to be described contain 0·005in thick Mumetal laminations of outside dimensions $1\frac{5}{8}$in × $1\frac{1}{8}$in. An assembly comprising the two cores and the associated windings occupies a volume of approximately $1\frac{3}{4}$in × $1\frac{1}{2}$in × $1\frac{1}{4}$in.

Balanced Circuits

The circuit described above, while representing a valuable improvement on the conventional magnetic amplifier in respect of stability, has two practical disadvantages.

(a) The polarity of the output does not reverse with the polarity of the input.

(b) Since the rectifier has a very high forward resistance for applied voltages less than about 400mV the sensitivity of the amplifier at and near to zero output is very much less than normal. (Because the rectifier passes current in short pulses this effect is apparent only for very low values of mean output current.)

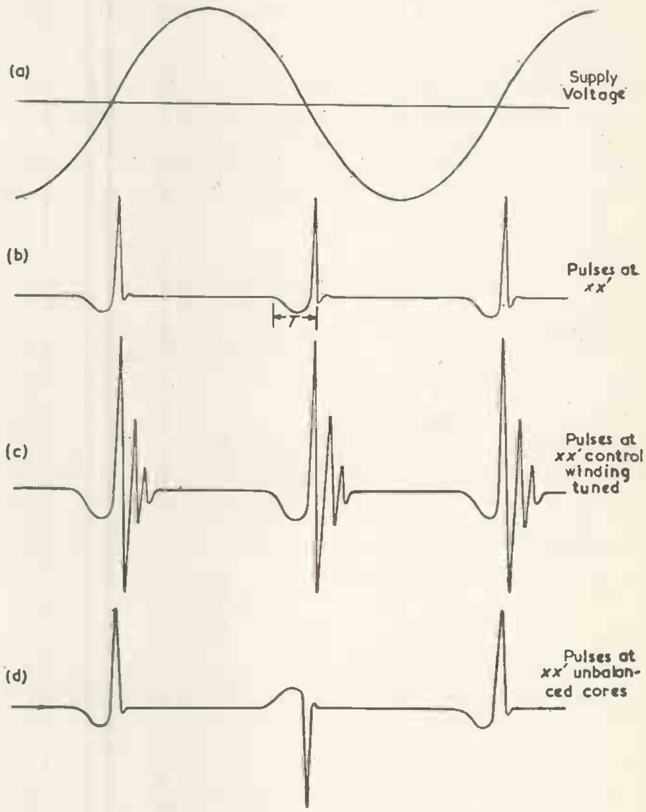


Fig. 3. Output voltage waveforms

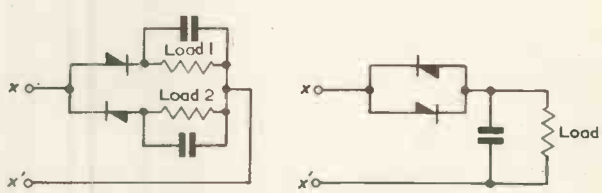


Fig. 4. Balanced output circuits
(a) *Joined load circuits*
(b) *Single load circuit*

These difficulties may be overcome by unbalancing the two cores, usually by connecting a suitable resistor in parallel with one of the excitation windings. The voltage at xx' when the control current is zero then contains fundamental and odd harmonic frequencies, and consists of alternate positive and negative pulses as shown in Fig. 3(d). The effect of positive control current is to increase the amplitude of the positive pulses and reduce the amplitude of the negative pulses, and *vice versa* for negative control current.

Two output circuits used with the unbalanced core arrangement are shown in Fig. 4. The one in Fig. 4(a) has two pairs of direct current output terminals; when the control current is zero equal currents flow in the two load circuits and the rectifiers are operated above the bottom bend in their characteristic. The amplitude and sign of the difference between the two output currents is dependent on the control current; the characteristic is linear and symmetrical about the origin. The double output circuit restricts the use of this circuit to applications where the two currents can be subtracted conveniently and it is frequently used as a pre-amplifier for a conventional magnetic amplifier. The stability of gain is comparable with that of the single output circuit while the zero stability is appreciably better.

The output circuit shown in Fig. 4(b) has similar characteristics to that in Fig. 4(a) and the single output circuit is an advantage in some applications. Because the only comparison elements are the two rectifiers instead of the complete output circuits the zero stability, expressed as an input power is improved in the ratio of approximately 5 : 1. The power gain is reduced by about 2 : 1. The rectifying action depends on the bottom bend of the rectifier characteristics and the allowable degree of core unbalance involves rather more careful setting up than is necessary with the other balanced output circuit. A disadvantage of this output circuit is that it is readily upset by voltages fed back from the next stage in a cascade arrangement. It is therefore not suitable for use as a pre-amplifier for a conventional magnetic amplifier but it can be used to feed another even-harmonic amplifier.

The combined characteristic of the two rectifiers in Fig. 4(b) is a symmetrical one and they can be replaced by a single silicon-carbide resistor thus eliminating possible zero drift due to differences in rectifier characteristics. The use of a silicon-carbide resistor leads to lower sensitivity, however, and, since the selenium rectifiers give satisfactory performance in respect of the zero stability, they are normally preferred.

Automatic Street Lighting Controller

An automatic lighting controller provides an example of the use of even-harmonic magnetic amplifiers in an on-off control system. The controller is designed to switch on lighting circuits automatically when the daylight intensity falls below a pre-set value and to switch them off when it rises above this figure. It can therefore be employed where the control of street lighting, public illumination, traffic direction lights at roundabouts, etc., is required at a given light intensity.

Requirements

For public street lighting the normal "switching-in" time is approximately 20 minutes after sunset; similarly, the normal switching-out time is approximately 15 minutes before sunrise. In order to make it suitable for other similar applications the controller can be set to operate at any time during the period of some 40 minutes after sunset and some 30 minutes before sunrise. The minimum overall range of light intensity over which the control must operate is estimated to be between ½ and 7½ foot-candles. Daylight intensity on a bright day often exceeds 1 000 foot-candles; this must not damage the light sensitive element nor cause damage to or faulty operation of the controller.

The Light Sensitive Element

A selenium barrier-layer photocell (67mm diameter) is used as the light sensitive element. It is mounted in a sealed housing and in order to avoid undue ageing due to prolonged exposure to direct sunlight only diffused daylight is permitted to fall on it. An important advantage of this type of cell is that it has an internal impedance of a few thousand ohms and thus the lead from photocell to amplifier can be of any reasonable length.

In order to provide the required accuracy and range of operating intensity the amplifier, whose input impedance is about 2 000Ω, is designed to give reliable operation of the relay for a change of input current of 0·5μA at any pre-set value between 0·5 and 20μA.

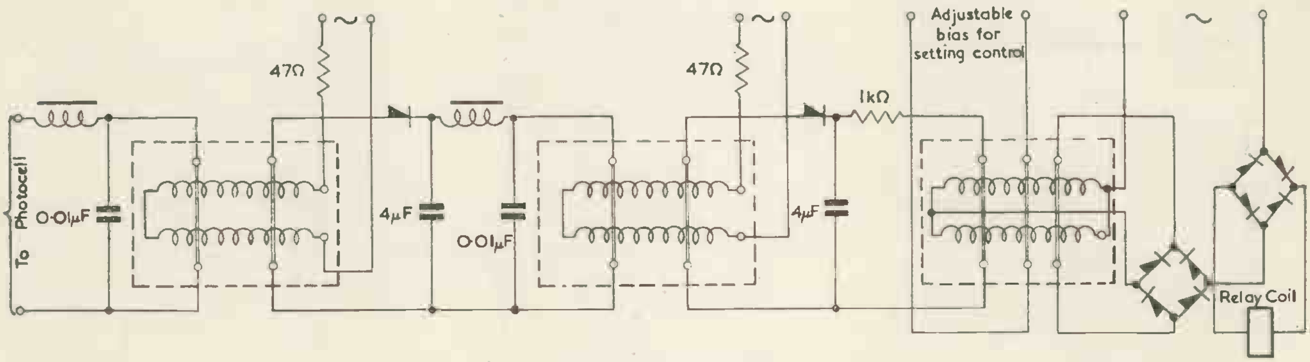


Fig. 5. Amplifier for automatic lighting controller


Fig. 6. Automatic lighting controller showing magnetic amplifier and relay in a weatherproof case, and photocell housing

The Amplifier

The amplifier, Figs. 5 and 6, consists of three stages in cascade. The output stage, which is a parallel-connected magnetic amplifier of conventional design, controls a relay (P.O. 3000 type carrying a mercury switch) capable of switching a load of 10A at 250V. The first two stages are even-harmonic magnetic amplifiers of the type described. The input current required to operate the relay is set by adjusting the bias current on the output stage.

Laboratory tests on the effects of variations in supply voltage and ambient temperature showed that the zero stability of the controller for normal settings corresponded to an input power of about 10^{-10} watts or a light intensity of 0·07 foot-candles. Field tests carried out over periods of many months showed no measurable drift due to ageing of components, etc.

An Amplifier for Thermocouple E.M.F.s

This amplifier was developed as a reliable and robust instrument amplifier particularly for use with thermocouples. The normal sensitivity gives full scale output for approximately 4·2mV (corresponding to 100°C temperature difference with a copper-constantan thermocouple). The output, 5mA into 500Ω, is sufficient to operate a large indicating instrument and/or a direct writing recorder. A simple modification of the amplifier makes it suitable for use in an on-off temperature control system.

Negative Feedback

To achieve the accuracy and stability required for an instrument amplifier it was necessary to provide negative feedback over the complete amplifier. Magnetic amplifiers are usually considered to be so stable that the sacrifice in gain associated with negative feedback is unnecessary. The reasons for using negative feedback in this case are as follows:

(a) A feedback voltage proportional to the output current is injected in the input circuit in opposition to the thermocouple E.M.F. The current flowing in the input circuit is therefore small and the resistive drop in the circuit is small compared with the input and feedback voltages. Thus variations in the resistance of the copper winding and the thermocouple leads have only second order effects.

(b) In a multi-stage amplifier, particularly when even-harmonic amplifiers are used, it is not practicable to maintain a linear characteristic which is stable with normal variations in ambient temperature and supply voltage and frequency.

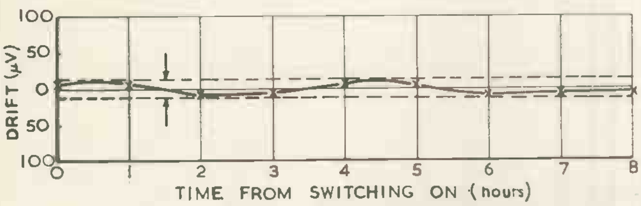


Fig. 7. Initial drift of instrument amplifier

The Amplifier

The amplifier comprises three stages in cascade. The first two are even-harmonic amplifiers and the last is a conventional balanced magnetic amplifier. The core and winding assembly of the first stage is enclosed in a Mumetal can to shield it from the earth's magnetic field. A proportion of the output current flows through a small resistor in the input circuit to provide the overall negative feedback. In order to avoid spurious thermo-electric E.M.F.s in the input circuit the feedback resistor is wound with manganin wire and junctions between dissimilar metals are avoided.

The output stage was designed to have as slow a response as practicable. This was necessary in order to stabilize the closed feedback loop by making the lag in one of the three stages very much greater than that in either of the other two. Some form of internal gain control was necessary so that the loop gain could be set to its best value. The method which was chosen as having the smallest effect on zero setting and zero stability was that of an additional negative feedback loop enclosing the two even-harmonic amplifiers. The loop gain here is small but it provides the necessary degree of control over the gain round the main loop.

Fine controls of zero setting and of overall gain are provided. The gain control is an adjustment of the proportion of current feedback and the zero setting is a variable bias on the first stage.

Test results obtained using a matched input of 10Ω resistance show that the characteristic, which is symmetrical about the origin, is linear within $\pm\frac{1}{4}$ per cent full scale output. With combined variation of supply voltage, ±10 per cent, and frequency, ±5 per cent, the zero error was less than 8μA (10^{-12} watts input power or 0·16°C with a copper-constantan couple) and the maximum error in the 5mA output was 20μA ($6{\cdot}4 \times 10^{-12}$ watts input power or 0·4°C). (See Fig. 7.)

Long term drift tests showed no significant zero drift or change in sensitivity.

The response time of the amplifier to a sudden change in input is about $2\frac{1}{2}$sec.

The Controller

The amplifier without its negative feedback circuit is a high gain amplifier with good zero stability suitable for use in control systems. When used for furnace temperature control the output circuits of the two magnetic amplifiers which comprise the output stage are separated and each controls an independent relay. The bias currents supplied to each of the output stages are independently adjustable so that the two relays which control separate sections of the furnace heater can be arranged to operate at slightly different temperatures, a feature commonly provided in the "chopper-bar" type of controller.

The main backing-off bias which determines the temperature at which the relays operate is provided by passing a current through a small resistor in the input circuit. When, as is often the case, the controlled temperature exceeds 300 to 400°C the main cause of error in the controller is the backing-off current which is normally obtained from a neon stabilized supply. Switching errors of the order of 1 or 2°C can be expected from this source compared with $\frac{1}{4}$ to $\frac{1}{2}$°C due to the amplifier.

Conclusion

The even-harmonic magnetic amplifier is a useful addition to existing magnetic amplifier techniques; it reduces the gap between the zero stability obtainable with the magnetic modulator type of electronic amplifier and that obtainable with solely magnetic techniques. The useful range of input impedance, up to about 3kΩ, makes it suitable for use with many types of transducer but its poor response time restricts its application to cases where the input is a slowly varying quantity.

Acknowledgments

The authors are indebted to Messrs Elliott Brothers (London) Limited for permission to publish the information contained in this article, to their colleagues, Messrs J. H. Aird and J. A. Chitty, for their assistance and suggestions in the work described, and to the Institution of Electrical Engineers for permission to reproduce Fig. 7.

REFERENCES

1. Gale, H. M. Magnetic Amplifiers and their Application to Industrial Purposes. Trans. Instrum. Meas. Conf. Stockholm (1949).
2. Pizzey, C. F. British Patent No. 62987 (1946).
3. Brewer, A. W., Squires, J., Ross, H. McG. Some Developments in Electronic Magnetometers. *Elliott J. 1*, No. 2, 38 (1951).
4. Noble, S. W., Baxandall, P. J. The Design of a Practical D.C. Amplifier based on the Second-Harmonic Type of Magnetic Modulator. *Proc. Instn. Elect. Engrs. 99*, Pt. 2, 314 (1952).
5. Hemingway, A. V., Atkinson, P. D. British Patent Application No. 113/49.
6. Frost-Smith, E. H. The Study of a Magnetic Inverter for Amplification of Low-Input-Power D.C. Signals. *Proc. Instn. Elect. Engrs. 100*, Pt. 2, 362 (1953).

A Torquemeter for Testing Gas Turbine Components

At 11 000rev/min 500kW

(Part 1)

By J. F. Field* and D. H. Towns*

Since the useful power output of a gas turbine is the difference between two relatively larger quantities (i.e. compressor and turbine energy), it is important that the thermodynamic efficiency of both compressors and turbines in any such engine should be most accurately determinable. The most satisfactory way of doing this involves accurate measurement of mechanical power output or input; a variety of torquemeters have already been developed for the purpose; hitherto these have not had an accuracy of better than about 2 per cent.

An improvement in accuracy to about ¼ per cent has been achieved by introducing a multiple frequency phase-angle measuring device, which the authors have called an "Electronic Vernier".

SOME three years ago the Electricity Supply Research Council†, when considering the application of gas turbine technique, to steam power[1], thought it advisable to determine experimentally whether it was possible to compress steam in an axial flow compressor, as used in gas turbines, with about the same efficiency as when compressing air, and whether the steam could be compressed along a wet adiabatic with no deterioration in efficiency.

It was decided to set up a test rig for dry saturated steam at the compressor inlet and to inject enough finely divided water to enable the compressor to work approximately on the desired wet adiabatic. It was hoped that if the water were in a fine enough state of suspension the compressor efficiency would be as high as with dry saturated steam. The latter effect would inevitably indicate itself as a reduction of power input to the compressor when the water mist was injected. The fundamental requirement was a very accurate indication of change of power input with a change in dryness fraction of the steam, since this would have the great advantage of eliminating errors due to insufficient accuracy in weighing the quantity of steam compressed under given conditions. It is in effect a null method of testing. Its success depends on attaining especially high sensitivity to small changes of power or torque at a fixed speed and it is the purpose of this article to indicate the manner in which this was achieved.

A review was first made of known methods of power measurement at high speeds, the results of which may be summarized as follows:—

(1) A Continental installation was inspected, in which the compressor driving motor was arranged to swing about a highly sensitive weighing machine mechanism so that the reaction torque on the motor under load conditions could be measured. This machine was, however, expensive and the delivery time long.

General view or calibration test rig for high speed torquemeter. Normally the main motor drives the speed increasing gearbox through a Sinclair fluid coupling, the input speed being 3 000rev/min. For calibration purposes, the fluid coupling has been removed and a low speed chain driven jackshaft substituted, so that the torquemeter speed for calibration is some 2 300rev/min.

(2) As an alternative to (1) above, the use of the compressor itself as a reaction component was considered but the idea was not pursued owing to probable serious errors caused by reaction from the inlet and outlet steam velocities.

(3) There are one or two torquemeters which use electrical strain gauges but these appear to be of suspect stability.

(4) One very good torquemeter was shown to the authors under development, this depending on a comparatively small torque member of high stability steel, the exceedingly small angle of twist being measured by an optical multiplying device.

(5) A torquemeter similar to (4) above, developed for the Royal Aircraft Establishment, and described by the National Gas Turbine Establishment in one of their earliest post-war papers, measured the angle of twist by means of two phonic wheels, one at each end of the torque member, the change of phase of the alternating voltage at one end with respect to the other being measured by means of an electronic phasemeter. This apparatus gave an accuracy of measurement of twist, and so of transmitted torque, of about 2 per cent and had been originally conceived to function under airborne conditions on the short length of shaft between an aeroplane engine and the propeller.

This idea gives the prospect of almost unlimited accuracy because a torsional shaft movement (however small) can be stepped up to a readable figure by raising the frequency of the phonic wheels, i.e., increasing the number of electrical degrees relative to the actual twist in mechanical degrees, the limiting feature being the frequency characteristic of the phase-angle meter itself. Eventually it was considered that the phonic wheel was not as suitable as an arrangement of exciter lamps and photo multiplier

** South East Scotland Division, British Electricity Authority.*

† At that time under the Chairmanship of Sir Harold Hartley, F.R.S., and now under the Chairmanship of Sir David Brunt, Sec. R.S.

cells, the phonic wheel at each end of the torque member being replaced by a stainless steel disk with 120 $\frac{1}{8}$-in diameter holes on a pitch circle diameter of 9·9/16in. At a speed of 11 000rev/min this gave an alternating voltage signal of 22kc/s. and a small inherent frequency error in the phase-angle meter, but at the same time gave enough electrical degrees for an exceedingly small twist in the shaft to show up quite clearly on the phase-angle meter. The obvious additional step to increase both the absolute and differential sensitivity was to lengthen the torque member and at the same time reduce its diameter to as low a figure as kept the material reasonably within the elastic limit.

The relatively considerable length and twist should also completely swamp any errors due to bearing clearances but the additional precaution was taken of calibrating the torque meter against a Heenan & Froude dynamometer at 2 300rev/min, a separate very small correction then being applied for frequency effect at 11 000rev/min. This frequency error can be accurately determined by rendering the torsion assembly axially solid and running it unloaded first at the speed of calibration and then at the working speed. Errors are mainly due to harmonic voltage effects in the photocell generators and can be largely eliminated by the precautions described later.

Heenan and Froude magnetic or hydraulic drag dynamometers are in effect weighing machines incorporating a slipping clutch. For a given maximum torque those required to operate at a relatively high speed involve a relatively high dissipation of power. Accordingly their construction is heavier and the weighing machine components are less accurate than those designed for slow speed measurement. Hence there is an obvious advantage in choosing for calibrating purposes the lightest construction which can absorb the torque, necessarily at a relatively low speed.

A magnetic type dynamometer of light construction was therefore selected as the basic standard. This has an accuracy in the upper range of readings of better than $\frac{1}{4}$ per cent. The further loss of accuracy inherent in the process of transfer to the torquemeter is probably exceptionally small, i.e., less than 0·1 per cent.

The above method of calibration is considered not only at least as reliable as any method of static calibration, but bearing in mind that re-calibration should certainly be carried out before and after each test, is far easier to apply since mechanical details of static calibration would be complicated and expensive compared with the extreme simplicity and freedom from errors in the dynamometer substitution method.

A torsion rod of the kind proposed was bound to suffer slightly from hysteresis and it was necessary to compromise in the maximum shear stress allowable at the surface of the material. It was decided that the most practical material would be the special torsion rod steel developed in recent years for motor car springing where high stability over a large number or strain cycles of widely varying amplitude is now obtained. Fortunately, a torsion rod made by the English Steel Corporation for a well-known motor car front end suspension was suitable. This torsion rod is some 4ft 3in long with heavy serrated dumb-bell ends to take the drive and with a diameter of about 0·935in; thus the effective part is roughly 50 diameters long. The material is described as silico-manganese spring steel. For motor car use, these torsion rods are oil hardened and tempered in a controlled atmosphere. The material is then shot-peened and painted. The rods are invariably pre-set after heat treatment by twisting one end with respect to the other by about 90°, i.e., somewhat further than the full travel of the rod when installed in the car. This gives a pre-set in the torsion rod of roughly 10°and thereafter it is very stable in normal use. The material would appear to be ideally suitable for a torque measuring device provided there is no difficulty due to hysteresis. It was found in practice that hysteresis gave no trouble in making very accurate measurements, provided the torque was always measured from the same side, e.g., under gradually increasing torque conditions, and the calibration was remarkably consistent under repeated variations of load. During the tests, the maximum load was about 350kW and the maximum strain was equivalent to some 7° mechanical

The possibility of modes of lateral vibration and of torsional oscillation due to the heavy mass of the compressor rotor under surging or pulsating steam flow conditions, resulting from the use of a long thin torsion rod at this very high speed, were dealt with by enclosing the rod in a stiff concentric tubular shaft with continuous light alloy support bearings, the rod resting on a thin film of oil throughout its entire length. The shot-peened surface of the rod was lightly honed without removing the identation which carried the oil film. Torsional vibration was eliminated by a vane oil damper between the two concentric outer shaft bodies. The layout of the torsion rod component as a whole is indicated in Fig. 1. Oil is injected into the damper cylinder by means of an ordinary grease gun at four equi-distant nipples and it is essential, because of the high centrifugal forces, to have effective sealing plugs, each consisting of an Allen screw with a ball-bearing to retain the oil after the damper chambers have been filled.

The strain of 6° to 7° mechanical is equivalent with 120 equi-distant holes in each disk to some 700° to 800° electrical. The phasemeter cannot, however, show more than 90° electrical on its scale, a reading of 90° to 180° being achieved by the return of the meter pointer to zero. Thus there is a complete cycle, minimum to maximum reading and back again, for each 180° electrical. To keep track of the number of such complete cycles of movement a second signal 1/10th of the frequency is generated by each disk by means of the twelve rectangular notches on the disk periphery and an associated photocell. By switching over to the low frequency signal (2·2kc/s) a coarse reading over a range of 70° to 80° electrical is obtainable and clearly establishes the precise quadrant of the high frequency high sensitivity reading. The idea is analagous to that of an hour hand to supplement the information given by the minute hand of a clock and has been described by the authors as an electronic vernier.

An important application of this instrument is the possibility of measuring with a high degree of accuracy the exchange of power in free running gas turbine compressor units such as are often utilized in compound gas turbine cycles, since a precise knowledge of the actual exchange of power is bound to be a considerable step forward in interpreting the normal temperature and pressure measurements. In such an application the torquemeter would probably have to withstand a considerable thrust load necessitating the introduction of a ball or roller thrust bearing in such a way that it would have no appreciable effect on the torsion rod calibration.

In ship propulsion, where advantage can be taken of the often considerable length of the propeller shafts, it would be advisable to attach the photocells to a tubular stationary component mounted around the shaft and supported on it by means of suitable anti-friction bearings, the stationary component being prevented from rotating by an arm attached to the hull. The photocells would then be immune from errors or cyclic variations due to the working of the ship's hull and would be truly concentric with the shaft.

Calibration of the particular length of propellor shaft would have to be carried out on shore either against a water brake or by means of a static test. The arrangement for such a static test would consist of mounting the photocell assemblies on the shaft at the positions normally occupied by the disks and rotating round the shaft a

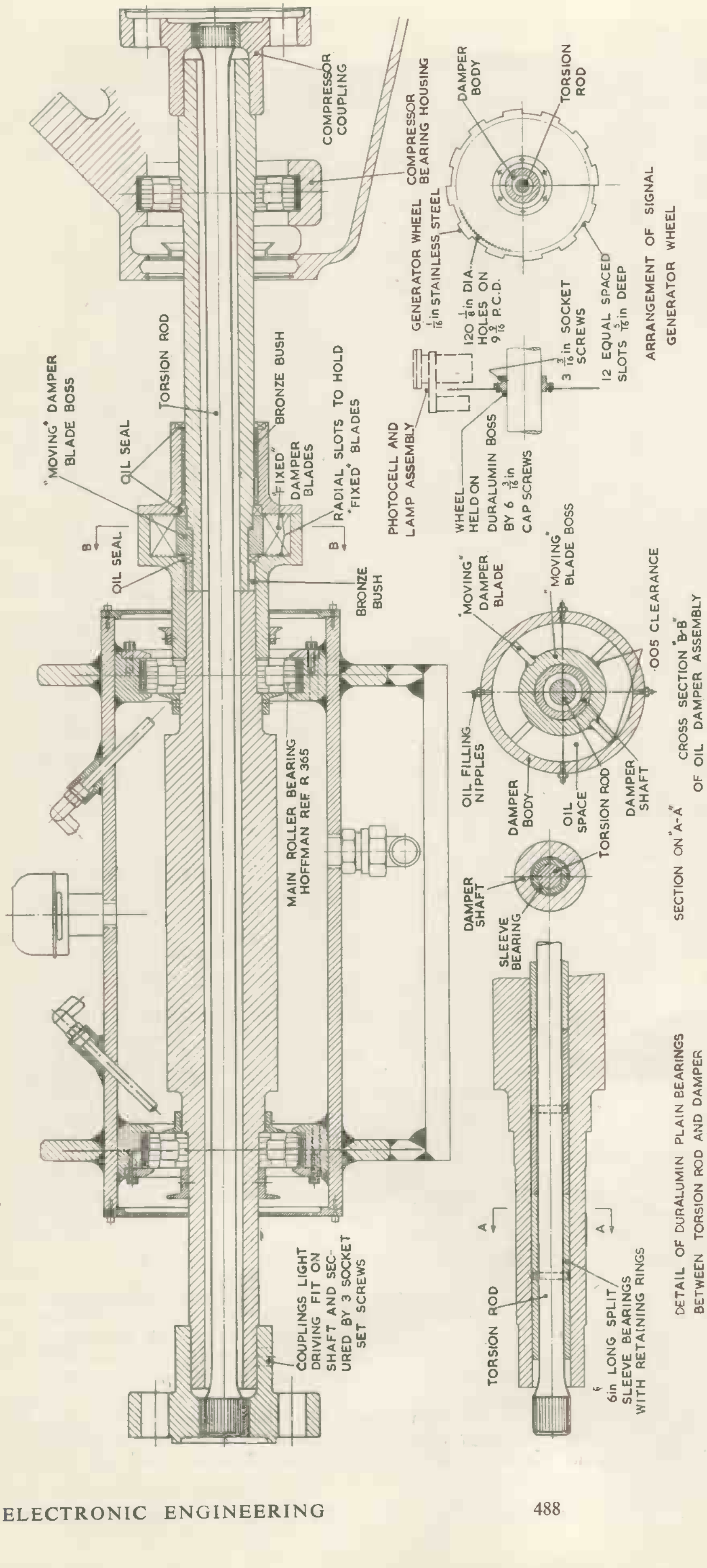


Fig. 1. General arrangement of torsion rod assembly for 11 000 rev/min 500kW torquemeter

tubular member carrying two perforated disks similar to those normally used on the shaft. The stationary propellor shaft would be subject to torsion by a suitable cantilever and weights, while at the same time the outer tubular member and the perforated disks would be rotated at a speed corresponding to that of the shaft when in the ship.

In the case of large electric generators, the power output is measurable by electrical metering with a high degree of precision and it is more useful in this case to measure only the losses amounting to about 2 000kW in the case of a 100 000kW 3 000rev/min machine. For this purpose a torsion rod of similar material to that already used, about 2½in diameter and say 10ft long would suffice, the actual length depending on the diameter of the wheels. Internal stops would be required in the outer concentric shaft and oil damping gear so that the acceleration of the heavy mass of the electric rotor would not overtwist the torsion rod when starting up. It would then be possible to carry out short-circuit stator current tests and open-circuit excitation tests and so obtain the losses alone under simulated full load operating conditions and temperature, more accurately than has been possible by conventional loss tests based on cooling water condition.

Electronic Components

The phase-angle measuring device was designed by the Royal Aircraft Establishment and was developed and produced by McMichael Radio Ltd. In its original airborne form it was operated from a 14 volt D.C. supply, had a frequency range of 500c/s to 40kc/s, a maximum error of $\pm 2°$, and was known as a torquemeter, but the authors were able to make use of a later version of this instrument, which is intended for operation from A.C. mains, has a frequency range of 20c/s to 50kc/s, a maximum error of only $\pm 1°$, and, since it is capable of application to many kinds of phase measurement apart from those appertaining to the determination of torque is known as a phasemeter. There are other forms of phase measuring gear which might also be adaptable to this purpose.

The basic circuit of the instrument can be represented by two resistors of equal value, a milliammeter, and an electronic switch having two positions, X and Y (Fig. 2). When the switch is in position X, current flows through the meter in one direction and when the switch is in position Y, an equal current flows through the meter in the opposite direction. Fig. 3 shows a series of waveforms of two alternating voltages between which it is required to measure the phase displacement, and which comprises the inputs to the phasemeter. The operation of the phasemeter is such that when one of the two alternating voltages passes through zero going from negative to positive, the

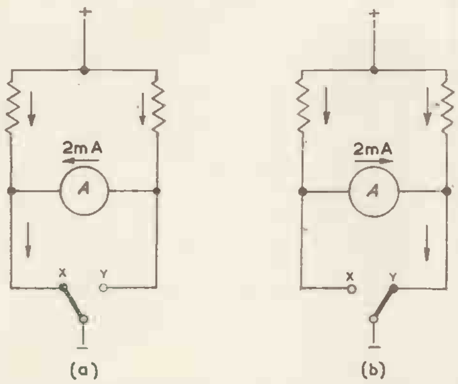


Fig. 2. Basic circuit of phasemeter

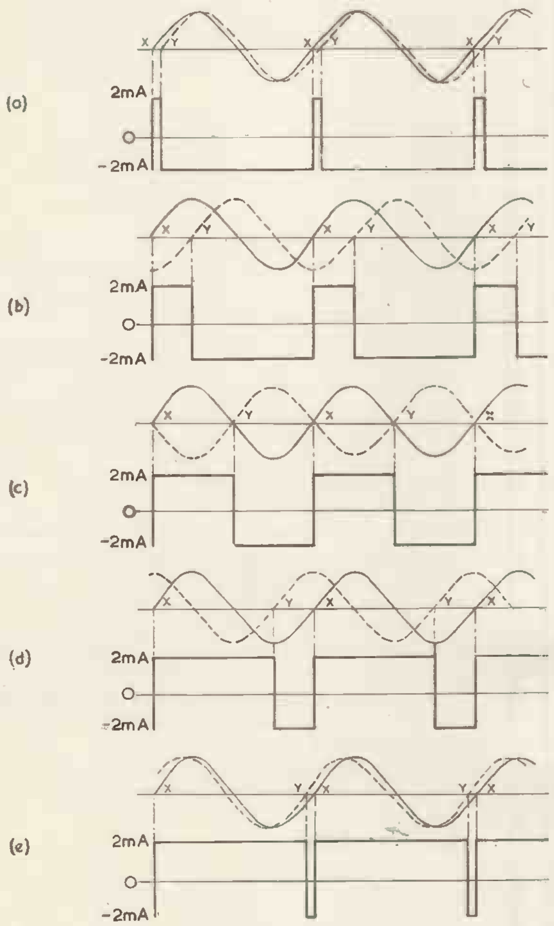


Fig. 3. Phasemeter input and output waveforms

switch moves to position X, and when the other alternating voltage passes through zero going from negative to positive, the switch moves to position Y. These switching instants have been designated X and Y to correspond to the switch positions and are shown in Fig. 3, together with the waveform of the current in the meter. Except at the very lowest frequencies the meter cannot respond to the positive and negative pulses of current, and indicates only the mean current during one cycle. The resulting relationship between mean meter current and phase displacement is, therefore, of the form shown in Fig. 4, the current varying in rectilinear manner from 2mA positive at 0° phase displacement to 2mA negative at 360° phase displacement, passing through zero at 180° phase displacement. Although the relationship between meter current and phase displacement theoretically exhibits a discontinuity at 0° and 360° (which are identical points in angular measure), in practice the current will follow the dotted line in Fig. 4 for the following reasons. If there are N alterations of voltage for each revolution of the generator, there will be N switching instants X and N switching instants Y per revolution. At changeover from phase displacements less than 360°, when Y precedes X, to phase displacements greater than 0°, when X precedes Y, it is not possible for mechanical reasons to ensure that all

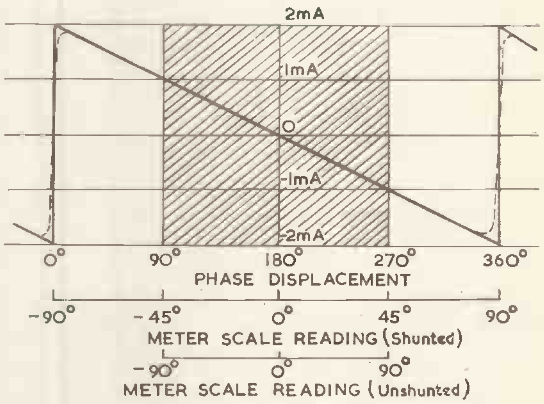


Fig. 4. Characteristic of phasemeter

Fig. 5. Current in phasemeter output circuit dur.ng changeover period

N switching instants in one revolution of the generator simultaneously change over from Y preceding X to X preceding Y. It is, in fact, reasonable to assume that they change over one at a time in a random sequence, so that the changeover is spread over a band of phase displacement values, the width of the band depending on the accuracy with which the generators are constructed and extending in a typical case from say 0° to 20° and 340° to 360°.

During the changeover period, the meter current has neither the waveform shown in Fig. 3(a) nor yet that shown in Fig. 3(e), but is instead a combination of the two as shown in Fig. 5.

The meter movement has a full scale deflexion of 1mA, has its zero at one end of the scale, and is provided with a reversing switch. Zero on the meter scale is marked 0° and full scale deflexion is marked 90°. Thus the meter indicates 0° when the inputs have a phase displacement of 180°, it indicates 90° when the inputs have a displacement of 270°, and it indicates −90°, i.e. +90° with the reversing switch in the other position, when the inputs have a displacement of 90° (Fig. 4). The advantage of this arrangement is that for a total change of phase displacement not exceeding 180°, the available scale length is utilized to the maximum extent.

Where it is required to measure phase displacements in excess of 180°, the meter can be shunted by means of

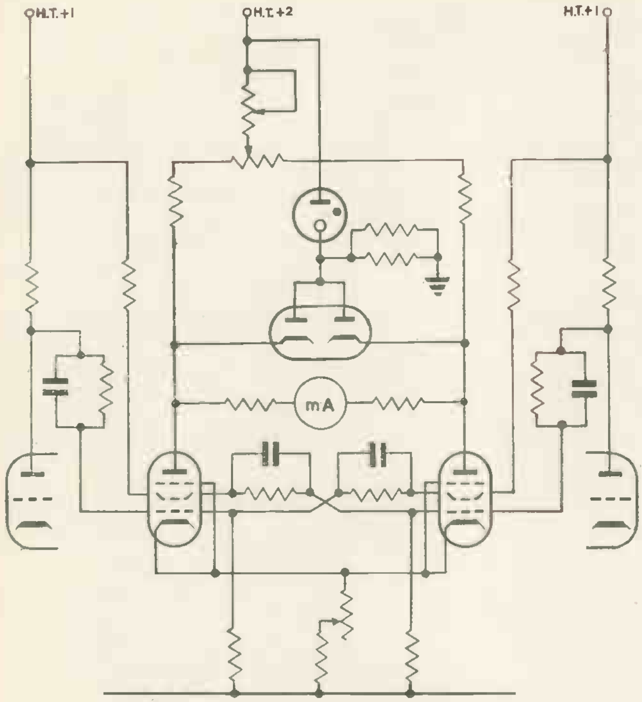


Fig. 6. Phasemeter output stage

switch S_{14} (Fig. 8) and its sensitivity halved. While it is then theoretically possible to measure phase displacements up to 360°, in practice this may be limited to say 320°, since, as already explained, that part of the phasemeter range in the neighbourhood of 0° and 360° is unusable owing to the inherent inaccuracies which are bound to be present in the construction of any voltage generator, and to the inability of the phasemeter itself to resolve very small phase displacements.

The electronic switch, which has a useful frequency range from 20c/s to 50kc/s, comprises two pentode valves connected to form a D.C.-coupled trigger pair, as shown in Fig. 6. This circuit has two stable states, in one of which the current flows through the meter in one direction, and in the other of which an equal current flows in the opposite direction. The circuit is triggered into one or other of the two states by means of pulses applied to the control grids of the valves, the pulses being derived from the two voltages between which it is required to measure the phase displacement. In order that the meter indication shall be accurate it is important that the current in the meter shall be equal in magnitude in both positive and negative senses, and it must therefore be independent of the characteristics of the two pentode valves. To achieve this a neon tube is connected from the H.T. supply to the pentode anodes through two diodes. The anode current of whichever of the two pentodes happens to be conducting at any given time then flows through three parallel paths, namely its own anode load, the neon tube in series with the appropriate diode, and the meter in series with the anode load of the other pentode. The voltage across the neon tube is constant and independent of the current passing through it, so that the current in the other two parallel paths, including that containing the meter, remains constant and independent of variations in the pentode anode current, these variations being introduced only into the path containing the neon tube.

A block diagram of the whole instrument is shown in Fig. 7 and a circuit diagram in Fig. 8, from which it will be seen that there are two identical amplifying and pulse-forming channels.

Considering one of these two channels, the input is first amplified by a two-stage amplifier, V_1 and V_2, which has stable gain, wide frequency response, and is free from phase shift and distortion. A double-diode limiter, V_3, restricts the positive excursion of the amplified signal to a value such that the grid of V_4 is never driven positive with respect to its cathode. The precise level at which this limiting occurs is determined by the setting of VR_1. This potentiometer obtains a voltage from the main H.T. supply, this voltage being fed through R_{11} to the anode of the diode V_{3b}. V_{3b} cuts off as soon as the applied voltage reaches a value which makes the cathode positive relative to the anode. The other diode, V_{3a}, is inverted and connected in parallel with V_{3b} to avoid a D.C. voltage being established across VR_1 and R_{13} due to rectification of the signal, which would upset the biasing conditions of V_4.

V_4 and V_5 comprise a D.C. trigger pair with two stable states. The control grid bias of V_4 is set critically by adjusting VR_1 so that the trigger pair may assume either of the stable states with equal ease. This ensures that V_4 will trigger on its control grid as nearly as possible at the instant when the signal from V_{3b} passes through zero on both positive and negative excursions, the actual backlash being about 0·2V.

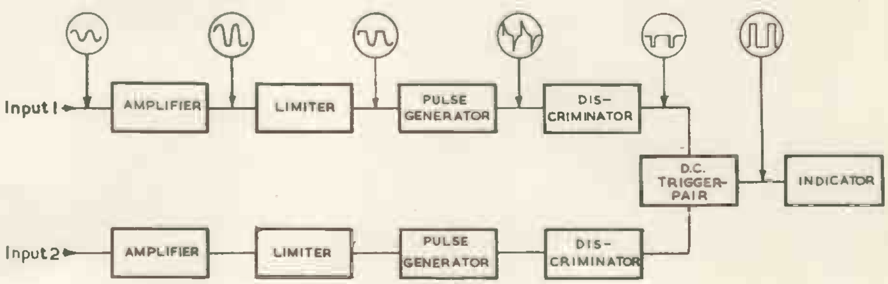
The anode current of V_5 is of square waveform of the same frequency as the input to V_1. The differentiation of this square-wave current due to the inductance of L_1 appears at the anode of V_5 as a voltage having the waveform shown in Fig. 7.

V_{6a} is a triode amplifier biased beyond cut-off so that negative pulses applied to the grid have no effect, but positive pulses of adequate magnitude receive considerable amplification and appear as short negative pulses, of 1·5μsec duration at the anode. Similar pulses appear at the anode of V_{6b} and are derived via the amplifying and limiting channel associated with the other input. Each of the two sets of pulses is time-related to its associated input.

V_7 and V_8 are the D.C. trigger pair used as an electronic switch for the milliammeter, as previously described. Either valve may be triggered by the application to its control grid of a negative pulse from the anode of the associated triode. It may also be triggered in the reverse sense by the application to its control grid of a positive pulse received from the screen grid of the other valve of the pair. The effect is that a pulse at the anode of V_{6a} or V_{6b} not only triggers its associated pentode into a non-conducting state, but also triggers the other pentode into a conducting state. The time, therefore, that the trigger pair spends in either of its two stable states depends upon the interval between the negative pulses which are arriving alternately from the anodes of V_{6a} and V_{6b}.

Adjustment of the meter current is by control VR_3, which is set so that the scale reading of the meter is 90° (2mA)

Fig. 7. Block diagram of phasemeter



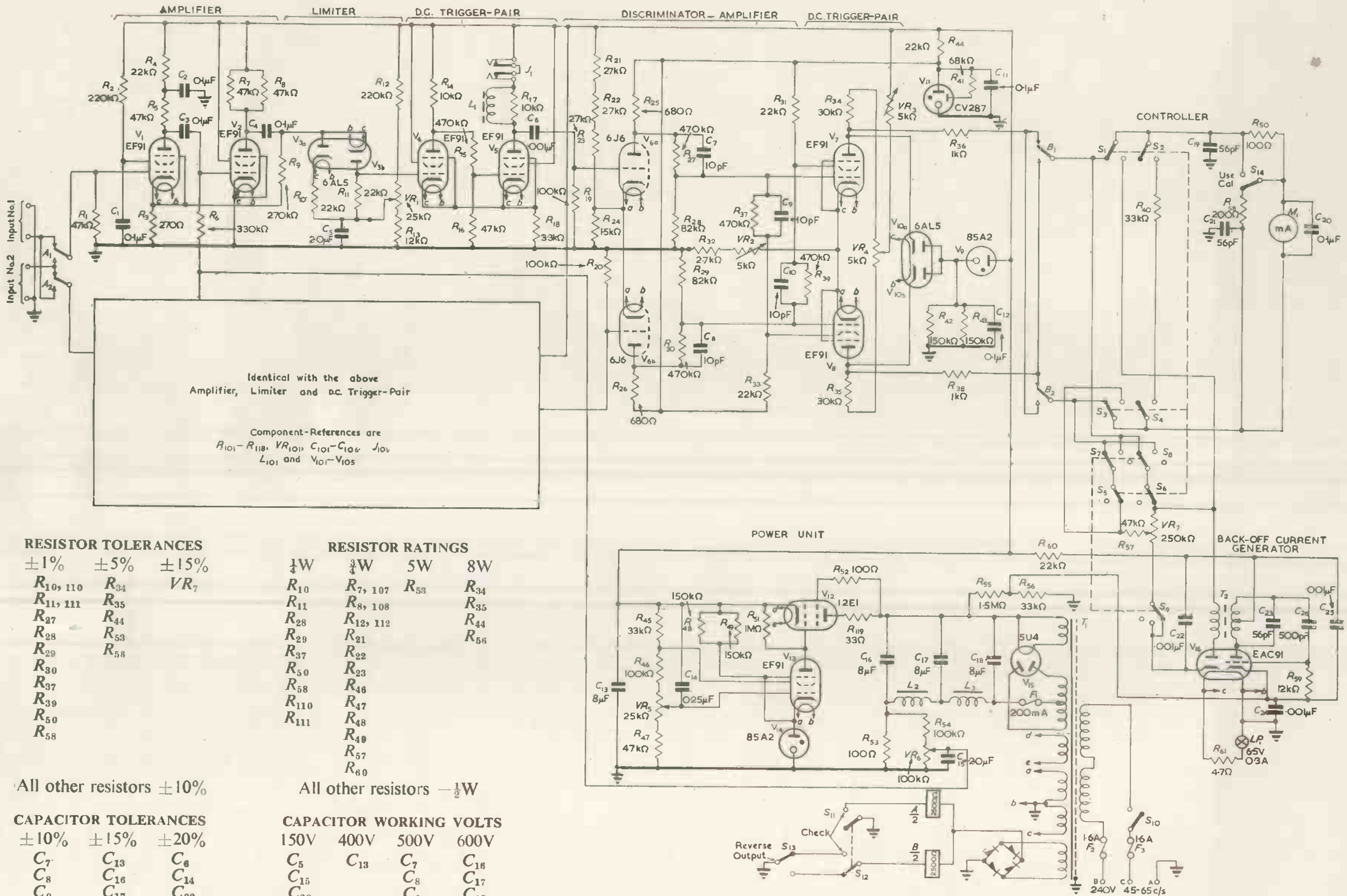


Fig. 8. Circuit diagram for phasemeter

RESISTOR TOLERANCES

±1%	±5%	±15%
$R_{10, 110}$	R_{34}	VR_7
$R_{11, 111}$	R_{35}	
R_{27}	R_{44}	
R_{28}	R_{53}	
R_{29}	R_{58}	
R_{30}		
R_{37}		
R_{39}		
R_{50}		
R_{58}		

All other resistors ±10%

RESISTOR RATINGS

½W	¾W	5W	8W
R_{10}	$R_{7, 107}$	R_{53}	R_{34}
R_{11}	$R_{8, 108}$		R_{35}
R_{28}	$R_{12, 112}$		R_{44}
R_{29}	R_{21}		R_{56}
R_{37}	R_{22}		
R_{50}	R_{23}		
R_{58}	R_{46}		
R_{110}	R_{47}		
R_{111}	R_{48}		
	R_{49}		
	R_{57}		
	R_{60}		

All other resistors –½W

CAPACITOR TOLERANCES

±10%	±15%	±20%
C_7	C_{13}	C_6
C_8	C_{16}	C_{14}
C_9	C_{17}	C_{22}
C_{10}	C_{18}	C_{24}
C_{19}		C_{25}
C_{21}		C_{26}
C_{23}		C_{106}

All other capacitors ±25%

CAPACITOR WORKING VOLTS

150V	400V	500V	600V
C_5	C_{13}	C_7	C_{16}
C_{15}		C_8	C_{17}
C_{20}		C_9	C_{18}
C_{105}		C_{10}	
		C_{19}	
		C_{21}	
		C_{23}	

All other capacitors –350V

in the shunted condition. Control VR_4 is adjusted so that this meter reading is maintained whichever of the two pentodes is conducting.

At very high frequencies, the input signals may be subjected to unequal phase shifts due to the limitations of the signal amplifier and trigger circuits, and this error may be introduced into the meter indication. The check switch S_{11}, S_{12}, which operates relays *A* and *B*, is a device for interchanging simultaneously the two amplifying and triggering channels one with the other. In this way any spurious phase shift is re-introduced into the system in a reversed sense and the difference in the meter indication at the two positions of the check switch is equal to twice the error. The mean of the two indications is the correct reading.

In some applications it may not be convenient to arrange that the inputs to the phasemeter from the voltage generators shall have zero phase displacement at the zero-torque condition, and means are therefore provided for backing-off any initial reading on the meter by injecting into it D.C. of suitable sense and magnitude. The method of generating back-off current is shown in Fig. 8. It consists of a diode-triode V_{16}, the triode section of which is arranged as a Hartley oscillator operating at about 1Mc/s. The H.T. supply for this oscillator is from the main stabilized supply and is compensated for heater voltage variation. Power in the oscillatory circuit is transferred to the secondary winding of T_2 and rectified by the diode of V_{16}, thus providing an isolated source of D.C. VR_7 gives control of the magnitude of the back-off current and switch S_7, S_8, S_9 provides reversal of the sense of the back-off current in the meter circuit. The third position of the switch allows the back-off current to be removed entirely without disturbing VR_7. The amount of back-off current can be measured directly and checked at any time while the instrument is in use by operating switch S_1, S_2, S_3, S_4.

The phasemeter will operate satisfactorily with input signals having an amplitude of between 2mV and 80mV R.M.S. Signals of unequal amplitude constitute a possible source of error, so that care should be taken that the signals are equal and as large as possible without exceeding the 80mV limit.

Since the phasemeter error is constant, accuracy of measurement can be increased if it can be arranged that the total number of electrical degrees recorded is large. So far as the meter is concerned, there is no limit to the total number of electrical degrees which can be recorded, the meter merely repeating its readings cyclically. If the milliammeter is used in the shunted condition, the current in the milliammeter circuit will change from +2mA to −2mA as each successive 360° of phase displacement occurs. There are, however, two objections to operating the instrument with the milliammeter in the shunted condition; first the fact that the meter will be working on its less sensitive range, and secondly the fact that phase displacements in the region of 0° and 360° will fall in the unusable part of the range. Both these difficulties can be simultaneously avoided by arranging that the phasemeter is used only over the range of phase displacements from 90° to 270°, corresponding to a change of the current in the milliammeter circuit from +1mA to −1mA. When the phase displacement reaches 270°, the current in the milliammeter circuit then being −1mA, the phase of one of the two inputs to the phasemeter is shifted by 180°, so that the phase displacement again becomes 90° and the current in the milliammeter circuit returns once more to +1mA. As the current in the milliammeter circuit will at no time exceed 1mA in either sense, the meter can be used in the unshunted condition and the sensitivity will be a maximum.

In view of the marked advantages of the second of the two methods outlined above, it was used as a basis for further development, the first problem then being to evolve a means of shifting the phase of one of the inputs to the phasemeter by 180°, as and when required. Such a phase shift can be most readily achieved by reversing or inverting one of the generator outputs, but in so doing it is important that certain precautions are observed. In the first place, the phasemeter has one of each pair of input terminals connected to earth so that if the output from the generator is a voltage with reference to earth, reversal cannot be obtained by simple transposition of the leads to the input terminals of the phasemeter. Secondly, inversion will produce 180° phase shift only if the waveform is symmetrical, that is to say if it does not contain even harmonics. When the generator output is a voltage with reference to earth, a transformer can be interposed between the generator terminals and the phasemeter terminals, and reversal can be effected on the secondary side of the transformer. The use of a transformer, however, is likely to introduce a phase shift which, while not objectionable if it were to remain constant, would almost certainly vary with frequency and introduce an error in the reading of the meter. On this account inversion was attempted by interposing a valve amplifier between the generator terminals and the phasemeter terminals when 180° phase shift was required, care being taken in the design of the amplifier to ensure that any phase shift which it introduced did not change with frequency. It was found, however, that the generator output was not sufficiently symmetrical to produce exactly 180° phase shift by means of inversion. The idea was then conceived of using a second generator on one end of the shaft, the two generators being so disposed relative to each other that there would be 180° phase difference in their outputs. It was further realized that if these two outputs could be combined in push-pull and subsequently split again so as to produce two voltages with reference to earth, any unbalance of the generator outputs, whether in the form of even harmonics, inequality of amplitude, or phase difference other than exact 180°, would tend to disappear. The generator outputs were combined and then split again by means of a differential amplifier in preference to a transformer, although it was appreciated that the transformer would have been simpler and equally effective had it not been for the phase shift problems which it would probably introduce.

REFERENCE

1. FIELD, J. F. The Application of Gas Turbine Technique to Steam Power *Proc. Instn. Mech. Engrs.* *162*, 209 (1950).

(*To be continued*)

New Uses for Polytetrafluorethylene (P.T.F.E.)

Polytetrafluorethylene (P.T.F.E.) is a resin-like substance unique among organic compounds in its chemical inertness, its toughness over a very wide range of temperatures, its excellent insulating properties and its unusually low co-efficient of friction.

Unfortunately these same properties of chemical inertness and non-sticking have hitherto presented difficulties of fabrication which have in turn limited its application.

Now by newly developed processes The Edison Swan Electric Co., Ltd., are able to produce P.T.F.E. bonded to metal or rubber, P.T.F.E. bonded fibre-glass laminates, continuous length P.T.F.E. cylinders and P.T.F.E. beakers for laboratory use.

Metal-backed P.T.F.E. will find a number of applications in the electrical industry. It can be readily fixed to any support by soldering or mechanical means and the adherence of the metal bond is such that satisfactory hermetic joints can be achieved.

P.T.F.E. bonded with rubber combines the flexibility of rubber with the complete chemical inertness of P.T.F.E. Laminates of this type make excellent valve and pump diaphragms, washers, seals and flexible couplings.

P.T.F.E. bonded fibre-glass laminates have excellent electrical and mechanical properties which remain unimpaired at extremes of temperature.

Relay Scale-of-Two Circuits

(Part 2)

By R. C. M. Barnes*, B.Sc.

Other Circuits with Two Relays

The remaining circuits with two relays which will be described do not include a prime pair circuit element to produce the sequence of operations when the first pulse is received. In one type of circuit the *B* relay is short-circuited during the first pulse, and the *A* relay during the second pulse, to produce the required sequence. Another type of circuit uses relays with balanced windings to prevent *B* operating during the first pulse and to release *A* during the second pulse. A third type of circuit uses side-stable polarized relays so that both relays have two stable conditions without the need for holding circuits.

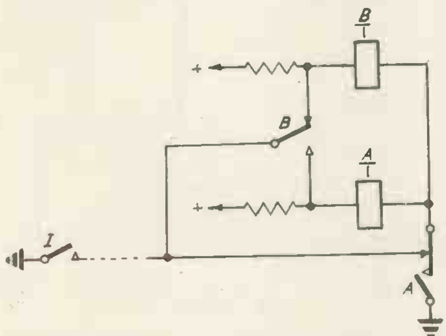


Fig. 10. Well-known circuit with single-wound relay coils

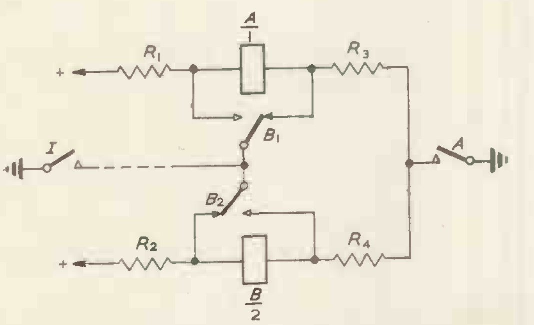


Fig. 11. Another circuit for single-wound relays

First Pulse Short-Circuits B; Second Pulse Short-Circuits A

One of the best known scales-of-two[6,7] (Fig. 10) is of this type. The sequence of operating and releasing is the same as before: *A* operates during the first pulse, *B* operates after the first pulse and *A* remains operated; *A* is released during the second pulse and *B* is released after this pulse. It will be seen that the *B* contact routes successive pulses to prevent the operation of *B* and to release *A*. The resistors are of convenient values to limit the current and protect the driving contact. The first pulse is also routed by the *A* contact to operate *A*. The make-before-break (*K*) changeover then establishes a holding circuit for *A* before disconnecting the incoming pulse. When the pulse ends *B* is free to operate in parallel with *A*.

The second pulse short-circuits *A*. The *K* contact, in releasing, connects the incoming pulse to hold *B* before disconnecting the previous holding circuit. After this pulse ends *B* releases. The short-circuit release of *A* is necessarily slow and the need for a *K* contact makes the circuit unsuitable for high speed relays and S.T.C. midget relays. The single coils and the *K* contact are suitable for "normal miniature" sealed relays.

A second circuit of this type is shown in Fig. 11 and is suitable for relays with single coils and break-before-make changeovers, such as the S.T.C. midget relay. The *B* contacts route the first pulse to operate *A* and prevent *B* from operating. The *A* contact holds *A* operated and prepares to operate *B* when the pulse ends. The *B* contacts now

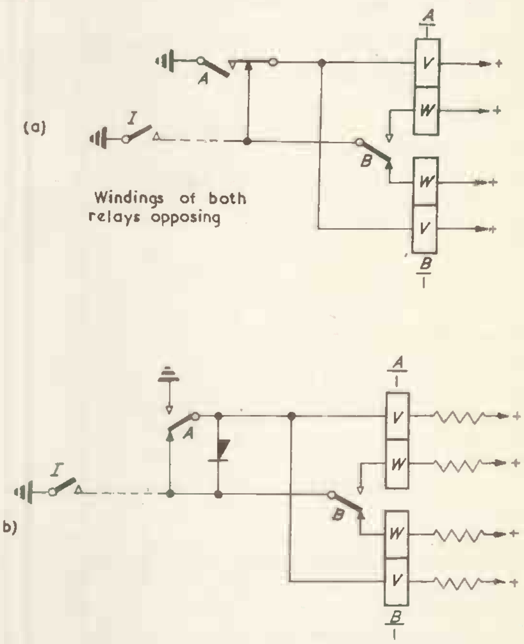


Fig. 12(a). Circuit for two relays with balanced windings. (b) Modification of Fig. 12(a).

route the second pulse to short-circuit *A* and hold *B* operated after *A* has released.

Resistors R_1 and R_2 are chosen to limit the current passed by the driving contact. Resistors R_3 and R_4 are such that, after the first pulse, the *A* coil receives not less than the rated hold current and *B*, which is in series with R_4 and shunted by R_3, receives the rated operate current. R_4 appears as a shunt across R_3 and *A* after *B* operates. Under these conditions both *A* and *B* must pass the rated hold current. The circuit has one more contact and two more resistors than Fig. 10, but may be used with relays which cannot have a *K* contact.

Two Relays with Balanced Windings[8]

In Fig. 12(a) both relays have balanced windings (i.e. windings providing equal ampere-turns). The first pulse is applied to both windings of *B* and one winding of *A*. The windings are connected in opposition so that *B* does not operate. The *K* contact connects a hold circuit to the

* *A.E.R.E. Harwell.*

A_v and B_v windings before disconnecting them from the incoming pulse as *A* operates. When the pulse ends only windings A_v and B_v are energized and relay *B* can operate. The next pulse energizes winding A_w which is in opposition to A_v. Relay *A* releases and returns windings A_v and B_v to the incoming pulse so that *A* continues to be balanced out and *B* remains operated until the end of the pulse. The circuit has two practical disadvantages. The release of *A* is retarded by the presence of a second winding in series with the power supply, and the necessity for a *K* contact and balanced windings restricts the circuit to 3 000 and 600 type relays.

These difficulties are overcome in the modified circuit of Fig. 12(b). Here the *K* contact is replaced by a normal changeover contact and a rectifier, which maintains the operating circuit of *A* during the transit time of the changeover contact. The release of *A* is improved by adding series resistors and operating the circuit from a supply of higher voltage. The balance of the *B* windings is disturbed by the forward resistance of the rectifier during the transit time of the *A* contact, but this effect will, in general, be negligible. The circuit is claimed to count 50 pulses per second with 3 000 type relays (or 600 type relays with special windings) and almost 100 pulses per second with high speed relays (e.g. Siemens type H96D).

A Circuit with Side-Stable Polarized Relays

The basic sequence demands that relay *A* should change

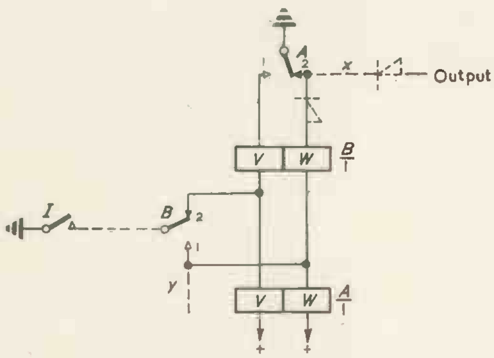


Fig. 13. Circuit for two polarized relays

its state when each pulse is received and that relay *B* should follow *A* when the pulse ends. These conditions are satisfied very simply by the circuit of Fig. 13. The relays are polarized, i.e. the changeover contacts take up one of two positions, depending on the polarity of the energization, and they are side-stable, i.e., the contacts remain in the position to which they are moved. Assume that current flowing from the positive supply through windings A_w and B_w moves the *A* and *B* contacts to position 2. Similarly current flowing from the positive supply through windings A_v and B_v moves both contacts to position 1.

When the relays are in the state shown, current flows to the *A* contact in position 2 through windings A_w and B_w in series. Both contacts are retained in position 2. The first pulse is routed by contact B_2 to the A_v winding. The current in winding A_v is twice that in A_w and the energization of relay *A* is therefore reversed. The *A* contact changes over to position 1, but winding B_v is short-circuited during the remainder of the pulse. After this pulse current flows to contact A_1 through windings A_v and B_v. The *B* contact moves to position 1. The circuit is completely symmetrical and the next pulse restores the relays to the original condition. Outputs may be taken from points x and y if the output circuits are isolated from the scale-of-two by rectifiers as indicated at x.

This circuit does not possess the objectionable feature of a relay released by a short-circuit or balanced windings so that the greater cost of polarized relays may often be justified where high speed is necessary.

Scales-of-Two with only One Relay

The circuit shown in Fig. 14 is probably the best known scale-of-two circuit with only one relay. It is controlled by two changeover contacts I_1 and I_2. In the rest condi-

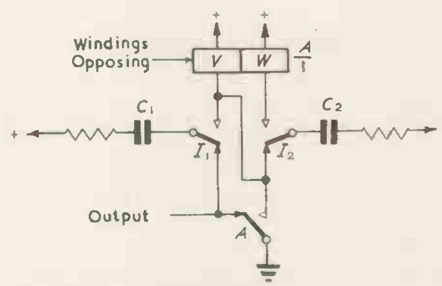


Fig. 14. Simple circuit for one unpolarized relay

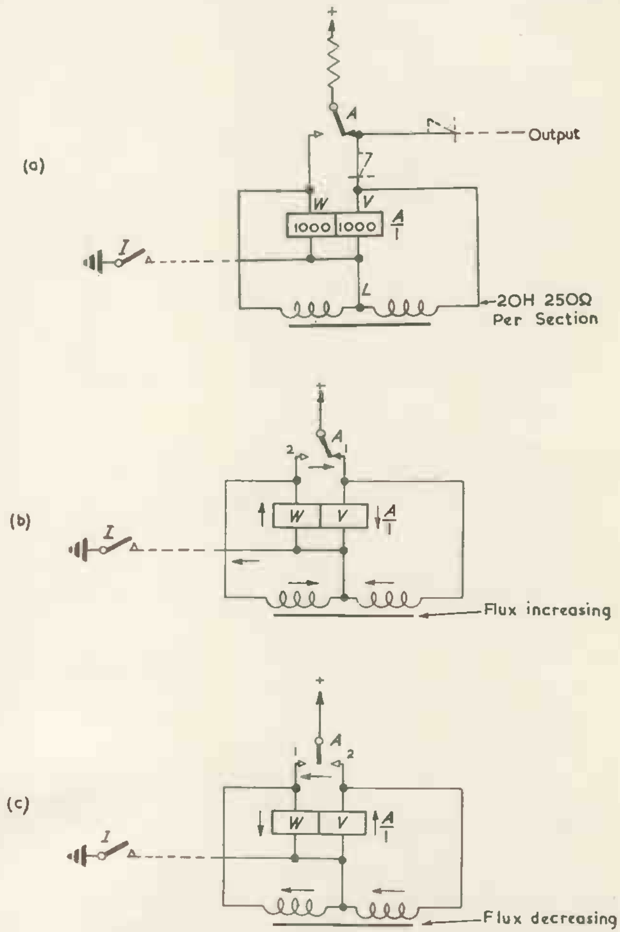


Fig. 15(a). Circuit with one polarized relay and inductance. (b) Circuit conditions with input contact closed. (c). Circuit conditions after input contact re-opens

tion, as drawn, capacitor C_1 is charged and C_2 is discharged. During the first operation of *I* C_1 discharges through winding A_v. Relay *A* operates and holds over its own make contact. When *I* releases, C_2 is charged and the condition of C_1 depends on the nature of the output load. The second operation of *I* allows C_2 to discharge through winding A_w. Windings A_w and A_v are balanced and connected in opposition so that the relay releases. The relay coil and capacitor C_2 must be chosen so that the relay does not re-operate with reversed energization. When I releases, with A released, C_1 is charged and C_2 remains discharged. The charging currents must be limited by resistors to suit the ratings of the relay contacts. The complicated input with two changeover contacts limits the usefulness of this circuit.

A more useful circuit, which is controlled by a make contact, uses one side-stable polarized relay and a choke with a centre tap (Fig. 15 (a)). The operation of this circuit will be described in detail with the aid of Figs. 15(b) and (c). Assume that the windings of the relay are drawn so that current flowing downwards through winding V or upwards through W moves the contact to the right (to position 1) and currents in the opposite directions move the contact to position 2. If the relay is in its rest condition against contact 1 it is maintained there by the side-stable feature and no current flows in the circuit.

The conditions shown in Fig. 15(b) are produced when the input contact closes. Current flows from contact A_1, through winding V of the relay and the parallel winding of the choke to earth. The increase of magnetic flux in the choke is opposed by a current induced in the other winding of the choke and relay winding W. Both these currents tend to hold the relay against contact 1.

The flux in the choke decays when the input contact opens, and currents are induced in both windings of the

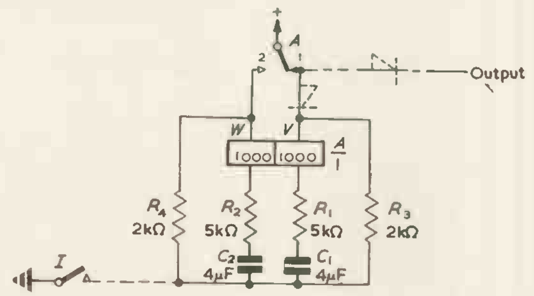


Fig. 16. Circuit with one polarized relay and capacitors

choke and relay (Fig. 15(c)) in directions tending to move the relay contact to position 2. The circuit is completely symmetrical and the next pulse returns the relay to contact 1 in a similar manner. Outputs can be taken from the A contacts if the load is isolated from the scale-of-two by rectifiers as indicated in Fig. 15(a). The circuit is claimed to operate with an input of 50 pulses per second.

A second circuit with a side-stable polarized relay is shown in Fig. 16. In this case capacitors are used to determine the direction in which the relay moves after each input pulse. In the rest condition no currents flow. If the relay is resting against contact 1 the first closure of the input contact allows current to flow through winding V of the relay to charge capacitor C_1. There is also a parallel path through R_3. Current flowing in this direction through winding 1 maintains the relay against contact 1. C_1 discharges through R_1, winding A_v and R_3 when the input contact opens at the end of the pulse. Current flowing in this direction through winding 1 moves the contact to position 2. The circuit is symmetrical and the next pulse returns the relay to contact 1. Outputs can be taken from the A contacts if isolating rectifiers are used as shown.

Fig. 17(a) shows a circuit in which there is only one unpolarized relay with a single changeover contact, but which requires a choke, a transformer and a driving contact switching the positive supply. The driving contact applies the positive supply during the first pulse and current flows in the choke L. Rectifier MR_1 isolates winding A_v during this pulse. Current continues to flow in L through the relay winding A_v and rectifier MR_1 when I opens at the end of the pulse. The relay operates and current flowing through resistor R and the transformer secondary T_2, rectifier MR_2 and relay winding A_w holds the relay operated.

The next closure of I finds the original circuit through L disconnected and current flows through the transformer primary T_1 and rectifier MR_3. The E.M.F. induced in the secondary T_2 is in such a direction as to augment the holding current in relay winding A_w. An E.M.F. is induced in

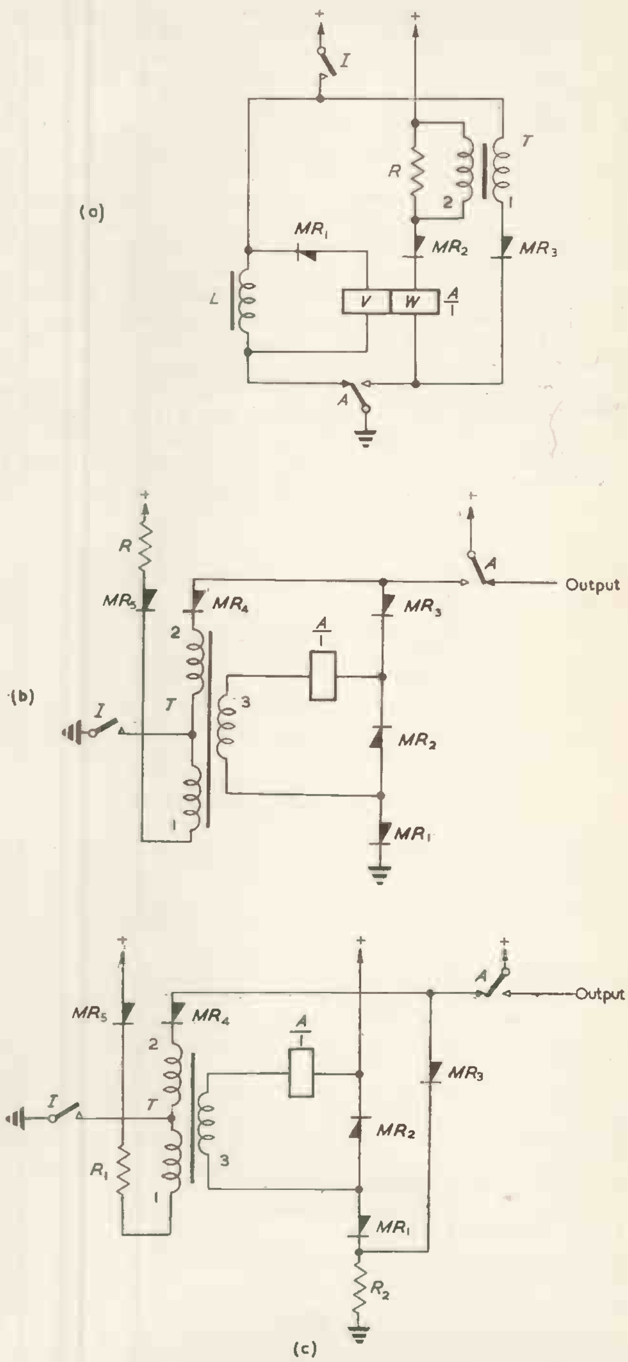


Fig. 17(a). Another circuit with one unpolarized relay. (b). Improved version of Fig. 17(a). (c). Further modification of Fig. 17(a)

the opposite direction in the transformer secondary T_2 when I opens and the supply voltage is momentarily opposed, so that the relay releases.

A more useful variety of this same circuit is shown in Fig. 17(b). Here the three inductances have been rearranged to be wound on a common core. The driving contact I is earthy. Current flows through resistor R, rectifier MR_5

and transformer winding T_1 during the first pulse. An E.M.F. is induced in the transformer secondary T_3 in the non-conducting direction of rectifier MR_2 so that the relay does not operate. At the end of this pulse an E.M.F. is induced in the opposite direction in winding T_3 and the relay operates. A circuit is then completed through the relay contact, rectifier MR_3, the relay coil, transformer winding T_3 and rectifier MR_1 to hold the relay operated. Rectifier MR_4 and transformer primary T_2 are connected in parallel with MR_5 and T_1, but in the opposite sense to await the next input pulse.

R has approximately the same resistance as each transformer primary winding and current flows in T_1 and T_2 when *I* recloses, the resultant change in flux in the transformer being in the opposite sense to that produced by the first pulse. The E.M.F. induced in T_3 therefore augments the current holding the relay operated. At the end of this pulse the E.M.F. induced in T_3 opposes the supply voltage and relay *A* releases. Rectifier MR_5 opposes the E.M.F. induced in primary winding T_1 at the end of the second pulse.

Fig. 17(c) shows a further variety of the circuit in which the make contact is free to give an output.

A recently published circuit[9] (Fig. 18) uses an unpolarized relay and is controlled by a free changeover contact. Contact A_2 provides a circuit to discharge the capacitor in the rest condition. The capacitor begins to charge up through both windings of the relay in series when the

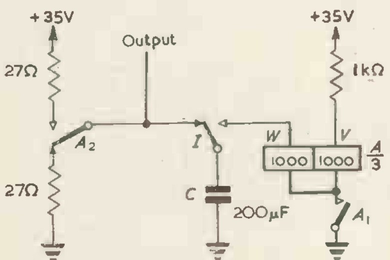


Fig. 18. Circuit for one unpolarized relay

input contact *I* operates. The relay operates and holds over winding *V*. The capacitor is sufficiently large that the voltage across it has only risen by a few volts while the relay is operating. The capacitor discharges through winding *W* after the relay has operated, but the small voltage applied to this winding does not reduce the total energization below the hold ampere-turns. The capacitor is charged through the current limiting resistor when *I* releases.

Current flows through winding *W* of the relay to discharge the capacitor when *I* re-operates. This current is twice that in winding A_V and the relay releases before the voltage across the capacitor has decreased by more than a few volts. The capacitor charges up through both relay windings when A_1 open, but the small voltage applied to the relay does not re-operate it.

Other Published Circuits

Two circuits with inherent weaknesses have been published. These will now be described and a brief reference will be made to various scale-of-two circuits which have been used as illustrations of the application of algebraic methods to circuit design.

Published Circuits which are not Recommended

Fig. 19 shows a scale-of-two using four relays[10], of which *A*, *C* and *D* were specified as high speed relays and *B* was a multi-contact relay (3 000 type) in order to provide contacts in associated circuits. The first input pulse operates *C* and *A* in series. The break contact of *C* relay prevents the operation of the slower relay *B*. At the end of this pulse *A* holds over the *D* break contact, *C* releases, and *B* operates. The next input pulse operates *D* in series with *A*, the 500 ohm resistor being necessary to prevent the *A* hold contact short circuiting *D*. When *D* operates, the hold circuit for *A* is broken. After this pulse *D* and *A* release, followed by *B*. The weakness of the circuit is that it depends on *D* and *A* having approximately equal release times. If *D* releases faster than *A* it may re-establish the condition with *A* holding over the *D* break contact. The performance of this circuit is limited by the operating and releasing speed of *B*. Many of the circuits described above give a similar performance with only two relays.

Another circuit[11] (Fig. 20) has two relays. Relay *B* has balanced windings which are used to prevent its operation during the first pulse. Relay *A* is released by short-circuiting during the second pulse. The first pulse operates *A*, which holds, and also energizes winding B_W. The B_V winding is energized to balance out B_W when *A* operates.

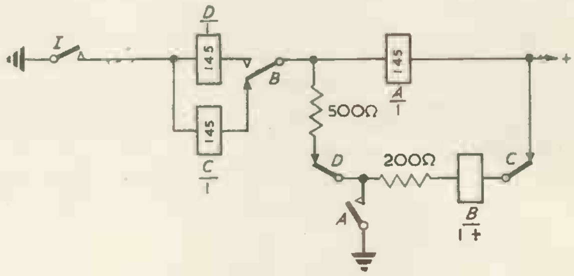


Fig. 19. Circuit with four relays

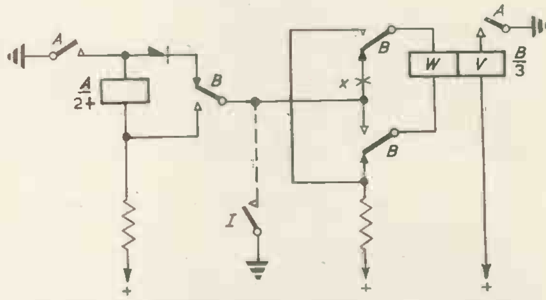


Fig. 20. An elaborate circuit with two multi-contact relays

It is therefore essential that *A* should operate before the *B* contacts break. When the first pulse ends *B* is energized over winding B_V only and can operate. The second pulse is then routed to short-circuit *A*, which releases, and also energizes winding B_W with the polarity which holds *B* operated. After this pulse *B* releases. The momentary unbalance of *B* while *A* is operating could be prevented by adding a third *A* make contact at the point x so that both windings of *B* are energized simultaneously. The circuit would then require three contacts on each relay and has no advantages compared with other circuits which have two contacts on one relay and only one contact on the other relay.

Circuits Illustrating Algebraic Design Methods

Several symbolic methods have been described which can be used to form an algebraic expression representing a relay circuit. The behaviour of the circuit can then be revealed by re-arrangement and simplification of the algebraic representation. Conversely, if the logical requirements are stated it may be possible to construct an algebraic expression which can be manipulated into a form representing a practicable circuit. Montgomerie and Lewis give examples of the application of algebraic methods to the design of scale-of-two circuits. It may be of interest to examine the circuits which have been used to illustrate these methods, bearing in mind that the principal aim was presumably not so much to produce useful circuits as to demonstrate the design procedure (for details of which the reader should refer to the original papers).

Montgomerie[12] uses a method which takes into account the finite transit time of relay contacts to derive the circuit shown in Fig. 21(a). The impulsing relay I has a changeover contact and a late break (Y contact) which breaks after the changeover action is complete. An alternative form (Fig. 21(b)), combines the make from the changeover and the late break to form a make-before-break contact.

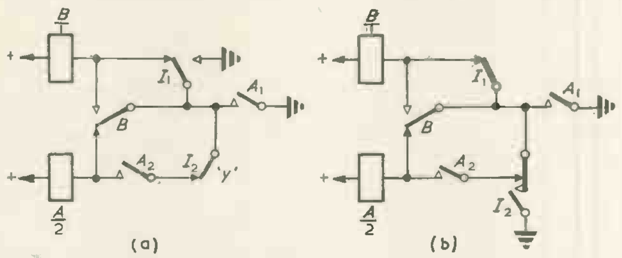


Fig. 21. Examples of an algebraic design method

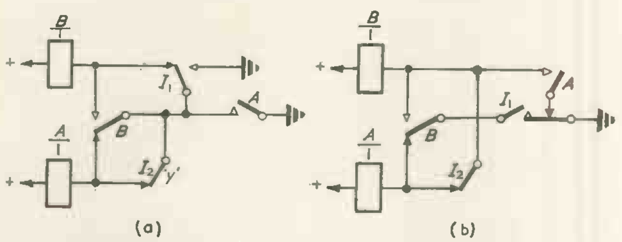


Fig. 22. Circuits developed from Fig. 21

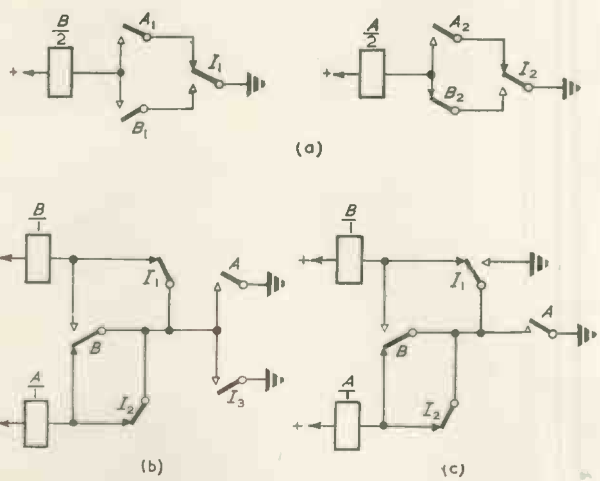


Fig. 23. Examples of another algebraic design method

Elliott [13] shows that a further simplification can be applied to obtain expressions representing the circuits of Fig. 22(a) (corresponding to Fig. 21(a) and Fig. 22(b) (corresponding to 21(b)). The requirements for the impulsing contacts in Fig. 22(a) are formidable unless it can be assumed that the transit time of the I changeover is small compared with the release time of A, in which case the I break contact need not have a late action. In Fig. 22(b) the impulsing contacts appear to be less complex but, unless it can be assumed that the I break opens before (or not long after) the K contact closes, relay B may be operated prematurely. This sequence cannot be guaranteed with standard relay adjustments.

If the complexity of a circuit is measured by the number of terminals which are interconnected it is remarkable that Fig. 1(a) has 16 interconnected points and Fig. 22(a) has only 14 interconnexions.

Lewis[14] uses a different method which does not allow for the finite transit time of the I contacts and derives the circuit of Fig. 23(a). If the I contacts are redrawn as make-before-break changeovers this circuit is practicable and has some similarity to Fig. 1, although using more contacts. He further simplifies this into the forms of Fig. 23(b) and 23(c) which will be seen to be identical with Fig. 22(a) and similar to Fig. 22(b), respectively, if the sequence of operation of the I contacts is corrected.

Acknowledgments

The author is indebted to his colleagues in the Automatics Group for their help in collecting scale-of-two circuits from various sources, and to the Director, A.E.R.E., for permission to publish this article.

REFERENCES

7. Frost, G. R. Counting with Relays. *Trans. Amer. Inst. Elect. Engrs. 68*, 587 (1949).
8. Swire, B. E. Relay Scaling Circuits. *J. Sci. Instrum. 29*, 339 (1952).
9. Corbett, B. D. A Single Relay Scale-of-Two Counting Unit. *J. Sci. Instrum. 29*, 270 (1952).
10. Deacon, E. L. Two Types of Sensitive Recording Cup Anemometer. *J. Sci. Instrum. 25*, 44 (1948).
11. McCallum, D. M., Smith, J. B. Feedback Logical Computors. *Electronic Engng. 23*, 458 (1951).
12. Montgomerie, G. A. Sketch for an Algebra of Relay and Contactor Circuits. *J. Instn. Elect. Engrs. 95*, Pt. 3, 303 (1948).
13. Elliott, R. L. Discussion on above. *Proc. Instn. Elect. Engrs. 96*, Pt. 3, 166 (1949).
14. Lewis, I. A. D. A Symbolic Method for the Solution of Some Switching and Relay-Circuit Problems. *Proc. Instn. Elect. Engrs. 98*, Pt. 1, 181 (1951).

Marconi Image Amplifier

A New Development in X-ray Diagnosis

This unit manufactured by Marconi Instruments Ltd. is a considerable development in the field of diagnostic radiology. Fitted to the screen frame of the Marconi Tilt Table, it produces an image, available in the normal viewing positions, at one-tenth of the current required with conventional fluoroscopic screens.

Among the advantages offered are greater detail, reduction of dark adaptation, due to the brighter image, and reduced radiation. Details which are present but not discernible on the conventional fluoroscopic screen are rendered clearly visible and can be recorded directly from the output phosphor by either still or cine camera using normal screening current. The long periods of dark adaptation necessary for conventional screening are largely eliminated with this brighter image. Amplification of the image also permits faster examination with low X-ray intensity, thus reducing the amount of radiation absorbed by both patient and operator.

The optical system not only serves to reorient the image, but also aligns it correctly with the patient. The viewing mirror, which provides binocular vision, is so mounted that a radiologist of any stature may view the image in perfect comfort regardless of the angle to which the table is tilted.

Normal spot-film technique can be used with the Image Amplifier connected to the screen frame and the counter-balancing suspension enables the entire Image Amplifier to be pushed up to the ceiling for parking when not in use. The Marconi "500" Tilt Table has a readily removable fluorescent screen with specially designed fittings for rapid substitution of the Image Amplifier. The use of the Image Amplifier, however, is by no means limited to this particular table and it may be readily adapted for use with tables of other manufacture, and may have many applications in industrial radiography.

Image Amplifier operation entails the substitution of an electron accelerator tube for the normal fluoroscopic screen.

This tube has its own 5in diameter fluorescent surface upon which the X-rays passing through the patient will impinge. The fluorescence excites a photo-electric plate and the electrons emitted are accelerated by a high potential applied to the tube by an external power source. A system of electron lenses focuses the inverted image on another screen 1in in diameter, where the combined effects of acceleration and minification give a considerable increase in brilliance. The optical system then reorients this image, which is viewed in a convenient mirror, at its original size.

"Starved Amplifiers"

By G. E. Kaufer*, M.S.

This article describes a type of D.C. *amplifier, known as a " starved amplifier ", in which very low anode and screen voltages are used. The design of this type of amplifier is considered in some detail, together with its advantages and possible applications.*

PRIOR to the introduction of so-called " starved " methods of valve operation, the two most widely used single valve high gain D.C. systems were the application of a high voltage power supply with correspondingly large anode load resistors and the series connexion of a dual triode which, when operated properly, yields a gain approximately equal to that obtainable from a single pentode. Both of these systems have their shortcomings and it is predicted that, as more engineers become familiar with starved amplifiers, this circuit will take a leading place among the older, more standard modes of operation.

The chief drawback in employing a large load resistor and attempting to operate the valve so that its mutual conductance is large lies in the power supply requirements. If normal valve operation is contemplated (which will yield mutual conductances in the order of 4mA/V for the average pentode) with the hope of securing a stage gain approximating the product of g_m and R_a, it is true that this gain will continue to rise as the load resistor (R_a) is increased, but the anode supply voltage will increase proportionately. Reasonably high values of g_m are obtained only with substantial valve anode currents and Ohm's law imposes its limitations on this circuit. A definite advantage which must not be overlooked in passing, however, is the fact that, since the quiescent potential appearing between anode and cathode of the pentode is in the order of that found for normal valve operation (100 to 400 volts for most receiving type pentodes) the anode swing can be made large. This circuit is capable of handling a fairly large input signal and yet will deliver a large undistorted output voltage. Operation is reliable and stable, as the valve is operated under the normal specified conditions. As a D.C. amplifier, the usual coupling problems arise since the anode is at a fairly high D.C. potential with respect to cathode. Design is simple and foolproof, involving the selection of a suitable quiescent point, determining the required load resistor knowing the desired stage gain and the mutual conductance at the quiescent point selected, and then plotting the load line on the standard anode characteristics (for the correct screen grid voltage) for the R_a chosen from the knowledge that the slope of this line is equal to the reciprocal of R_a and it must pass through the given quiescent point. The intersection of this load line and the abscissa $i_b = 0$ gives the required anode supply voltage.

The second method (see Fig. 1), even more popular than the first because of its added feature of providing dual inputs while requiring nothing in the way of extraordinary components or voltages, yields a gain (from g_1 to the output) approximating $g_m R_a$. Incorporating a dual triode, it combines the high gain and stability of a pentode amplifier with the low noise characteristic of a triode amplifier. This circuit is commonly employed as a mixer and amplifier at radio as well as at audio frequencies. Stage gains are not " high " in the true sense of the word since, as the mutual conductance of a triode is approximately of the same order of magnitude as that of a pentode (g_m is determined by grid-cathode electrode spacing and other features of tube construction) the magnitude of load resistance again imposes the limitations on the gain obtainable. The gains of both inputs are far from equal. Care in selection of valve types in the design of the cascode amplifier is necessary. Caution must be used since the heater-cathode potential of one section is high and the valve ratings must not be exceeded. Types 6BQ7 and 6BK7 have been developed especially for this application, incorporating a high g_m, a 200V peak heater-

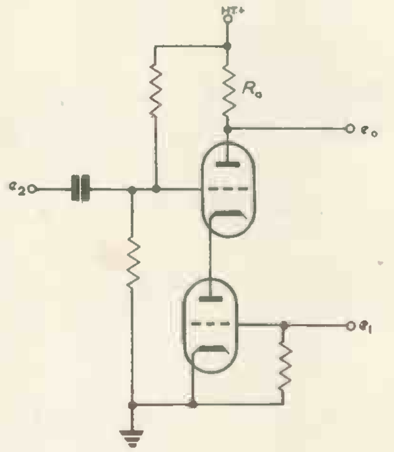
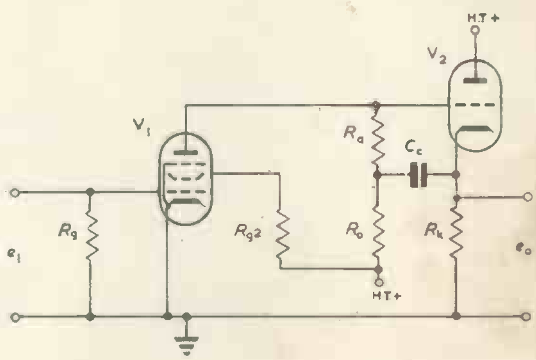


Fig. 1 (left). Cascode circuit

Fig. 2 (below). Experimental high gain D.C. amplifier

C_c determines low frequency limit.



cathode potential (as high as 300V under special conditions of operation), low interelectrode capacitances and an internal shield for circuit isolation. When used as a D.C. amplifier, the usual coupling problems exist since the valves draw normal current and the quiescent points are standard in every respect.

A circuit, too recent to be considered at this point since it is still in the early stages of development, has come to the author's attention. It is capable of producing very large stage gains (in the tens of thousands) by employing a second valve as a large dynamic anode load for the high gain stage. Referring to Fig. 2, V_2 reflects back into the anode of the preceding stage a load impedance equal to the actual load resistor (R_a) multiplied by a factor equal to the reciprocal of $(1-K)$ where K is the gain of V_2.

* *Columbia University, New York.*

The ideal load for starved amplifier operation is thus provided while still maintaining a high g_m, as valve potentials are standard. By nature of its operation, however, this circuit does require two valves per stage of gain although its phase shift and other characteristics are seemingly equivalent to that of a single valve. While this circuit works well for audio frequencies, further experimentation along the line of coupling methods is necessary (neon bulbs are used at present) until it can be made to perform adequately and reliably on direct current input signals.

In the circuit illustrated in Fig. 3 $E_2 \ll E_{bb}/10$ and the load resistor is greater than one megohm. Such a circuit, known as a "starved amplifier", is capable of producing three or more times the gain obtainable from the same valve wired as a conventional amplifier, even though the mutual conductance of the starved valve is considerably decreased. Although certain disadvantages accompany this mode of operation, they are far outweighed by the features gained.

Advantages

Starved amplifiers have many distinct advantages which, when fully realized and utilized, will make this circuit outstanding in its class. With this mode of operation, one can obtain stable, high gain amplification, requiring fewer valves for a given gain than with other conventional cir-

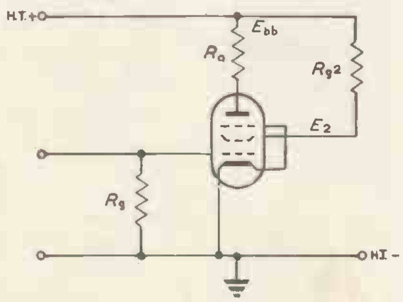


Fig. 3. Basic "starved amplifier" circuit

cuits. The circuital phase shift is therefore reduced (a maximum of 90 degrees phase shift per stage of amplification) and hence more feedback can be applied to the circuit for stability. In fact, such a circuit is ideally suited for applications where a high base gain is desired for proper operation and then an overall feedback loop is closed to get the nominal gain, bandwidth, stability, etc. Internal feedback loops are readily added to this circuit, the commonest forms consisting of screen voltage control. In extreme cases, the signal may be fed into the cathode of the starved stage with feedback loops encompassing both screen and control grids. Because of the high load resistances employed, loading effects of the following stage may be severe unless a cathode-follower is resorted to. The starved amplifier-cathode-follower combination, however, has the added feature in that, while consisting of a complete and stabilized unit (internal feedback loops from cathode-follower load to screen and/or control grid of starved stage), it is capable of delivering power to an external load, while at the same time preserving the high frequency response of the amplifier (which, incidentally, is poor to begin with because of the high resistances employed).

All D.C. amplifiers are inherently susceptible to drift because a slight change in grid to cathode voltage in the first stage (due to a slight variation in anode supply or heater voltage, resistor drift, or valve unbalance) is amplified in succeeding stages providing a large change in output voltage. In starved amplifiers, all the gain is concentrated in a single (or comparatively few) stage, thereby confining all minor voltage variations which will have any effect to the input to this one stage. Since the aforementioned is true, if that stage is stabilized, the entire amplifier is stabilized.

Throughout this discussion, it must be borne in mind that the starved amplifier is basically a direct coupled amplifier, lending itself admirably to this application. Problems of interstage coupling, the scourge of D.C. design, are reduced to almost nill, since the D.C. voltage appearing on the anode of the starved stage is quite low and can easily be fed into the grid of the succeeding stage with few attendant difficulties.

Multiple stages of starved amplification are also easy to come by if the anode load resistors are reduced to more nominal values in all stages following the first. The necessary decoupling for three or more stages may be made quite thorough and compact by connecting a 2MΩ resistor by-passed with a 0·05μF capacitor in series with the anode load to the first stage (or first two stages as the case may be). The reduction in physical size and cost of the decoupling capacitor is made possible by the large value series resistor employed. As the current consumed by the

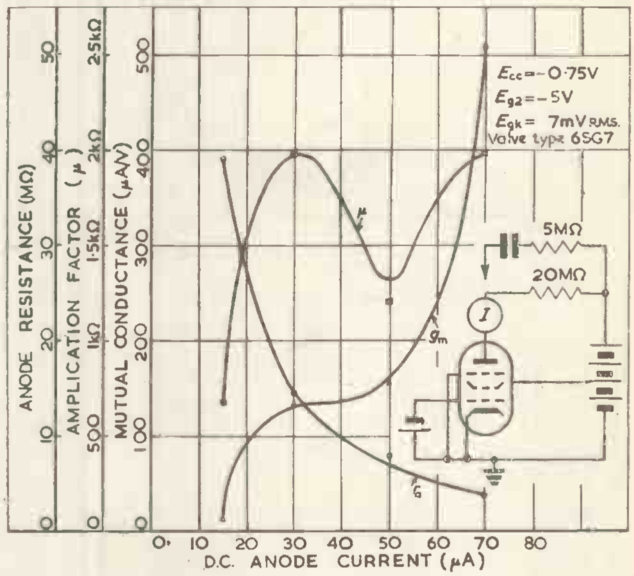


Fig. 4. Variation in valve parameters as a function of anode current

input starved stage can be made quite low (the valve is required to handle only a small input swing), the drop across the series element of the filter is not prohibitive.

Mention must be made of the fact that a negative H.T. supply is not required for normal operation of a starved amplifier stage. Power supplies employed are standard in every respect. A further saving can be effected in the supply components since current consumption is reduced by this method of operation.

When the remaining features of, (1) inexpensive design which leads to compact packaging due to the minimum number of circuit components needed, (2) long valve life due to the low voltages on the elements and the subsequent low current drawn from the cathode, and (3) the possibility of eliminating all effects due to electrostatic and electromagnetic pick-up on the grids of the high gain stages by special design of push-pull circuits are considered, one can readily realize the large number of applications of the starved amplifier, some of which will be discussed later.

Theory

For a pentode with high load resistance, g_m decreases with increasing anode load if the supply voltage is kept constant. To raise the gain of the stage, one must increase the anode resistance of the valve, since $\mu = g_m r_a$. This can be accomplished readily by lowering the screen voltage. The starved stage thus obtained will then be found to exhibit a higher gain characteristic than that of the pentode with normal screen voltage, high load resistor and the same anode supply voltage. The principle underlying this method of operation is that, although the transconductance is decreased to a small fraction of its normal value, the anode resistance increases at a much greater rate over a portion of the operating curve and hence the μ of the valve increases. As can be seen from an examination of a typical μ/I_a curve (see Figure 4), this analysis cannot be extended to include continuingly increasing values of load resistance, as a point is reached at which the μ of the valve will drop off rapidly and continue to drop at a fast rate as valve current is further decreased.

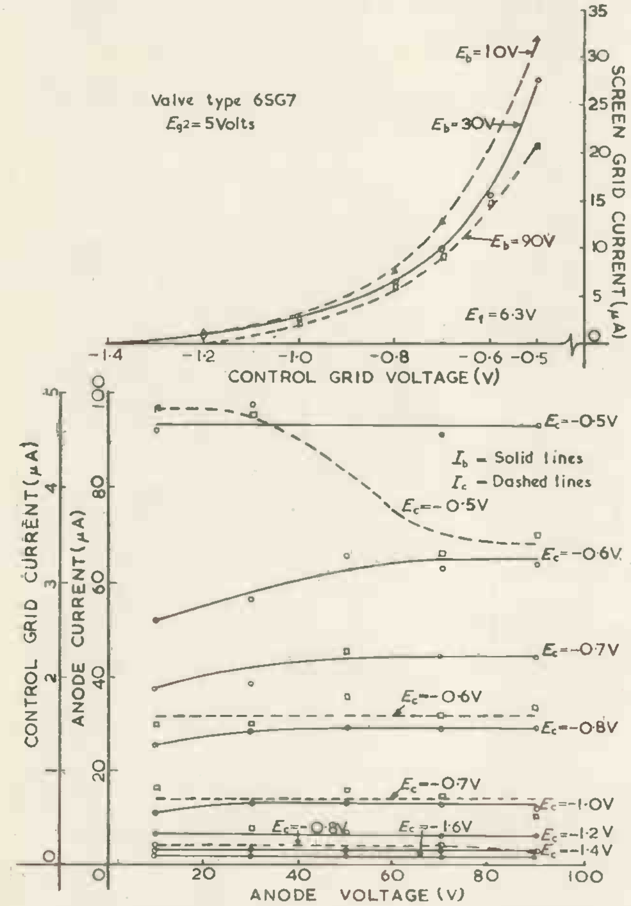


Fig. 5. Static characteristics of 6SG7 for screen voltage of 5V

This illustrates the fact that there is an "ideal" operating point for each valve, one which will yield a maximum gain for a given set of operating conditions (for a given screen and anode supply voltage, there is a definite value of anode load resistor which will give maximum stage gain).

It is not possible to maintain zero grid current in a D.C. amplifier stage in which anode current is flowing. The grid current is a function of the anode current and may be made relatively constant by operating at low anode levels. The starved amplifier circuit fully utilizes the constant grid current feature as low anode current is inherent in its design. Reference to the curves found in this article indicate the validity of the aforementioned statement where operation does not permit the anode current to exceed 50μA (quiescent points are usually chosen well below this figure).

Valve Data

Before one can begin to consider the design of a starved stage, one must first become familiar with the orders of magnitude of the valve parameters and their manner of variation under these special operating conditions. It is necessary to recall at this point that a starved valve must, by definition, satisfy two stringent requirements: the screen voltage must be less than 10 per cent of the anode supply voltage and, the current which would flow when the valve is connected as a diode (all grids connected to the anode) must be 1 000 or more times larger than the load current when the valve is wired as an amplifier employing a load resistor and the same supply voltage source.

The initial procedure is therefore apparent. Since valve

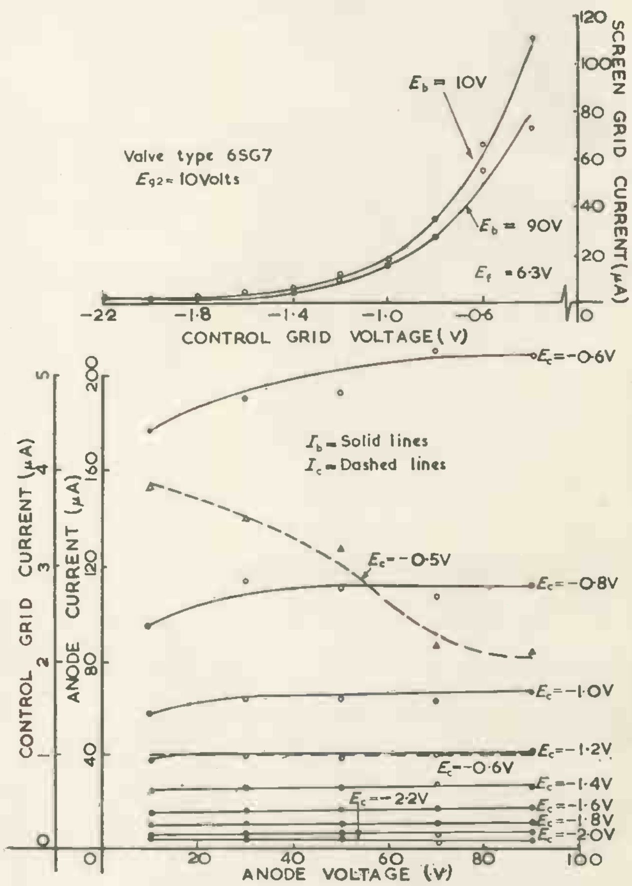


Fig. 6. Static characteristics of 6SG7 for screen voltage of 10V

parameters for the low operating potentials used are not normally supplied, they must be determined (at least approximately) by the designer. Typical curves for the type 6SG7 octal and the type 6AG5 miniature pentodes have been obtained by the author (see Figs. 5, 6, 7 and 8) and are reproduced here for convenience. It it necessary to differentiate between the A.C. resistance and the D.C. anode resistance, two entirely different quantities. For a given operating point, this latter value is equal to the reciprocal of the slope of the line joining the origin and the point in question on the anode characteristics of the valve (see Fig. 9). To illustrate this difference more strongly, it may be stated that under certain conditions of starved operation, the A.C. anode resistance may be of the order of 40MΩ whereas the D.C. value is approximately 1MΩ.

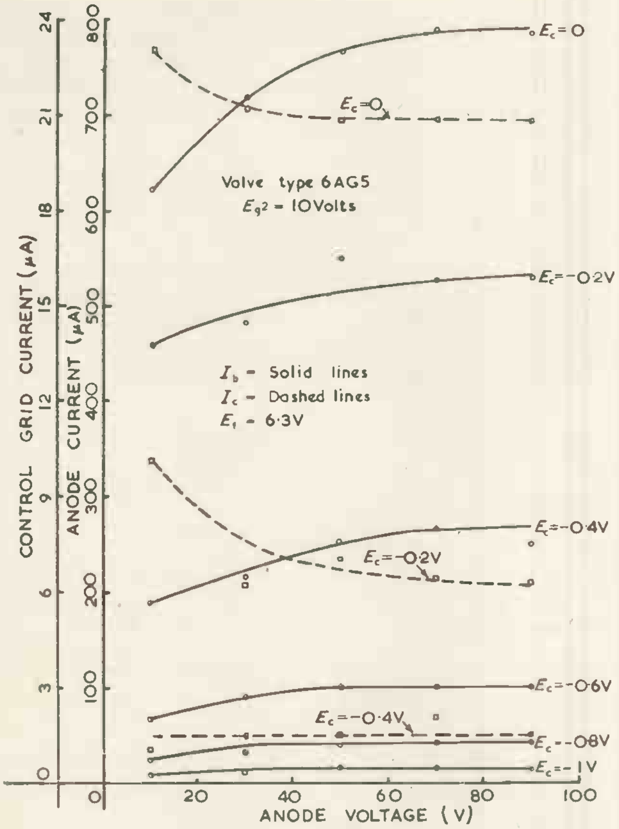
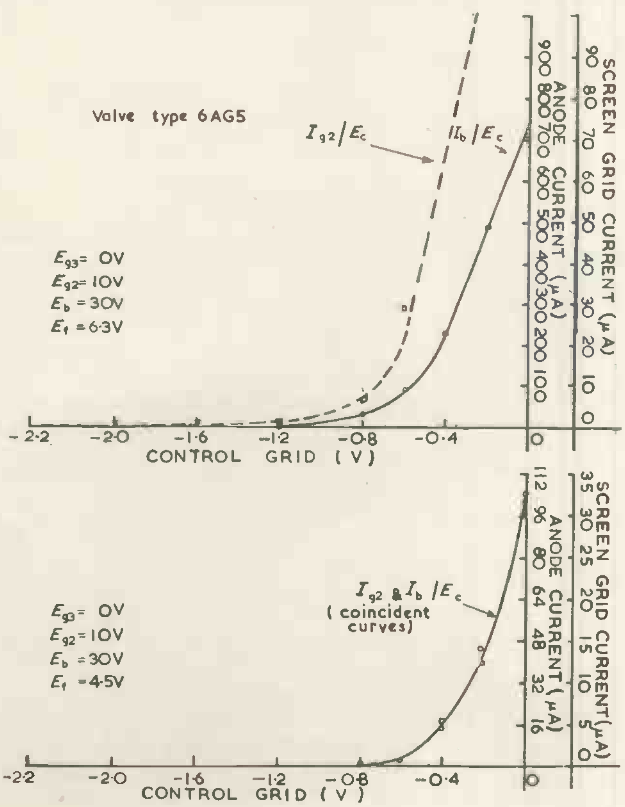


Fig. 7. Static characteristics of 6AG5 for screen voltage of 10V

Fig. 8. Anode and screen current/control grid voltage for 6AG5



Analysis of Results

It is interesting to note that, while five valves of each type were tested, the resulting data obtained from each differed greatly. In an effort to correlate this discrepancy with a characteristic of the valve which can be measured

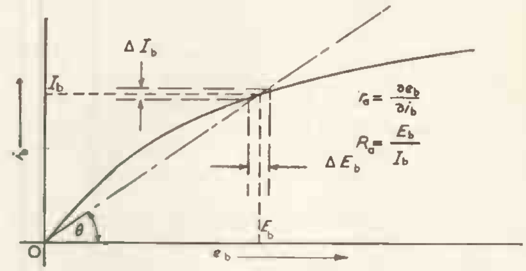


Fig. 9. Graphical determination of anode resistance

under normal operating conditions, all valves were first checked in an emission type valve tester and were found to indicate on exactly the same portion of the meter scale. The next test was that of mutual conductance, this quantity being measured on a commercial dynamic valve tester. In this respect, a difference in readings was obtained and it was found that a definite correlation pattern resulted, as can be seen from the tabulation of results in Table 1 for both 6SG7 and 6AG5 valves.

Examination of the data shows that in all cases, as the mutual conductance of the tube as measured under normal operating conditions is increased, the quiescent anode current under starved conditions of valve operation is decreased for a given anode voltage. This is of interest in that a given set of curves for starved operation can be adapted (qualitatively speaking) to other valves of the same type or possibly even of different types (provided the normal operating conditions are similar) by a simple measurement of the mutual conductance on a reliable, standard valve tester. There is thus a method of circumventing the "critical" aspect of starved circuit design, since matching of valve g_m's under normal operating conditions is equivalent to matching them under actual conditions of starved operation.

The magnitude of the space current in a pentode is

TABLE 1

6SG7		6AG5	
MUTUAL CONDUCTANCE	ANODE CURRENT	MUTUAL CONDUCTANCE	ANODE CURRENT
(mA/V)	(μA)	(mA/V)	(μA)
3·180	50	4·080	30
3·100	77	4·000	33
2·910	90	3·930	116
2·870	180	3·700	200
2·840	330	3·360	410

determined almost entirely by the control grid and screen grid potentials. The anode potential determines only what fraction of space current is transmitted to itself. It does, of course, have a second order influence upon the anode current, with the result that I_b rises slowly as the anode voltage is increased. Thus, as can be seen by referring to the anode characteristics, all of the curves are similar in shape and differ only in scale. The space current (see Fig. 10) is even more constant with anode voltage than is the anode current. The only departure from near constancy occurs near zero anode voltage. Here the space current increases by about 20 to 40 per cent as the anode voltage is increased to about half of the screen grid potential. This increase in space current occurs because there is a change in the space-charge conditions around the screen grid as the condition of reflexion of electrons from the anode changes to one of transmission.

Although not proven here, use can be made of the fact that the suppressor grid is able to control the fraction of the current transmitted past the plane of the screen grid that goes on to the anode. When the suppressor is at a low potential relative to the anode and the screen grid, as it usually is, it can sort out the electrons having a large component of energy directed towards the anode from those which, because of deflexion on passing close to a screen grid wire, have a lower component of anode directed energy. The anode voltage is moderately sensitive to suppressor grid voltage and the suppressor is readily capable of completely cutting off the flow of anode current.

The use of a positive suppressor potential will give considerable sharpness to the shoulder of the anode characteristics. An important fact to note in connexion with this is that for negative suppressor voltages the anode resistance decreases with increasingly negative applied voltages. This is evident from an inspection of the anode characteristics (Fig. 11). The reverse effect is true to some extent, and hence slightly positive sup-

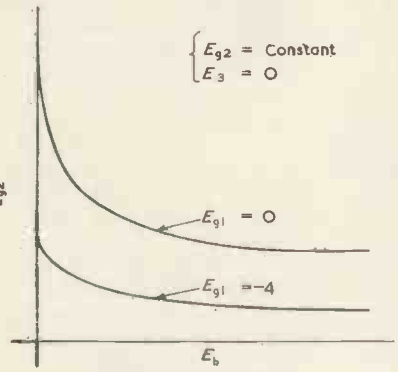


Fig. 10. Space current

pressor voltages offer additional possibilities for obtaining a higher gain per stage.

Another fact worth mentioning at this point in conjunction with the valve characteristics is the rather high control grid current flow which presents additional problems and must be considered in the design of a starved stage.

Design Considerations

Performance to be expected from a given design must be viewed with caution due to the considerable differences between valve types, the critical nature of the operating voltages where maximum gain is desirable, and the low operating currents involved. An approximate design may be carried out on paper, the final adjustments being made by trimming or adjusting the screen voltage of the unit after construction has been completed. Certain items must be kept in mind while determining component values and circuit voltages and a typical design procedure would be somewhat as follows assuming the proper characteristics for the valve type selected are available (if a stage gain not in excess of one thousand is desired, the graphs included in this article may be utilized as a first approximation. These curves were obtained from a type 6SG7 valve with a normal mutual conductance of 3·15mA/V):

1. From the μ/I_b curve, select a quiscent anode current which lies slightly to the right of the highest peak. (If a lower stage gain may be tolerated, select an anode current such that the μ of the valve remains approximately constant as I_b is varied slightly to either side of the quiescent point.)

2. Determine g_m of the valve for the anode current selected above by referring to the g_m/I_b curve.

3. Choose a suitable load resistor (usually from 3 to 20MΩ) from a knowledge of the desired stage gain and the approximate relationship: $R_a = K/g_m$ (which is applicable when the anode resistance is high compared to the load resistance).

4. For a given anode supply, draw a load line on the anode characteristics, selecting two sets of values for end points such as: (a) $I_o = E_{bb}/R_a$, $E_b = 0$;

(b) $I' = 9E_{bb}/10R_a$; $E_b = E_{bb}/10$.

5. Knowing the anode current, locate the quiescent point on the graph and read off the bias voltage. At this point the anode current or load resistor may have to be revised if the bias is found to be too low (not negative enough).

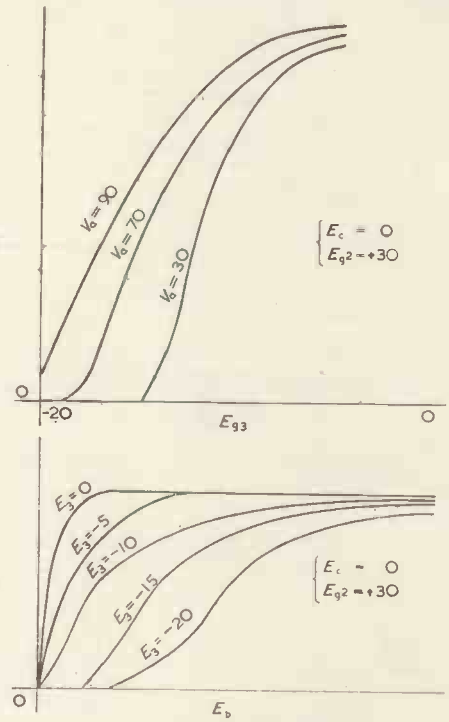


Fig. 11. Anode characteristics

6. A suitable method of biasing must now be selected. From the E_c/I_c curve, note the grid current flow for the bias voltage determined above. If it is zero, the bias must be obtained by inserting a resistor in series with the cathode of the valve such that $R_k = E_c/(I_b + I_2)$. If a definite value of grid current flows, economy may warrant the utilization of the grid resistor as the biasing device (rather than employing a transformer input or low resistance grid leak and cathode biasing), and this resistor must be chosen such that $R_g = E_c/I_c$.

The advantage of cathode bias is that grid current flow, with its inherent distortion of the signal, can be eliminated. Select a high enough negative bias so that the grid current is zero for quiescent operating conditions and for the range of grid swing in question (which is usually less than five millivolts). This assures a more stable design and less difficulty is encountered when valves are replaced.

7. Design the following stage, preferable a cathode-follower for minimum loading (the anode load of the starved stage acting as the grid leak for the cathode-follower), to provide the desired screen voltage from a cathode divider. If this voltage source is made variable to a slight degree, any design errors can be compensated for in the completed circuit by making a slight adjustment

at this point. This method of securing the screen grid voltage also provides for the necessary stabilization of the stage.

It will be found that the screen voltage influences the linearity of the stage to a large degree. When substantial anode swings are involved the screen voltage must be adjusted with this fact in mind; optimum voltage being about 80 per cent of the quiescent anode voltage.

Factors which should not be overlooked in this design include:

1. Bandwidth is exchanged for gain, the frequency response of the stage decreasing with increasing anode load resistance (upper frequency limit is of the order of 2kc/s for a 15MΩ load). Another limitation imposed on the magnitude of the load resistor is that it cannot be made too high since it is the grid resistor of the following stage.

2. If desired, a compensating network consisting of a parallel *RC* combination may be added in series with the grid of the starved stage to prevent positive grid operation and high frequency oscillations. If low frequency operation only is desired, a small by-pass capacitor (10 to 50pF) from the anode of the starved stage to earth will help improve the stability of the system.

3. In critical systems an internal gain control may be desired to compensate for valve replacements. If high quality components are used in the networks which determine the operating potentials of the starved stage, little difficulty should be experienced with gain variations during the life of the valve.

4. With both internal and external feedback loops applied, reliability of circuit operation is quite good. It is not possible, however, to cancel drift due to variation in filament potential with inverse feedback. A regulated filament supply or auxiliary valve cancelling circuit must be employed for this purpose where extremely high gain and critical circuits warrant its use. For oxide coated cathodes, a 10 per cent increase in heater voltage is the same as a cathode-potential decrease of about 0·1V.

5. In cascading stages for high gain, it must be remembered that the ultimate gain attainable is limited by the inherent noise of the system as well as problems of instability. As will be shown in the following section, the equivalent noise voltage is higher for starved operation than for normal operation of the same tube.

Valve Noise

Random noise similar in character to that produced in a resistor is generated in valves as a result of irregularities in electron flow. The equivalent grid resistance R_{eq} representing the noise of a negative-grid pentode amplifier is given approximately by the relations:

$$R_{eq} = \frac{I_b}{I_b + I_2}\left(\frac{2{\cdot}5}{g_m} + \frac{20 I_2}{g_m^2}\right) = \frac{2{\cdot}5}{g_m}\left(\frac{\quad}{I_s}\right)\left[1 + 8\frac{I_2}{g_m}\right]$$

Using the latter relationship, the relative noise for normal against starved operation of a type 6SG7 pentode can be computed as:

Normal operation:

$E_{bb} = 250\text{V}$ $\quad I_b = 11{\cdot}8\text{mA}$

$E_2 = 125\text{V}$ $\quad I_2 = 4{\cdot}4\text{mA}$

$g_m = 4{\cdot}7\text{mA/V}$ $\quad I_s = 16{\cdot}2\text{mA}$

$$R_{eq} = \frac{2{\cdot}5}{4700 \times 10^{-6}}\left(\frac{11{\cdot}8}{16{\cdot}2}\right)\left[1 + 8\left(\frac{4{\cdot}4 \times 10^3}{4700}\right)\right] = 3\,300\Omega$$

Starved operation:

$E_b = 50\text{V}$ $\quad I_b = 29{\cdot}3\mu\text{A}$

$E_2 = 5\text{V}$ $\quad I_2 = 6{\cdot}0\mu\text{A}$

$g_m = 0{\cdot}125\text{mA/V}$ $\quad I_s = 35{\cdot}3\mu\text{A}$

$$R_{eq} = \frac{2{\cdot}5}{125 \times 10^{-6}}\left(\frac{29{\cdot}3}{35{\cdot}3}\right)\left[1 + 8\left(\frac{6 \times 10^{-6}}{125 \times 10^{-6}}\right)\right] = 22\,960\Omega$$

The equivalent resistance calculated for normal operation corresponds to a noise voltage of 0·53μV, whereas that for starved operation is equivalent to a noise voltage of 1·4μV. The latter operating condition thus increases the noise by a factor of approximately three.

Applications

1. Pre-amplifier for use with low gain amplifiers and magnetic direct writing oscillographs (current models have a frequency response relatively flat from D.C. to 100c/s and are ideally suited for use in the medical field for the measurement of brain, heart and nerve potentials in the microvolt range).
2. Amplifier for use with magnetic pen-motor.
3. Transient recorder amplifier for low frequency phenomena.
4. Photocell amplifiers.
5. D.C. servo-amplifiers.
6. D.C. valve millivoltmeters and microammeters.

Conclusion

A starved amplifier does not employ any new or unusual circuit components to achieve its relatively high stage gain. The circuit is basically simple, the essentially "new" aspect involving the investigation into the method of variation of the valve parameters at low anode and screen voltages. Further exploitation of this circuit will undoubtedly lead to the manufacturing of valves especially designed for this type of service, alleviating many of the current disadvantages restricting its use.

BIBLIOGRAPHY

1. Volkers, W. K. Ultra High Gain Direct-Coupled Amplifier Circuits. Paper presented at the I.R.E. 1950 National Convention.

Communications in the Antarctic

Wireless reception is notoriously bad in the Antarctic. The noise level is high, there is a great deal of static, and in the winter the aurora australis causes heavy interference. Despite these difficulties a recent expedition based at Hope Bay in North Graham Land, some 700 miles to the South East of Cape Horn, was able to maintain close radio-communication both with the sledge parties operating from the base and with other expedition bases in the Antarctic. The sledge parties were equipped with Services Type T68 transmitter-receivers, and a BRT 400 communication receiver, made by The General Electric Co. Ltd., was used at Hope Bay.

The expedition forms part of the Falkland Islands Dependencies Survey, which exists for the purpose of making a biological, geographical and geological survey of Graham Land and the neighbouring regions. In the course of the survey bases have been established at various points and sledge parties go out from these centres to survey the surrounding terrain. From Hope Bay such parties operate up to 300 miles from base in the winter when, though radio reception is more difficult, conditions are more favourable for long journeys than in the summer.

Radio communication is essential for relaying weather information back to the Falkland Islands for requesting supplies and for similar purposes.

The Hope Bay had to relay three hourly weather observations made by the expedition to Port Stanley where they were incorporated in a forecast for shipping in the South Atlantic; frequencies of 4·4, 5·8, 5·9 and 7·3Mc/s were used for these transmissions. The Hope Bay base was also in contact with other stations in the Falkland Islands, Deception Island, Admiralty Bay, Port Lockroy, the Argentine Islands and Signy Island, using frequencies of 1·6, 2·2, 4·4, 4·7 and 3·8Mc/s. In addition, the communication receiver was used for entertainment and the expedition was able to pick up broadcasts from England.

LETTERS TO THE EDITOR

(We do not hold ourselves responsible for the opinions of our correspondents)

A Transistor Performing the Dual Function of Rectification and Amplification for Chemical Analysis at Radio-Frequencies

Dear Sir,—The employment of conductimetric analysis now covers quite a wide commercial field. For example it is used for ascertaining the percentage of water in alcohol. In botany and agriculture to determine the acidity or alkalinity of soil. Leather tanners use it to determine the presence and quantity of acid in tan liquor. It is employed also for the analysis of wine and beer. To estimate the acidity of fruit and fruit juices. To compare and measure the concentration of solutions and for many other purposes[1,2].

When such work is carried out by rectified radio-frequency it is essential to use very small currents to avoid any detectable rise in the temperature of the solution. In the case of the author's R.R.F. method where a conductimetric tube is used it is usual to work with currents not exceeding 60μA.

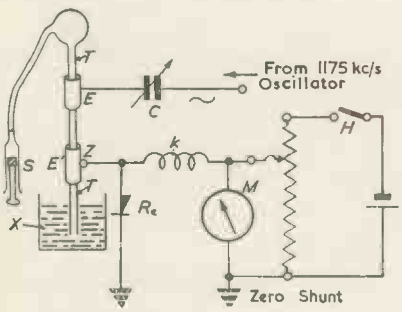


Fig. 1 (above). The R.R.F. method

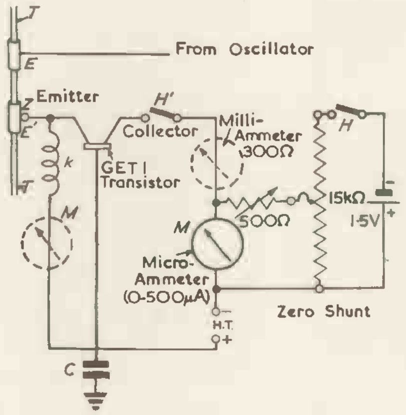


Fig. 2. The transistor circuit

The method is illustrated in Fig. I. Briefly it is as follows: By means of a syringe *S* a sample of the solution is drawn up the conductimetric tube *T*. (This is a glass tube fitted externally with two metal electrodes *E* and *E'*.) A radio-frequency current controlled by a coupling capacitor *C* is fed to the upper electrode *E*, a displacement current passes through the glass down the liquid column and out via the second electrode *E'*. It is then rectified by means of a crystal diode R_e and the rectified current is registered by means of a zero-shunted microammeter[3] *M*.

It occurred to the writer that it might be possible to employ a transistor in place of a diode using the emitter to base as the rectifier and to obtain an amplified current from the collector circuit.

As anticipated emitter to base gave rectified R.F. current readings comparable to those obtained by the original germanium diode. Deflexions of from 50 to 100μA were obtained for a N/400 Kcl solution with only quite a loose coupling to the oscillator.

Fig. 2 shows the transistor circuits. With the microammeter *M* placed in series with the emitter the coupling between the oscillator and the conductimetric tube was adjusted to give a deflexion of 50μA for N/400 KCl and set permanently at that adjustment. The conductimetric tube was then emptied.

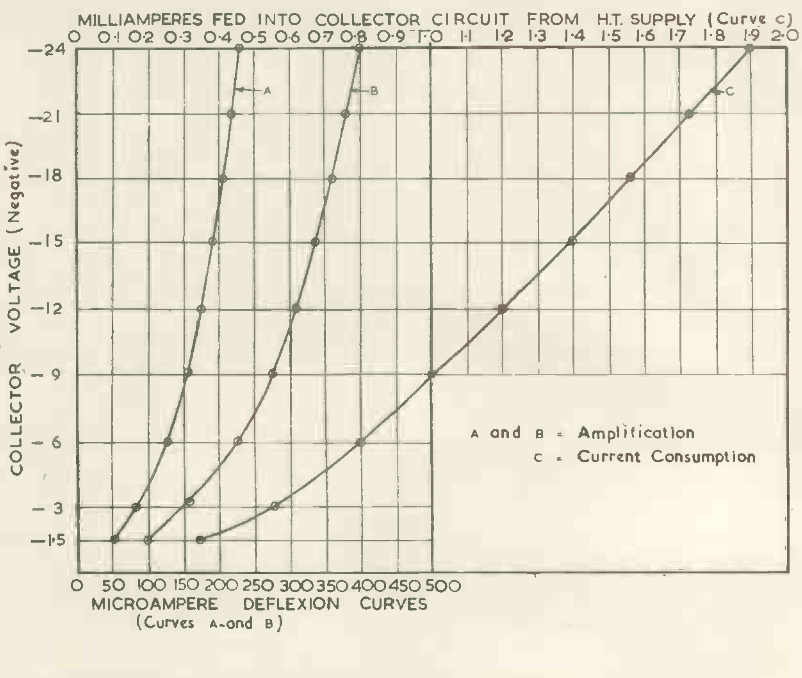
The meter was removed and placed at *M* in the collector circuit, and after closing switches *H'* and *H* the zero-shunt was adjusted to return the meter deflexion to zero. Samples of the solution were then drawn up the conductimetric tube and the deflexions were noted for 1·5, 3, 6, 9, 12, 15, 18, 21, and 24 volts negative H.T. applied in turn to the collector. In each case the meter deflexion was readjusted to zero by zero-shunt while the tube was empty and before the reading was taken.

When a milliammeter (having a resistance of 300 ohms) was included in the collector circuit in order to ascertain the current consumption (see curve C (Fig. 3)) curve A was plotted.

When the milliammeter was removed a considerable increase in amplification was obtained (see curve B (Fig. 3)). By employing a transistor in this manner meter deflexions up to 400 or 500μA can be obtained, while still no more than 50 or 60μA are passed through the solution.

The results obtained also suggest the possibility of operating a relay for the control of liquid flow[4], by the employment, if necessary, of several transistors in cascade.

Fig. 3 (below). GET 1 transistor graphs. Curve A plotted with milliammeter in collector circuit (resistance of meter = 300Ω). Curve B plotted with meter removed, i.e. with no load in collector circuit. Curve C current consumption in collector circuit (in milliamps)



Yours faithfully,

G. G. Blake,
Department of Chemistry,
Sydney University,
Australia.

REFERENCES

1. Blake, G. G. Improved Apparatus for Rectified Radio-Frequency Conductimetric Analysis. *The Analyst 76*, (April, 1951).
2. Blake, G. G. Conductimetric Analysis at Radio-Frequency. Chapman & Hall, London.
3. Blake, G. G. The Development of the Zero-Shunt Circuit. *Aust. Journal of Science* (April, 1944).
4. Blake, G. G. New Method for Rapid Measurement of Solution Concentration which also provides for the Automatic Control of Solution Strength. *Chemistry and Industry 65*, (Jan. 1946) and Ref. 2.

A Stable Multivibrator

Dear Sir,—A multivibrator with a relay in the anode circuit of one of the valves constitutes a simple automatic switching device and often provides a simple means of closing a contact periodically at a predetermined rate. Such a circuit is, however, sensitive to stray negative going triggering impulses or transients occurring when, for example, nearby equipment is switched on and off. The mechanism of triggering follows from consideration of the waveform appearing at the grid of each valve (Fig. 1). The multivibrator can change state prematurely when either a negative pulse is applied to the grid of the conducting valve or a positive pulse is applied to the grid of the non-conducting valve. The

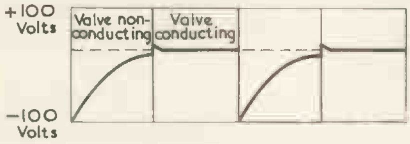


Fig. 1. Grid waveform of conventional multivibrator

negative going pulses are generally much more objectionable since the valve to which they are applied will serve as an amplifier, thereby applying a much larger positive pulse to the other valve.

The effect may be eliminated by using the circuit illustrated in Fig. 2, in which the capacitors C and C', intercoupling the valves, have been shunted with 10 megohm resistors R_1 and R_1' and series resistors R_2 and R_2' have been included in each grid circuit. This raises the potentials of the points A and A′, so that grid current flows during the relevant por-

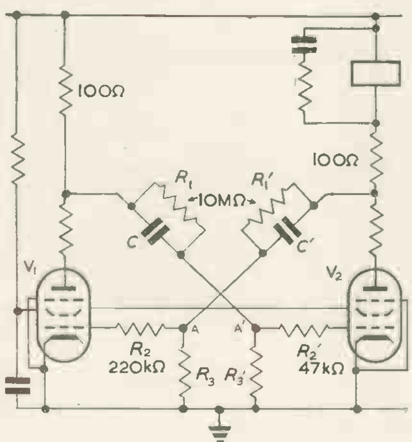


Fig. 2. A stable multivibrator

tions of the cycle and only a fraction of any small signal picked up on the circuits connected to these points will be applied to the grid. In practice the values of R_1, R_2' and R_3' are chosen to maintain A′ at a steady state potential of about 1 volt when V_2 is conducting and V_1 is cut off.

The resistors R_1 and R_1' do not substantially reduce the period of the multivibrator because their values are so high and because they are not returned to the H.T. line but to the anodes of the two valves, which are at a low potential during the relevant portions of the cycle. The circuit modifications described do not, in fact, give rise to any appreciable change in the anode wave forms. The positive going fronts are actually faster since the loading on the anode resistor-grid coupling capacitor network has been reduced.

If a relay is included in one anode of the conventional circuit a damped wave train occurs as the valve changes from a conducting to a non-conducting state, and vice versa. These trains are superimposed on the normal waveform at the grid of the other valve. While no premature triggering results when the grid is biased beyond cut off it can occur during the other half of the cycle. The interposing of the grid stopping re-

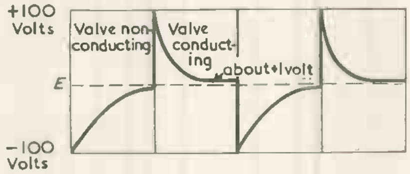


Fig. 3. Waveform at A and A′ in circuit of Fig. 2

sistor R_2 will allow the point A to sweep positive (see Fig. 3) during this period, thus preventing the amplification of the interfering waveform and subsequent triggering.

J. H. McGuire,
Boreham Wood, Herts.

Continuous Recording of the Human Heart-Rate

Dear Sir,—Would you be good enough to permit my observations on the article of Messrs. Boyd and Eadie which appeared in the August, 1954, issue.

Under the section "mechanical methods," the authors state that the Mechano-Electronic transducers employing the mechanically actuated method of thermionic transference of electrical energy suffer from the same objections as the microphone.

This certainly appears to be a correct statement within the context of the article but to people who have not experienced the use of the thermionic transducer it would tend to militate against their consideration of the instrument in research applications.

The triode thermionic transducer type 5734 (produced by RCA in America), presents an overall constant impedance to an amplifier as well as an electrical displacement which is linear with respect to the mechanical forces applied. No microphone, or other method of transferring energy from one source to another, is capable of meeting the limits of the thermionic transducer, and therefore I feel that in fairness to the unit itself, these remarks should be placed on record.

Yours very truly,
George Levine,
London, E.14.

The authors reply:

Dear Sir,—We are indebted to Mr. Levine for raising this point. Our rejection of any particular method was, of course, not intended in any way to detract from its value in other applications. His views are fully endorsed on the merits of the thermionic transducer when used under conditions wherein its unique features can be adequately employed.

At the same time we are of the opinion that these valuable features are more widely known in scientific circles than he perhaps suggests, and that thermionic transducers would be more freely employed if the present price could be brought within the financial capacity of research workers.

Yours faithfully,
W. E. Boyd, W. R. Eadie,
Boyd Medical Research Trust,
Glasgow.

The Design of High Efficiency Radio Frequency E.H.T. Supplies

Dear Sir,—I was very interested in the Radio Frequency E.H.T. unit described by Mr. J. Barron in your September issue, and feel that this has a very wide range of potential applications.

In working out the example, however, Mr. Barron appears to ignore the loading due to the heater and other auxiliary windings. In Example 1, for instance, as the coupling factor is nearly unity, the 4V 1A winding will impose a load of

$$\frac{4 \times 2\,500^2}{6^2} = 0{\cdot}695\text{M}\Omega$$

on the E.H.T. winding. The total load on this winding is therefore 0·625MΩ, which with a 2 500 turn coil gives a Q of only 2, well below the limit specified by Mr. Barron. In this example it would appear more appropriate to use an 800 turn coil, giving a Q of approximately 9.

However, as the author states that his unit has been in satisfactory operation for some time, I feel that there must be a fallacy in my argument, and I should be glad to have his views on this point.

J. A. Colls,
Director, Southern Instruments Ltd.,
Camberley.

The author replies:

Dear Sir,—I must thank Mr. Colls for bringing to my attention the error which he mentions. Mr. Colls is quite correct in his statement, and the error is due to confusion on my part between data for different units. In the example quoted by Mr. Colls, the high voltage coil data were for a unit giving E.H.T. only, while the performance figures are those for the actual unit described. I apologize for my error, and the correct data are as follows:

Example 1

Total effective A.C. load on E.H.T. winding 0·616MΩ, Q = 8·8, transformer efficiency 98·5 per cent. E.H.T. coil 800 turns, anode coil 64 turns, grid coil 27 turns, rectifier heater coil 3 turns, tube heater coil 2 turns, remaining data as published.

Example 2

Total effective A.C. load on E.H.T. winding 0·875MΩ, Q = 12·4, transformer efficiency 98 per cent. Remaining data as published.

Example 3

Total effective A.C. load on E.H.T. winding 6·51MΩ, Q = 8·2, transformer efficiency 95·4 per cent. Remaining data as published.

Yours faithfully,
J. Barron,
University of Cambridge,
Department of Physics.

ELECTRONIC EQUIPMENT

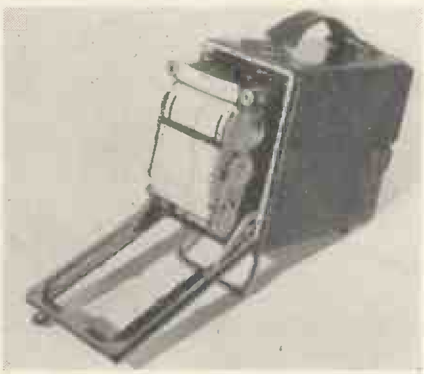
A description, compiled from information supplied by the manufacturers, of new components, accessories and test instruments.

Miniature Recorder

(Illustrated below)

THIS recorder has been produced to meet the trend towards miniaturization in industrial control equipment. It measures only 4¼in by 6¼in by 9in deep.

The recorder is of the tapping type, the record being made by an ink-impregnated ribbon brought into contact with the chart by the movement pointer, which is depressed by the chopper bar operating every 5sec. There are therefore 12 taps and consequently 12 recorded points made on the chart every minute (this is at a chart speed of ½in per hour). The chart has straight time lines and hence rectangular co-ordinates. This feature enables the record to be read easily and to be readily integrated if desired.



The recorder is provided with change gears which can be easily selected to provide chart speeds of ½in, 1in, 10mm or 20mm per hour. The recorder is designed to house 33ft of chart, which will provide for 31 days duration at ½in per hour plus 2ft for setting purposes.

The drive for the chart, chopper bar and record ribbon is provided by a self-starting synchronous motor.

The recorder movements are of the moving-coil and rectifier-operated moving-coil types, and have a sensitivity down to 1mA for full-scale deflexion with a resistance of 250 ohms. The speed of response is 0·8 seconds for full-scale deflexion. The movement is adequately damped.

The maximum self-contained ranges are 500 volts and 10 amperes. The maximum set-up permissible is 4 to 5, e.g., the chart of a voltmeter may be scaled from 200 to 250 volts.

Evershed and Vignoles Ltd,
Acton Lane Works,
Chiswick, London, W.4.

Ferrous Metal Standardizer

(Illustrated above right)

THE Celsonic standardizer type E.S.2 provides a simple and rapid method of testing small ferrous production samples and components for metallurgical uniformity as compared with a known

standard sample or component. The instrument detects differences in magnetic permeability between the standard and the sample under test and consequently does not damage or mark the test piece. The degree of departure from standard is indicated on a meter. Three different size test heads are normally supplied, but special sizes or special shape test jigs can be supplied to order.

Excel Sound Services Ltd,
Celsonic Works,
Garfield Avenue,
Bradford, 8.

U.H.F. Transmitting Tetrode

(Illustrated below)

THE Communications and Industrial Valve Department of Mullard Ltd have recently made available a U.H.F. transmitting tetrode, type QV1-150A. This is an external-anode forced-air-cooled ring-seal valve, with an anode dissipation of 150W, for use on frequencies up to 500Mc/s. It is an extremely compact valve, with a seated height of less than 2in, and has a high power gain at low anode voltages. The QV1-150A should be useful as a U.H.F. power amplifier, oscillator, or driver, and as a high power video amplifier. These features make it suitable for use in low-power Band Four television transmitters, and U.H.F. radio links.

The QV1-150A tetrode has an oxide-

coated cathode rated at 6V, 2·6A. It has a high mutual conductance (12mA/V) and low interelectrode capacitances. At 500Mc/s, it will deliver an output of 140W, the D.C. input power being 250W. This valve is equivalent to American type 4X150A.

Mullard Ltd,
Century House,
Shaftesbury Avenue,
London, W.C.2.

Electronic Motor Controller

(Illustrated below)

THE outfit comprises a D.C. motor of about 1/10th b.h.p. joined by a flexible cable to the electronic control unit. The main features are:—

A speed range of 1 000 to 1 in either direction.

The speed is independent of load and supply changes.

An accurate electrical tachometer is provided.

The motor armature is supplied with a constant current of 5A D.C. derived from the A.C. mains. The back E.M.F. has virtually no effect on the armature current, with the result that the maximum rated torque is available over the whole range of speeds. Mechanically coupled to the motor is a D.C. tachometer generator, which is specially designed to give an output voltage accurately proportional to speed. The output is metered and forms the basis of the tachometer. In addition, the generator voltage is compared with an electronically stabilized reference voltage, and the difference or error voltage is amplified and applied to the motor field coils. Thus, if the error is only 6 rev/min, the motor develops full torque to accelerate the armature to the correct speed. The effect is that over the rated range of torques, the speed error can never exceed 6 rev/min for more than a few milliseconds, and it is normally much less than that.

The speed can be smoothly varied over the range 0 to 6 000 rev/min in either direction, set by fine and coarse controls on the panel.

A high quality electrical tachometer is

provided on the control panel, with a scale length of 3½in and ranges of 100, 300, 1 000, 3 000, 10 000 rev/min. The accuracy is plus or minus one per cent.

**Servomex Controls Ltd,
Crowborough Hill,
Jarvis Brook, Sussex.**

Anti-vibration Mounts

(Illustrated above)

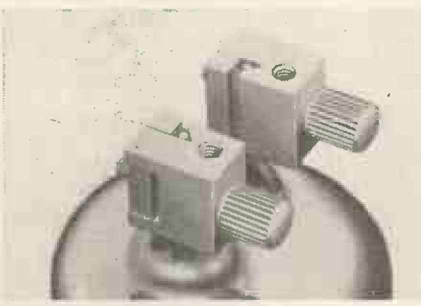
BARRYMOUNTS are now being made in this country under licence from the Barry Corporation of America.

The anti-vibration mounts have been specially developed for use with airborne equipment of all types, while the shock mounts are primarily intended for use in vehicles and ships but under certain circumstances may also be used in aircraft.

The important features of all the anti-vibration mounts are: Use of non-linear springs to mantain substantially constant natural frequency over a load range of approximately two to one; exceptionally low natural frequency of 7 to 9c/s; high degree of damping, eliminating snubber contact under all normal operating conditions and resulting in improved shock absorption.

Illustrated is a standard air-damped Barrymount available in ratings from 2 to 35lb.

**Cementation (Muffelite) Ltd,
39 Victoria Street,
London, S.W.1.**



V.H.F. Anode Connectors

(Illustrated above)

THESE anode connectors have been designed for use with valves such as the Mullard QQV06/40 series. They have good heat dissipation, do not add significantly to the output capacitance of the valve and can be readily installed and removed in restricted positions.

**Power Controls Ltd,
Exning Road,
Newmarket.**

Miniature Relay

(Illustrated below)

THE type J.01 relay has a laminated armature and frame, a stainless steel armature shaft, Oilite bearings and buffered contacts. It provides heavy contact pressure with low coil consumption. Coils can be wound for any voltage up to 100V D.C., and 250V A.C. The maximum number of contacts is eight rated at 110V or four rated at 250V. The operating time is within one half-cycle on A.C., and 10 to 20msec on D.C.

**Besson and Robinson Ltd,
6 Government Buildings
Kidbrook Park Road,
London, S.E.3.**

Air Blowers

(Illustrated above)

THE latest addition to the Plannair range is the type 2PL81-84 axial flow blower. It has an overall diameter of 3in and a blade tip diameter of 2in. The air displacement at sea level conditions is 35ft³/min at 0·4in W.G. It is fully tropicalized and is suitable for ground or airborne duty.

**Plannair Ltd,
Windfield House,
Epsom Road,
Leatherhead, Surrey.**

Alternating Current Detector

(Illustrated above right)

THE Hivolt A.C. Voltector is an easily portable instrument which has been designed to avoid the necessity of making physical contact with a conductor carrying A.C. power in order to check whether it is alive or not. The instrument records the presence of the electro-

static field which surrounds a live A.C. conductor, by a deflexion of the meter. It cannot, therefore, be used if the conductor is totally enclosed in an earthed sheath. The A.C. voltector will operate on 50V wiring or, at the other extreme, it will indicate from the ground whether a 132kV overhead line is alive or dead.

An A.C. voltector will also indicate the exact position of a break or fault in a line carrying A.C., provided that the line is not contained in an earthed sheath.

**Hivolt Ltd,
34a Pottery Lane,
Portland Road,
London, W.11.**

Junction Transistor

THE XFT1 is a pnp junction transistor intended for use in hearing aids. It is hermetically sealed in a flat glass bulb having a maximum length of 15mm and a rectangular cross-section of 5·3mm by 3·8mm. The germanium junction element in this transistor is supplied by B.T.H. Ltd. The maximum collector-emitter voltage is −4·5V D.C., and the maximum collector dissipation 6mW. In a typical amplifier stage a power gain of 38db can be realized.

**Hivac Ltd,
Stonefield Way,
South Ruislip,
Middlesex.**

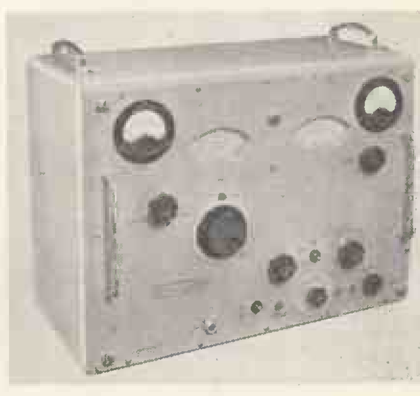
U.H.F. Signal Generator

(Illustrated below)

THE type L.1 signal generator covers the frequency range of 300 to 1 000 Mc/s and has a maximum output of not less than 100mV into 75Ω. The output is measured by means of a crystal voltmeter at the output of the piston attenuator, which provides a variation of 126db.

Internal sine and pulse modulation at 1 000c/s is provided and provision is made for external modulation of either type. The calibration accuracy is claimed to be within ±1 per cent.

**Advance Components Ltd,
Back Road, Shernall Street,
London, E.17.**



BOOK REVIEWS

Television Receiver Servicing

By A. E. W. Spreadbury. 310 pp., 187 figs. Demy 8vo. Vol. I. Iliffe & Sons Ltd. 1954. Price 21s.

THIS book, one of two volumes covering the subject, deals with time-bases and associated circuits and is stated to be "mainly intended for the professional radio service engineer who, having already become skilled in the art of fault tracing in radio receivers, wishes to extend his activities to television servicing."

It is a very well produced book, nicely printed and illustrated on good paper, and it is disappointing to find the contents less useful than a first inspection would suggest.

It assumes that the reader is at least fairly familiar with the theory of television receivers, the operation of television time-base circuits, and test equipment including the oscilloscope.

The order in which the material is presented is mainly logical and practical, and it is clear that the author is familiar with the problems facing the service engineer.

The first chapter deals with many of the causes of a blank screen, their location and elimination. It is obviously difficult to clear time-base faults if no raster is visible on the C.R.T. and although not really within the scope of this book, the faults not connected with time-bases which cause a blank screen, such as the incorrect adjustment of the ion trap, failure of the supplies to the C.R.T. or the tube itself, are discussed. Line flyback E.H.T. systems and their troubles are conveniently dealt with in this chapter and pulse and sine wave voltage multipliers are illustrated and discussed. The author makes the somewhat misleading statement that "If the E.H.T. is derived from a flyback system this lethal danger . . . ." (of shocks) ". . . . is entirely absent, and after very little practice a simple trick will reveal the presence of E.H.T. volts. This is to hold a screwdriver, which should preferably have a wooden or insulated handle, close to the anode cap of the tube, when bright blue sparks should be drawn between the two if E.H.T. is present." Preferably insulated! Also "An E.H.T. supply derived from an R.F. oscillator is usually perfectly safe to handle in the same way as the flyback system and sparks can be drawn from it also." In the reviewer's opinion the danger of shock is treated far too lightly and any shock may be considerably worse than "unpleasant."

Chapter II follows a logical order and deals with obtaining a raster. Various types of time-bases and faults which they may develop are dealt with in a very practical way. H.T. boost circuits and their possible faults are also discussed but the subject of H.T. boost is covered all over again and more fully in Chapter VII.

Chapter III covers the application of a signal to the C.R.T. which is again a logical step after the production of a raster. The chapter includes useful photographs of oscilloscope traces. It also includes sync separators of various types and the effects and location of faults. However, Chapter IV entitled "Synchronization" deals with sync separators more fully and some material is repeated. In this chapter the transmitted waveform is dealt with, particularly the frame pulses, and the effect of differentiator and integrator circuits upon the shape of the pulses. Interlace filters and clippers are shown. The numbering of the lines in the illustrations is rather confusing as the top line in the raster is numbered line 1, as is the first line interval in the complete frame pulse. This might suggest that the frame pulses occur during the first few lines of the scan, i.e. at the top of the picture. Fig. 58 states incorrectly that the picture modulation recommences half-way along line 127.

Interlace quality is considered in Chapter V and some of the causes of bad interlace are mentioned. The author mentions the deduction of the "Q" of the deflexion circuit from the flyback traces. This method can easily be shown to be incorrect.

Chapter VI is entitled "The Synchonized Time-base" and would have more logically appeared before the material on interlace. It is a useful chapter and deals with many time-base circuits and the position of their amplitude, hold, and linearity circuits. The television service engineer beginner should find much to help him to classify the types of time-base circuits and variations when dealing with a particular circuit for the first time. Under "single valve line time-bases" two and even three valve circuits are shown, as well as true single valve circuits such as that used so successfully by the Plessey Co. This circuit is at first called "the transitron type oscillator" and the true reason for connecting g_2 to g_3 via a capacitor (for line linearity purpose) is not given. It is stated, however, that it is "actually an inductive system." It is also stated that the C and R in the grid circuit "determine the time-constant." Actually the only effect of removing the capacitor is a degradation of line linearity.

Chapter VII, as previously mentioned, deals with H.T. boost and does so in a comprehensive way. Like Chapter VI it has more explanation of the working of the circuits than their faults and elimination. There are several parts to puzzle the reader such as "the voltage of the . . . ." (line) ". . . . output valve anode, however, can always be measured at the opposite end of the mains transformer winding which is 'earthy,' as can also be anode current."

Chapters VIII and IX cover many of the circuits associated with scanning and the tube itself such as picture shift, spot wobble, and tube protection circuits. The theory and practice of ion trapping is covered very neatly.

Following a useful chapter on flywheel circuits the book concludes with D.C. restoration and the use of test instruments and test card 'C.'

In this reviewer's opinion the book falls between the two stools of clear explanation of the workings of television circuits, and the purely practical approach to fault-finding. Where explanations are given they are not always clear and may not be very useful to the reader who is seeking help. For example: "Like the blocking oscillator the multivibrator circuit oscillates in sudden spasms"; "Negative charge is built up by frame pulses in C_1." Actually C_1 is discharged more during frame pulses than during line pulses. Again, when describing single diode sync separators "It does actually employ two valves but the second one is a pentode and is only 'borrowed' to amplify the output in reflex." The book contains many loose statements like ". . . . line output valve goes down below chassis . . ."; ". . . . insulation of several thousand volts . . ."; ". . . . curved flyback . . . ." and so on.

Where the purely service angle is attempted a matey style is adopted such as "until the culprit is found"; "old friend the leaky capacitor"; "valve will try and burn itself up." It gives advice such as "a device employed by busy service engineers is to short-circuit the grid and cathode pins . . . ." (of the C.R.T.) ". . . . momentarily, when if everything else is in order the screen will light up."

Possibly the most odd advice given to the reader concerns a type of time-base which is "lazy." This is "not a fault." The symptoms are a single horizontal line. The customer must be "initiated into the simple trick of switching the receiver on and off quickly." "Providing the trick is known the remedy is at once obvious," and will save the "unsuspecting service engineer" unnecessary work.

C. H. BANTHORPE.

Principles of Mass and Flow Production

By F. G. Woollard. 196 pp., 102 figs. Demy 8vo. Iliffe & Sons Ltd. 1954. Price 25s.

THE principles and methods described in this book are suitable for the manufacture of almost every article that is readily and continuously saleable, and production executives in a very wide range of industries, as well as all students of engineering economics, will find the book of interest.

After defining the terms "mass production" and "flow production" the author briefly traces the history of this type of manufacture. He then lays down a series of eighteen basic principles that relate to the setting up of flow production plant, and considers the implication of each in detail.

Rutherford, By Those Who Knew Him

69 pp., 20 figs. Demy 8vo. The Physical Society, London. 1954. Price 5s. (members), 8s. 6d. (non-members).

AFTER the death of Lord Rutherford in 1937 the Physical Society instituted a series of lectures in his memory; the first of these was given in 1942, and succeeding ones in 1946, 1949 and 1950. The lectures were published in the Physical Society's Proceedings, and the present volume consists of the first five lectures bound together. They admirably supplement the official biography "Rutherford" by A. S. Eve, which gives his life and work, with copious extracts from the correspondence, and N. Feather's "Lord Rutherford," a shorter work, giving a sketch of his life with a critical summary of the work and a few extracts from correspondence.

The first two lectures, by H. R. Robinson and Sir John Cockcroft, are reminiscent and personal, and cover the periods up to 1919 (New Zealand, Cambridge, Montreal and Manchester) and from 1919 onwards (Cambridge) respectively. Prof. Robinson concentrates mainly on the Manchester period, 1907-19, during a large part of which he was working under Rutherford.

The third lecture, by M. L. Oliphant, is entitled "Rutherford and the Modern World" and assesses the influence of Rutherford's personality on the progress of atomic physics, on the British scientific effort in World War II and on cooperation within the British Commonwealth.

In the fourth lecture E. Marsden gives a fascinating personal account of the Manchester researches, in which he himself played a notable part, leading to the nuclear theory of the atom, and includes also an extensive and equally fascinating story of Rutherford's upbringing and early life as a boy and young man in New Zealand.

A. S. Russell in the fifth lecture again covers the Manchester period, but from the standpoint of a chemist, and quotes many anecdotes which well bear repetition.

The book contains about 20 illustrations: these are mainly from personal snapshots and are of great interest for this reason, but lose much through poor reproduction.

From all the lectures appears the same picture of Rutherford's unique and abounding personality: his forthrightness, energy and boyish humour, allied to the keenest scientific insight and power of penetrating at once to the heart of a problem and solving it. He had all the qualities of great leadership, combining outstanding personal achievement with the power of inspiring others, and his death at the comparatively early age of 66 was a great loss to British science.

The present volume is a notable commentary, worthy of its subject, and may be confidently recommended to readers in the world of physics and in those worlds of engineering which have grown from the past century's discoveries in physics.

F. A. B. WARD.

Proceedings of the National Electronic Conference 1953

958 pp., 150 figs. Royal 8vo. Vol. 9. National Electronics Conference Inc., Chicago. 1954. Price $5.

THIS volume contains the texts of the papers presented at the 9th National Electronics Conference held at Chicago in September 1953. The total number of papers is ninety-eight and these are divided into twenty-three sections; each section consisting of four or five papers. The coverage includes magnetic amplifiers, servo-mechanisms, ultrasonics, television, computors, transistors, microwaves, nucleonics and communications. It is disappointing to find that there is only one electro-medical paper and that audio-frequency work is represented by one paper on a cable-less microphone system (using a sub-miniature radio transmitter) and two papers on valve microphony.

Magnetic amplifiers are discussed in five papers; of particular interest is the paper from Westinghouse describing a transistor-controlled arrangement. The combination of the transistor with a magnetic amplifier is, of course, particularly attractive from the reliability point of view. The section on computors has a paper on a magnetic ring counter. This uses a single driving valve per ring with a magnetic core, crystal diode and capacitor in each stage. The maximum counting rate is 50kc/s which compares favourably with gas-tube ring counters. However, it should be pointed out that magnetic counters do not give direct visual read-out, this is a serious disadvantage in many applications.

The section on circuits has a paper on the use of the parallel-T network as a linear discriminator for telemetering. Another paper in this section describes a new type of pulse-modulated oscillator which uses a single transmission line to determine both the pulse duration and the carrier frequency.

A paper from Bell discusses active-element *RC* filters. These are inductorless filters which use a transistor negative-impedance convertor. A further filter paper discusses electro-mechanical filters for the frequency range 100kc/s to 1Mc/s. Such filters have better selectivity characteristics than conventional double-tuned transformers and enable a superheterodyne receiver to be designed with virtually all the selectivity in the first I.F. stage. This means that the voltage level due to signals outside the pass-band is reduced at the later stages, with consequent reduction of intermodulation and other undesirable effects.

Three papers cover work on the Chicago Synchrocyclotron. One of these papers describes a high-speed scaler having a resolving time of ten millimicroseconds. The scaler uses Phillips EFP60 secondary emission valves and, due to the method of bias, is not suitable for continuous operation at high count rates.

A method of obtaining automatic gain control or transistor amplifiers is described; a n-p-n junction transistor is used and gain variation is achieved by utilizing the inverse relation between emitter resistance and emitter current. Further transistor papers deal with junction-transistor feedback amplifiers, with transistor switching circuits and with an amplitude stabilized transistor oscillator. Although these papers represent original work much of this material has now been published elsewhere.

The volume contains review papers on ultrasonics, transductor applications and on analog-digital conversion. Owing to the limitations of the conference timetable these papers are too brief to be of much value. In the case of the review of transductors only four references are given, one of which is incorrect.

The volume is well printed on good quality paper and, by current standards, it is not unreasonably expensive.

V. H. ATTREE.

Vector and Tensor Analysis

By G. E. Hay. 193 pp., 66 figs. Demy 8vo. Dover Publications, Inc., New York. 1953. Price $1·50 (paper cover), $2·75 (cloth cover).

THE tensor calculus of Ricci and Levi-Civita came into prominence with the advent of general relativity theory in 1916 and has since been successfully applied to the study of such subjects as elasticity, hydrodynamics, and electromagnetic theory. In 1932, Gabriel Kron, an American engineer, introduced tensor analysis to mathematical engineering and succeeded in developing the tensor theory of electrical machinery. Today, the tensor calculus is almost universally recognized as the proper basis for the unification of electrical engineering science. It is appropriate, therefore, that a purely mathematical text-book on tensor analysis should receive notice in an engineering periodical.

This pocket-size book is one of a new science series recently introduced by the publishers. Tensor analysis may be described as a generalized extension of the vector analysis of Gibbs and Heaviside. The latter is confined to Euclidean 3-space whereas tensor analysis facilitates the study of physical phenomena requiring generalized co-ordinates in Riemannian *n*-space for their geometrical representation. Accordingly, the author follows the usual procedure of approaching the tensor concept by way of vector analysis. Five of the six chapters contained in the book are devoted to vectors. The first chapter defines a vector and explains the rules of the algebra. The following two chapters discuss applications to analytical geometry and classical mechanics while Chapters IV and V deal with the differential vector calculus and integration. The final chapter introduces tensor analysis and begins with the inter-reference-frame transformation laws and thus defines contravariant, covariant, and mixed tensors. The remainder of the chapter deals with invariance, the algebra of tensors, and special tensors and concludes with applications to mathematical physics. Unfortunately, as is usual in mathematical text-books, no examples are given of Kron's application of tensors to electric circuit theory.

Although the final chapter of the book might be used to provide the mathematical background for an introduction to Kron's work, it is difficult to see what it has to offer to readers in this country that is not already well represented by such books as those of Rutherford and Spain in the Oliver and Boyd series. The book is available in cloth or paper binding but bears evidence of hurried preparation. Misprints such as *covaritan* and *invarinat* have escaped notice. Due to a printing blunder, several diagrams have been reproduced to the wrong scale necessitating the insertion of a loose supplement showing larger reproductions. The book has no introduction, no index, and gives no answers to the problems set in each chapter.

S. R. DEARDS.

Fluorescence Analysis in Ultra-Violet Light

By J. A. Radley and Julius Grant. 560 pp., 64 figs. Medium 8vo. 4th Edition. Chapman & Hall Ltd. 1954. Price 52s. 6d.

THE previous edition of this book was published as long ago as 1939 and the interval which has elapsed is due largely to circumstances arising directly out of the war. In addition, republication has been deliberately deferred because it was felt that it was desirable to wait until the work published during the war period, particularly in what were enemy countries, could receive the fullest consideration. Attention may be drawn in particular to the entirely new section dealing exclusively with the applications of fluorescence analysis to the evaluation of vitamin activity. New lamps for the production of ultra-violet light, and new apparatus and technique used for fluorescence analysis are also dealt with.

Laplace Transforms for Electrical Engineers

By B. J. Starkey. 280 pp., 60 figs. Demy 8vo. Iliffe & Sons Ltd. 1954. Price 30s.

IN this book a physical rather than a purely mathematical vocabulary is used in an attempt to attain the utmost simplicity, and throughout the approach is from analytical methods already well known to the reader. The work is not intended as more than a general introduction to a very large subject, but it is hoped that it will be of value in supplementing the more rigorously mathematical texts that have previously appeared.

The author, who is on the staff of the Royal Aircraft Establishment at Farnborough, has lectured electrical engineers on the subject.

The Oscilloscope at Work

By A. Haas and R. W. Hallows. 172 pp., 102 figs. Demy 8vo. Iliffe & Sons Ltd. 1954. Price 15s.

ALTHOUGH, as the title implies, this book deals mainly with the uses of the instrument and correct interpretation of the oscillograms produced, it also contains valuable information on oscilloscope circuits, construction and adjustment, while one chapter is devoted to explaining how it can be made to diagnose its own troubles when faults develop.

This work was originally published in France and has now been adapted for English speaking readers and considerably enlarged.

Short News Items

The Scientific Instrument Manufacturers' Association announce an exhibition of electronic aids to production, design and research, under the title, "Electronics at Work," to be held at the Chamber of Commerce Hall, Birmingham, from 23-25 November. Admission is by ticket, obtainable free on request from the Association at 20 Queen Anne Street, London, W.1.

A new private automatic branch telephone exchange has recently been installed in the headquarters of BOAC at London Airport. The exchange was built by the Automatic Telephone and Electric Co Ltd and has 1 300 extensions, 95 exchange lines and 60 private wires. Direct dialling between extensions is provided. An important feature is a "hold for enquiry" facility which enables users to hold an incoming exchange call and to make, at the same time and on the same telephone, a further call to either an external or internal line; the original call can be restored by merely pressing a button. An operator recall button has also been fitted. Outgoing calls up to a value of sixpence can be dialled from any extension, above this amount they are referred to the operator.

Metropolitan-Vickers Electrical Co Ltd announce that the Chairman, Sir George E. Bailey, and the Deputy Chairman, Sir Felix J. C. Pole, have resigned from the Board of Directors. The Rt. Hon. The Viscount Chandos (formerly Mr. Oliver Lyttelton), has been elected a Director and Chairman of the Board.

The United Kingdom Atomic Energy Authority has opened a Reactor School at Harwell as a step towards encouraging industry to play a greater part in the development of atomic power. The new school will provide, for a fee of £250, a three months' course of training for staff from industrial concerns to learn the techniques by which heat from atomic piles can be converted into useful power. Three courses will be held each year, starting in January, May and September. Applications for places in the school should be made to the Manager, Reactor School, A.E.R.E. Harwell, Berkshire, and should give sufficient information for the Management Board to assess whether the student has the required academic standard for entry to the school.

The Eastern Joint Computor Conference and Exhibition will be held at the Bellevue Stratford Hotel, Philadelphia, from 8-10 December. The programme includes papers on computor comparisons, input-output devices, computor systems and characteristics, mathematics, and business and scientific applications. Some sixty companies will be taking part in the exhibition.

The Golden Jubilee of the International Electrotechnical Commission was celebrated in Philadelphia in conjunction with a series of technical meetings which took place from 1-16 September. The number of delegates attending was among the largest in the history of the IEC. The majority came from the United States. The second largest delegation was that from the United Kingdom, followed by France, Germany, Italy, Sweden, Netherlands and Switzerland. Altogether twenty of the thirty member countries of the IEC were represented. Lord Waverley, Chairman of the Port of London Authority and immediate Past President of the British Standards Institution, led the comprehensive British delegation.

Marconi's Wireless Telegraph Co Ltd announce the placing of recent orders for aeronautical radio equipment from the U.S.A., India, South Africa and France. More than forty airlines and over twenty Air Forces now use Marconi aeronautical equipment. The first three of the Vickers-Armstrong Viscounts ordered by Capital Airlines (U.S.A.) will each have a dual installation of the new Marconi AD 7092C automatic direction finder (radio compass). The two Viscounts ordered by the Indian Government are to carry Marconi communications and automatic direction-finding equipments. Marconi radio equipment will also be installed in each of the Avro Shackleton Mark III aircraft now on order by the South African Air Force. France is also to have the AD 7092D radio compass in each of the English Electric Canberras on current delivery.

The Eighth Annual Amateur Radio Exhibition organized by the Radio Society of Great Britain will be held as in former years at the Royal Hotel, Woburn Place, London, W.C.1, from 24-27 November. The Exhibition will be open at 11 a.m. and close at 9 p.m. each day, admission 1s.

Redifon Ltd announce that a substantial order for radio equipment has been placed with them on behalf of the Soviet Fishing Authority. The equipment, comprising transmitters, all-wave receivers, combined medium and short-wave direction finders and associated ancillary units, will be installed in the twenty deep-sea fishing vessels now under construction for the Soviet Union by Brooke Marine Ltd of Lowestoft.

Mr. T. R. Thomson, Assistant Comptroller to J. Lyons & Co Ltd, has planned to give the following talks on LEO, Lyons Electronic Office, and associated matters. On 8 November, to the Insurance Institute of London, "The Practical Use of the Electronic Computor." On 18 November, to students of the North West Polytechnic, "High Speed Automatic Electronic Computing Designed for Office Work."

The BBC announces that the new television station at Rowbridge in the Isle of Wight will be brought into full programme service on 12 November. The new station will use initially a temporary mast and aerial system and is expected to provide satisfactory reception in the Brighton area, along the south coast to Bridport, and inland as far as Devizes and Newbury. When the permanent 500-ft. mast and aerial system are completed in about a year's time, the service will be extended to cover Seaford in the east, Seaton in the west, and Lambourn in the north.

Microwave Instruments Ltd have recently completed extensions to their factory at West Chirton Industrial Estate, North Shields. It is their intention to make the majority of this additional working space available to accept specialist sub-contract work.

20th Century Electronics announce the opening of an extension to their new factory at New Addington, Surrey. This extension doubles the size of the original building. The factory and research laboratories of the Cathode Ray Tube section, formerly at Dunbar Street, London, S.E.27, have now moved to New Addington.

Claude Lyons Ltd of Liverpool and London have acquired a new factory known as Valley Works, 4-10 Ware Road, Hoddesdon, Herts. In addition to housing research and development staff, the new premises will be employed for a small amount of new product manufacture, and also in increasing stock facilities.

W. Canning & Co Ltd of Birmingham announce the introduction of a new type of chrome plating anode. It has been developed from the older type of copper-cored anode, but now utilizes aluminium for its core.

Errata. The following alterations should be made to the article by Mr. R. Voles which appeared on pp. 452-453 of the October issue.

The lower limit of all the summation signs in equation (2) should be $p = 1$.

The term giving the position of the centre in section (c) of the paragraph headed "T Loci" should be $((1 - T)/T, 0)$.

The first inequality in the example analysis should have a summation sign with a lower limit of $p = q$.

The extreme terms in the inequality (3) should be preceded by minus signs.

Meetings this Month

THE BRITISH INSTITUTION OF RADIO ENGINEERS

Date: 24 November. Time: 6.30 p.m.
Held at: The London School of Hygiene and Tropical Medicine, Keppel Street, Gower Street, London, W.C.1.
Lecture: The Development and Design of Direct-Coupled Oscilloscopes for Industry and Research.
By: M. J. Goddard.

Scottish Section

Date: 14 November. Time: 7 p.m.
Held at: The Institution of Engineers and Shipbuilders, Elmbank Crescent, Glasgow.
Lecture: The Latest Developments in Television Cameras.
By: H. McGhee.
Date: 11 November. Time: 7 p.m.
Held at: The Department of Natural Philosophy, The University, Edinburgh.
Lecture: Nuclear Fission and Nuclear Fusion.
By: N. Feather.

Merseyside Section

Date: 4 November. Time: 7 p.m.
Held at: The College of Technology, Byron Street, Liverpool, 3.
Lecture: Radio Receiving Valve Manufacture.
By: G. P. Thwaites.

North-Western Section

Date: 4 November. Time: 7 p.m.
Held at: Reynolds Hall, College of Technology, Sackville Street, Manchester.
Lecture: Electronic Servo Mechanisms.
By: J. L. Russell.

North-Eastern Section

Date: 10 November. Time: 7 p.m.
Held at: Neville Hall, Westgate Road, Newcastle-upon-Tyne.
Lecture: Stereophonic Sound.
By: R. A. Bull.

South Wales Section

Date: 17 November. Time: 6.30 p.m.
Held at: Cardiff College of Technology, Cathays Park, Cardiff.
Lecture: The Techniques of Power Measurements from D.C to 5Mc/s.
By: G. F. Lawrence.

THE INSTITUTE OF PHYSICS

Date: 9 November. Time: 6.30 p.m.
Held at: The Institute's House, 47 Belgrave Square, London, S.W.1.
Lecture: The Materials of Atomic Energy.
By: H. M. Finniston.

Manchester and District Branch

Date: 12 November. Time: 6.45 p.m.
Held at: The Bragg Lecture Theatre, University of Manchester.
Lecture: Colour Measurement as a Tool in Scientific Research.
By: W. D .Wright.

THE INSTITUTION OF ELECTRICAL ENGINEERS

All London meetings, unless otherwise stated, will be held at The Institution, commencing at 5.30 p.m.

Ordinary Meeting

Date: 4 November.
Lecture: A Transatlantic Telephone Cable.
By: M. J. Kelly, Sir Gordon Radley, G. W. Gilman and R. J. Halsey.

Education Discussion Circle

Date: 8 November.
Discussion: Methods of Teaching Technical Writing.
Opened by: G. Parr.

Radio and Measurements Sections

Date: 10 November.
Lectures: Standard Frequency Transmissions.
By: L. Essen.
The Standard Frequency Monitor at the National Physical Laboratory.
By: J. McA. Steele.
Standard Frequency Transmission Equipment at Rugby Radio Station.
By: H. B. Law.

Informal Meeting

Date: 15 November.
Discussion: Has Nuclear Fission a Future as a Source of Industrial Power?
Opened by: Sir Harold Roxbee Cox.

Celebration of the Jubilee of the Thermionic Valve

Date: 16 November. Time: 2.30 p.m.
Opening Address by The Most Honourable the Marquess of Salisbury, Lord President of the Council, followed by lecture: The Genesis of the Thermionic Valve.
By: Professor G. W. O. Howe.
Time: 3.30 p.m.
Lecture: Thermionic Devices from the Development of the Triode up to 1939.
By: Sir Edward Appleton.
Time: 5.30 p.m.
Lecture: Developments in Thermionic Devices since 1939.
By: J. Thomson.

Measurements Section

Date: 30 November.
Discussion: The Servicing of Electronic Measuring Instruments and its Effect on their Design.
Opened by: Denis Taylor.

East Midland Centre

Date: 23 November. Time: 6.30 p.m.
Held at: The Gas Department, Demonstration Theatre, Nottingham.
Lecture: Telemetering for System Operation.
By: R. H. Dunn and C. H. Chambers.
Date: 26 November. Time: 6.30 p.m.
Held at: The College of Technology, Leicester.
Lecture: A Radio Position Fixing System for Ships and Aircraft.
By: C. Powell.

Cambridge Radio Group

Date: 8 November. Time: 8.15 p.m.
Held at: The Cavendish Laboratory, Free School Lane, Cambridge.
Radio Section Chairman's Address.

Mersey and North Wales Centre

Date: 29 November. Time: 6.30 p.m.
Held at: The Liverpool Royal Institution, Colquitt Street, Liverpool.
Lecture: A Short Modern Review of Fundamental Electromagnetic Theory.
By: P. Hammond.

North-Eastern Radio and Measurements Group

Date: 15 November. Time: 6.15 p.m.
Held at: King's College, Newcastle-upon-Tyne.
Lecture: A.C. Instrument Testing Equipment.
By: A. H. M. Arnold.

North Midland Centre

Date: 2 November. Time: 6.30 p.m.
Held at: The offices of the British Electricity Authority, Yorkshire Division, 1 Whitehall Road, Leeds.
Lecture: Technical Arrangements for the Sound and Television Broadcasts of the Coronation Ceremonies on 2 June, 1953.
By: W. S. Proctor, M. J. L. Pulling and F. Williams.

THE INSTITUTION OF POST OFFICE ELECTRICAL ENGINEERS

Ordinary Meeting

Date: 9 November. Time: 5 p.m.
Held at: The Institution of Electrical Engineers, Savoy Place, London, W.C.2.
Lecture: Future Demands for Telephone Service—possible trends and reactions.
By: J. M. Norman.

Informal Meeting

Date: 24 November. Time: 5 p.m.
Held at: The Conference Room, 4th Floor, Waterloo Bridge House, London, S.E.1.
Lecture: Some Personal Views on the Mechanization of Auto Exchange Maintenance.
By: F. H. Horner and B. H. E. Rogers.

THE TELEVISION SOCIETY

Date: 12 November. Time: 7 p.m.
Held at: 164 Shaftesbury Avenue, London, W.C.2.
Lecture: Faulty Interlacing.
By: G. N. Patchett.
Date: 18 November. Time: 7 p.m.
Conversazione at University College, London, to mark the Jubilee of the Invention of the Thermionic Valve.
Date: 25 November. Time: 7 p.m.
Held at: 164 Shaftesbury Avenue, London, W.C.2.
Lecture: European Television Programme Exchanges.
By: N. J. L. Pulling.

PUBLICATIONS RECEIVED

THE APPLICATION OF PLASTICS IN THE CABLE INDUSTRY is an interesting booklet on the subject produced by the Telegraph Construction and Maintenance Co. Ltd., Telcon Works, Greenwich, London, S.E.10.

COLLOIDAL GRAPHITE FOR METAL-WORKING OPERATIONS is the title of an illustrated brochure published by Acheson Colloids Ltd., 18 Pall Mall, London, S.W.1.

TCC CONDENSERS describes the many types of condensers produced by the Telegraph Condenser Company. This catalogue describes the types of condensers under the headings of Paper, Electrolytic, Mica, Ceramic, Plastic Film and Special Purpose, a different colour being used for each section. The Telegraph Condenser Co. Ltd. (Radio Division), North Acton, London, W.3.

PHILIPS SERVING SCIENCE AND INDUSTRY is the title of a new monthly publication. It will be devoted to new types of industrial equipment and industrial processes covering a wide field. The publication is distributed free of charge and though a substantial mailing list has already been built up, a limited number of applicants may still be accepted. Requests should be made to the Publication Department, Philips Electrical Ltd., Century House, Shaftesbury Avenue, London, W.C.2.

THE COUNCIL OF INDUSTRIAL DESIGN 9th ANNUAL REPORT covers the period 1 April, 1953 to 31 March, 1954, and suggests that, to supplement well established exports of traditional designs, British industry must study modern minded industry abroad. The Council of Industrial Design, Tilbury House, Petty France, London, S.W.1. Price 1s. 6d.

ENTHOVEN SOLDER PRODUCTS is a leaflet which is available free on application to Enthoven Solders Ltd., 89 Upper Thames Street, London, E.C.4.

HILGER COMPACT 3 METRE GRATING SPECTROGRAPH is a booklet describing this instrument which is specially designed for industrial and research work. HILGER MICRO-FOCUS X-RAY UNIT, incorporating the Ehrenberg and Spear tube is a leaflet describing the main features of this unit. Both publications are available from Hilger and Watts Ltd., Hilger Division, 98 St. Pancras Way, Camden Road, London, N.W.1.

BULLETIN OF SPECIAL COURSES IN HIGHER TECHNOLOGY 1954-55 is a booklet issued by London and Home Counties Regional Advisory Council for Higher Technological Education. The purpose of the bulletin is to give publicity to special advanced courses held in the London and home counties region which do not regularly appear in college calendars or prospectuses as part of a grouped course or as subjects offered for endorsement on Higher National Certificates. Copies may be obtained from The Secretary, Regional Advisory Council, Tavistock House South, Tavistock Square, London, W.C.1.

RADIO, TELEVISION AND RADAR is an excellently compiled list of books held in the Nottingham Public Libraries. All the items listed are held in either the Central Lending Library or in the Reference Library. Notes on using the services provided by the Public Libraries are given at the end of the list. Central Library, Sherwood Street, Nottingham.

CABINET SYSTEM AND TELESCOPIC MOUNTINGS is a catalogue which comprehensively describes the Widney-Dorlec Cabinet System, and embodies all the improvements and additions that have been made. Hallam, Sleigh & Cheston Ltd., Widney Works, Birmingham, 4.

INSULATING AND PROTECTIVE TAPES is a brochure which includes the tapes in most common use for solid type paper insulated cables up to 33kV and for vulcanized rubber insulated cables. Copies are available, free of charge, from British Insulated Callender's Cables Ltd., 21 Bloomsbury Street, London, W.C.1.