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A EUROPEAN COMMON MARKET

IN his Presidential Address, Mr. George Marriott introduced the subject of engineers having a knowledge of industrial administration*—a subject which necessarily involves some understanding of economics. It is, therefore, pertinent to refer to the recent White Paper on "A European Free Trade Area"† which envisages the free circulation of manufactured goods in an area containing a population of some 250 million people.

The proposed establishment of a Customs and Economic Union, consisting of France, Germany, Italy, Belgium, Holland and Luxembourg, is now approaching successful conclusion. The United Kingdom does not contemplate joining this Union under present conditions which would prevent the United Kingdom from treating imports from the Commonwealth at least as favourably as those from Europe. Subject to this consideration, the British Government has stated that it is willing to enter into negotiations in the organization for European economic co-operation.

A common market comprising the six nations mentioned will provide a community of over 160 million people, rising to 250 million if all Western Europe accepts the plan. Whilst such populations are less than the Americas, India, China, or Russia, the area covered is probably the most highly industrialized in the world.

The demands of such a market will greatly concern engineers, if only in the matter of securing agreement on various standards. Five of the countries mentioned are already represented on the International Electrotechnical Commission; economic conditions have certainly changed since the Commission was formed in 1906, but it still has the object of promoting the unification of standards in the whole field of electrical engineering, electronics, radio communication, telecommunications, etc. For this purpose it is affiliated to the International Organization for Standardization and technically advises the Economic and Social Council of the United Nations.

Like any other citizen, the engineer may be confused at the variety of bodies directly and indirectly concerned with the products he designs, develops, and produces. I.E.C., E.S.C.U.N., I.S.O. and other similar initials tend to confuse the mind. Some centralization of all these activities is provided in Great Britain by the British Standards Institution.

The radio and electronics engineer is particularly concerned with the fact that the Institution is directly represented on 12 Committees of the B.S.I. In recent years, the work of these various Committees has been concerned with the international electrotechnical vocabulary in electronics and on fundamental definitions; the colour coding of fixed resistors and their preferred values and associated tolerances; safety requirements for electric mains-operated amplifiers and for loudspeakers; dimensions of electronic tubes and valves; climatic and mechanical robustness; testing procedure for components.

Since the engineer will be vitally concerned with such a project as a European free trade area and its possible extensions, he is compelled to study the merits of standardization. Inevitably there must be points of disagreement: whilst the British Standards Institution throws a wide net in its efforts to secure authoritative opinion, a review of technical and professional journals suggests that engineers might do more to express views on a subject now of far reaching economic importance.

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* *J.Brit.I.R.E.*, **17**, p. 12, January 1957.
† Cmnd. Paper 72. (H.M.S.O., February 1957.)

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"ELECTRONICS IN AUTOMATION"

Second List of Papers Selected for Presentation at the 1957 Convention

Session 1—OFFICE MACHINERY AND INFORMATION PROCESSING

(Thursday, June 27th—9.15 a.m. to 12.30 p.m.)

Techniques for using Computers for Office Work

by E. A. Newman, B.Sc., and M. A. Wright, B.Sc.(Eng.) (National Physical Laboratory)

The paper will give an illustration of clerical work and point out why some clerical tasks involve more work in data processing than in calculation. A system for doing payroll in which a high speed computer does data marshalling as well as calculation and decision making will then be described.

Application of this system to related tasks such as cost accounting will be discussed. Mention will be made of special equipment required and some consideration given to the economics of high-speed computer systems and the limitations of the above techniques.

Session 2—MACHINE TOOL CONTROL

(Thursday, June 27th—2.30 p.m to 5.30 p.m.)

Backlash and Hysteresis Effects in Automation Systems

by Prof. L. M. Vallese (Polytechnical Institute of Brooklyn)

The stability of second and third order systems possessing backlash or hysteresis is investigated using procedures of non-linear analysis.

Automatic Positioning Systems for Machine Tools

by C. Borley, C. Braybrook and L. Coates (Mullard Research Laboratories)

The factors affecting the selection of numerical input automatic positioning systems are considered. A review of current technique is given to indicate the order of system cost and complexity. Various economic and operational features, such as cost, speed, accuracy, life and flexibility are emphasized and input, measurement and control schemes are classified according to basic principles. The need for unity of conception in new machine design is stressed and the adaption or conversion of existing machines is considered.

A novel requirement for a co-ordinate positioning machine allowed an integrated approach to the electronic and mechanical design of the "machine." The resulting design is discussed in detail as an illustration.

The Inductosyn and its Application

by H. J. Finden and B. A. Horlock (Plessey Company Limited)

The inductosyn is a position control element manufactured in rotary and linear form. In its rotary form it is capable of indicating angular position to an accuracy of 5 seconds of arc with a repeatability of 1 second of arc whilst in its linear form it is capable of a positional accuracy better than 0·0001 in. with a repeatability of 25 microinches. Particular reference is made to a programmed co-ordinate table where information is in the form of punched cards. Its use is illustrated by considering a typical problem in which hole centres are to be placed accurately in a small gearbox casting.

Session 3—CHEMICAL AND OTHER PROCESSES

(Friday, June 28th—9.15 a.m. to 12.30 p.m.)

Radio-active Tracer Techniques in Automatic Sample Assay and Process Control

by C. C. H. Washtell (Labgear Ltd.)

The paper will cover the application of a Recording Ratemeter and a Printing Counter with an automatic Paper Chromatogram Scanner to research and quality control problems in the chemical industry. Examples of continuous monitoring and control of processes in conjunction with a Scintillation Counter will also be described.

An Electronic Three Term Controller

by Z. Czajkowski (Winston Electronics Limited)

The paper gives a critical analysis of the existing systems, a review of electronic methods of analogue computation and their application to a specific problem of process control. The author has designed a novel three-term process controller, entirely electronic, and gives an appreciation of its performance as applied to a model plant.

Session 3 (*contd.*)

Instrumentation for the Control of Process Streams in Atomic Energy Projects

by H. Bisby (Atomic Energy Research Establishment, Harwell)

Quite apart from the application of conventional techniques for the control of such parameters as density, flow-rate, temperature, pH value and pressure, the radioactive process streams encountered in chemical plants associated with the Atomic Energy Programme require specialized instruments and techniques for monitor and control purposes. These nucleonic instruments are being used to control process operation, check process efficiency and to ensure a product quality. The present paper deals with a variety of recent techniques which have been applied to the processes of uranium extraction from mineral ore in South Africa, uranium-thorium separation and fission product extraction from spent reactor-fuel elements.

Session 4—AUTOMATIC MEASUREMENT AND INSPECTION

(Friday, June 28th—2.30 p.m. to 5.30 p.m.)

Automatic Control in Steel Strip Manufacture

by G. Syke, Dipl.Ing.
(Baldwin Instrument Co. Ltd.)

The paper will cover thickness gauges on strip rolling mills and their use for automatic screw control, measurement and control of extension on skin-pass or temper mills, and automatic sorting of steel sheet and tin-plate on cut-up lines.

Automatic Ultrasonic Inspection

by H. W. Taylor, B.Sc.
(Messrs. Kelvin & Hughes Ltd.)

This paper will describe the development of automatic methods for the detection by ultrasonics of internal and surface flaws in a wide range of materials.

Manual ultrasonic flaw detection has been employed as an industrial inspection method for approximately 14 years. Using this technique very high standards of inspection were maintained. It is however not suitable for modern high speed production conditions. The factors limiting the application of manual inspection under these conditions are considered and a description given of the fully automatic equipment recently developed to overcome these limitations.

Automatic Counting Techniques Applied to Comparison Measurement

by C. C. H. Washtell (Labgear Ltd.)

The paper will concern the repetitive counting of independent pulse sources which are required to be measured in ratio form, and the results presented as a paper record.

Examples in X-ray diffraction, tachometry and meter-testing will be given to illustrate the technique.

Session 6—AUTOMATION IN THE ELECTRONICS INDUSTRY

(Saturday, June 29th—2.30 p.m. to 5.30 p.m.)

The Use of Printed Circuits in the Manufacture of Electronic Equipment

by F. Hicks-Arnold
(A.C. Cossor Radio & Television Ltd.)

The advantages of all wiring between components lying in one plane are pointed out. Methods of printed circuit production and their relative merits and disadvantages are described. The possibilities of automation production of printed circuits are considered and automatic versus manual component assembly discussed. The inclusion of some components other than wiring at no extra cost is shown to be possible. Automatic soldering of complete assemblies, automatic testing, finishing and inspection are described. Possible developments are suggested.

Electronic Heating and Automation

by M. T. Elvy (Redifon Ltd.)

The principal methods of applying r.f. induction and dielectric heating are reviewed and details are given of some special purpose mechanical handling equipment. Some industrial applications of electronic heating are described, e.g. the outgassing and getter firing of electronic valves; petrol tank soldering; the hardening of engine components; the manufacture of moulded wood products from wood waste; the welding of plastic sachets; the dielectric embossing of upholstery; and the removal of moisture from foodstuffs.

NOTICES

OBITUARY

The Council has learned with regret of the death on 11th February last of Mr. William Evan Mantle (Associate), aged 44 years.

At the time of his death Mr. Mantle was an Experimental Officer at the Royal Military College of Science, where he was attached to the Radar and Telecommunications branch as an engineer demonstrator. He had held this position for the past eight years and he was responsible for the development of special electronics and telecommunication laboratory apparatus.

Mr. Mantle was elected an Associate of the Institution in 1954.

Graduate Allowance to Teachers

Corporate Members contemplating taking up teaching appointments are reminded that the Institution's Graduateship Examination is recognized by the Burnham Committee as a degree equivalent. This means that the Graduate Allowance is payable to Associate Members of the Institution who have qualified by passing the Graduateship Examination not earlier than May 1951. In addition to teaching appointments in Further Education establishments this recognition also applies to teachers in primary and secondary schools.

Change of Address

All members, and especially those overseas, are asked to make sure that the Institution is advised promptly of any permanent change of address as otherwise communications such as the *Journal* and examination correspondence may be unduly delayed. Temporary changes should *not* be notified.

Dr. P. Eisler

At an investiture in Paris last month, Dr. Paul Eisler (Member) was made an Officer of the French "Order of Merit for Research and Invention" for his invention and pioneering work of printed circuits.

Members will recall that Dr. Eisler received the Institution's Marconi Premium in recognition of his paper on "Printed Circuits: Some general principles and applications of the foil technique" which was published in the *Journal* in November 1953.

London Meeting

The last London meeting of the present session will be held at the London School of Hygiene and Tropical Medicine on Wednesday, 22nd May, at 6.30 p.m. A paper on "Barium Titanate and its Uses as a Storage Device" will be read by Mr. G. Campbell. Members wishing to bring guests to this meeting should apply to the Institution for tickets.

Institution Tie

The Council has authorized the manufacture of an Institution tie incorporating part of the Armorial Bearings. The tie will cost 25s. and it is hoped to give further details in the May *Journal*.

Technical State Scholarships

Changes in the arrangements for the award of Technical State Scholarships have been announced by the Ministry of Education and, as the first stage in the plan, the number of scholarships to be awarded in 1957 will be increased from 150 to 225.

In 1958, however, applications will be considered only from

(i) candidates who, for the two previous years, have been engaged in *part-time* study at Establishments for Further Education (however, students following Higher National Diploma courses will also be eligible).

(ii) students who have not proceeded beyond Ordinary National Certificate level, or A.1 level in Higher National Certificate courses; or corresponding levels in other types of course.

The effect of these changes will be to exclude from the scheme, in 1958 and later years, two categories of students hitherto eligible:—

(*a*) students who have followed full-time courses leading to G.C.E. (advanced level). In future such students will be expected to apply for ordinary State Scholarships and not Technical State Scholarships;

(*b*) students who have obtained Higher National Certificates. National Certificate students will require to decide at the Ordinary National Certificate stage, or at latest at the A.1 stage, whether they wish to enter for a Technical State Scholarship.

REMOTE PRESENTATION OF RADAR INFORMATION BY MICROWAVE LINK*

by

G. J. Dixon† and H. H. Thomas†

Read before the Institution in London on 14th December 1955

In the Chair: Wing Commander W. E. Dunn, O.B.E. (Member)

SUMMARY

The problems inherent in the transmission of radar information are reviewed. The bandwidth required by the information content is shown to be very low and some methods of bandwidth compression of the original radar signals are discussed briefly. The problems of transmitting a complete radar signal are then considered with particular reference to the transmission of the scanner angle, and finally a complete equipment operating at 4000 Mc/s and using pulse time modulation methods is described in detail with examples of typical circuitry.

1. Introduction

Many problems, technical and organizational, would be solved by the presentation of radar information at a point remote from the radar site. This paper discusses first some of the organizational problems and situations which would benefit from receiving the information from a remote radar site, then some of the basic properties of a radar picture, and the theoretical possibilities in obtaining minimum bandwidth, together with a brief summary of present devices.

The radar equipment is then discussed briefly, to give a background to the description of an equipment designed to present at a remote site a reproduction of the original p.p.i. presentation.

2. Operational Requirement

The efficient operation of a radar set for area movement control involves certain difficulties. In nearly all applications the information gathered from a radar set is of value only when combined with other data, either additional radar data from adjacent areas or miscellaneous additional information relating to the use to which the radar set is being put. This is particularly true in the case of defence networks, air traffic control, or harbour control.

The general method used to overcome this is that of reporting all the information to a plotting centre, where it is collected, evaluated, and the results displayed on a board. A number of elaborations have been devised to speed this process but it is still slow and the principal source of lost time. The location of the plotting centre is dictated by organizational considerations and may be a long distance from the radar sites.

A great deal of thought has been put into the design of air traffic control operating procedure to provide a high degree of safety, and this has led to elaborate precautions being taken to ensure that aircraft report arrival and departure correctly so that no traffic moves without the controller being aware of it. It is usual to have sufficient radar displays so that on aircraft reporting, a display and operator can be assigned to watch and identify each. The co-ordination problem is eased if the radar information, in addition to being available to an operator, is routed to the central controller and processed by having redundant information removed, extra information inserted, and then made available for selection by automatic means.[1]

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* Manuscript first received 12th October 1955, and in final form on 7th February 1957. (Paper No. 392.)

† Decca Radar Ltd., Radar Research Laboratory, Tolworth, Surrey.

U.D.C. No. 621.396.963.083.7.

The major problem in harbour control is that the harbour pilot, who is in fact the controller and has to assume responsibility for the safety of a ship once he has taken over command, has at present to carry out his pilotage entirely by visual means. If a vessel is equipped with radar this is of considerable assistance, but there are many cases of long, winding, narrow channels where the ship's radar is badly placed to give any information of movement at the harbour end of the channel.

Radar sets surveying the harbour have been installed to increase the amount of information available to the pilot, but the siting of a harbour radar presents particular problems in that very often the site for the best view of the harbour is not the best place from which to control it. The most general solution would be for the radar information to be transmitted to the piloted ship and displayed on a monitor under the control of the pilot, but unless such apparatus is extremely portable it is very difficult for it to be placed on board in bad weather when it is most needed.

From the point of view of the harbour master it is desirable to have the radar information presented directly to him, but this is seldom possible, and the need does exist for some method of linking a number of radar sets to the central harbour control office.

This general problem of traffic control has led to various schemes being considered to transfer radar information directly to the man carrying the responsibility.[2] Teleran was proposed in the United States of America, but this has considerable technical complexity, and its operational desirability has not been established.

The problem of defence networks are similar but on a far vaster scale, involving large areas and many radar sets.

There are thus two classes of equipment called for. In airfield or harbour use all aircraft and ships are required to report their arrival, and plotting does not commence until the target has been clearly identified. The organization is such as to prohibit unannounced movement and this eases considerably the requirements on the sensitivity of the reporting systems. A defence system on the other hand deals with targets which have minimum detectability and unpredictable approach. The reporting system must on no account degrade the performance of the radar set and if possible must be designed to enhance it.

3. The Information Content of Radar Data and the Bandwidth Requirements

Later on in the paper a short summary is given of the principal radar set characteristics from which it is seen that for typical surveillance types of radar the pulse lengths vary from 0·5 to 2 microseconds, involving radar bandwidths of between 0·5 and 2·5 Mc/s, and if the radar video signal is transmitted without alteration the transmission bandwidth must be at least this.

This poses the most difficult problem associated with the transmission of radar information: namely, the very large disparity between the bandwidth of the video information from the radar set and the theoretical bandwidth required for transmission of the information content.

The information from the radar set is contained in a basic element, the radar pulse echo. The output signal consists of a number of these elements in time sequence to form a recurrent waveform. Associated with each element are its co-ordinates with respect to the radar site in terms of its range and angular position. The number of unique echoes equal to a pulse length reported by a radar set in a complete aerial scan is given by the equation

$$\frac{\text{max. range } (\mu\text{sec}) \times 360}{\text{pulse length } (\mu\text{sec}) \times \text{beamwidth (degrees)}}$$

A typical radar with a maximum range of 1,500 microseconds, pulse length of 1 microsecond, and aerial beamwidth of 1 deg., has a target capacity of $5{\cdot}4 \times 10^5$. This quantity is never obtained in practice. Under the worst conditions of maximum ground clutter and rain a maximum of the order of 10^5 elements would be encountered. Of these, aircraft or wanted ground targets would be of the order of 300, aircraft being a maximum of about 50. The normal aerial rotation rate for a long range radar is about six revolutions per minute. If the definition of the radar set is not to be reduced there are $5{\cdot}4 \times 10^5$ alternative positions for a target to appear in. If it is required to specify each one of these positions this can be done with a binary number of 20 digits, assuming equal probability between positions. Shannon[3] gives for the capacity of a channel

$$C=B\log_2\left(1+\frac{P}{N}\right)$$

where B = bandwidth in c/s
P = transmitter power
N = noise power
C = bits per second.

Each target position requires 20 bits, therefore as no more than 300 targets are required to be presented in one aerial revolution, or 30 per second, a transmission rate of 600 bits per second is required. Presuming a required signal power to noise power ratio of 10, a bandwidth of 173 c/s is needed to transmit this if a sufficiently ideal form of coding can be found. The restrictions placed on the coding system are that it should completely occupy the bandwidth, that the information is sent at a continuous rate not exceeding this number of bits, and that a sufficient delay be incorporated to reduce errors to a negligible amount. Even less bandwidth is required if only the change from complete aerial scan to scan is sent. In this case the maximum number of targets required per ten seconds is 50, or 5 per second. This bandwidth could be further reduced if advantage could be taken of pre-knowledge of the repetition rate and the aerial rotation rate.

4. Methods of Data Processing and Transmission

The bandwidth can be reduced to some degree without elaborate coding by taking advantage of the fact that the aerial rotation rate and p.r.f. are usually chosen so that a number of radar pulses interrogate the target within a beamwidth and the resulting successive echoes are then integrated on the display phosphor. In effect, the target signal is not complete until these overlapping scans are added together.[11] By adding these in a store and then reading out at a slower rate, the bandwidth is narrowed directly by the ratio of the input and output rates. Any conventional method of transmission can be used to transmit the resulting signal and the picture reconstructed by using a display with all time scales increased by a similar amount.

If we apply such an equipment to the radar set of the previous example and assume that 10 pulses are received per beamwidth and the radar receiver bandwidth is 1,500 kc/s then the bandwidth required by the pulse after integration is reduced to one-tenth, or 150 kc/s. While this is useful for some purposes, it is still wider than the bandwidth of commonly available transmission equipment. The principal value of this method lies in the transmission of information from very high definition radar sets where bandwidths of 15 to 20 Mc/s are normally required.

A device using this principle is described by C. W. Doerr and J. L. McLucas.[3,4] This particular device is rather inefficient in the method used for the integration, as reading is simultaneous with writing, and the very narrow bandwidth of 2 kc/s claimed has been achieved by assuming a very low value of resolution.

Any method of storage can be used for this bandwidth reduction. A number of types of electrostatic storage tubes are now available commercially, but resolution is the limiting factor in their application. The average resolution claimed for these is of the order of 400–600 lines. For perfection the resolution required when used as a store is given by the ratio of longest range in use to pulse length, and for the example quoted would be 1,500 lines. This can be reduced if it is taken that the resolution need not be greater than that viewed on a normal display and the range scale chosen at the transmitter to meet this.

To reduce the bandwidth further towards the ideal the signal must be analysed, the unwanted echoes removed and the wanted echoes abstracted; the latter are labelled with their appropriate position co-ordinates and then fed into a store whose function is to issue the coded signals in a continuous stream at a rate and in such a form as to match the transmission channel. At the receiver the signals must be decoded and presented for evaluation by the form of display most convenient to the application.

Such a system is very complex and expensive and can only be applied and designed in conjunction with an overall control plan specifically designed for continuous use over large areas.

If we consider the rate of growth of air traffic over the last few years it is certain that such a system will be required within the next decade or so. It is freely acknowledged by air traffic authorities that if air safety standards are to be maintained all the major cities in Europe will have to be linked together by a direct central traffic authority which must have an exact and up to the minute picture of air movement.

Another method of transmitting radar information is to transform the radar polar co-ordinates into rectangular co-ordinates by writing on to a storage surface in polar form and reading off with a television type scan, and transmitting and displaying the picture by normal television techniques. The main disadvantage is that this method increases the bandwidth, the minimum bandwidth now being that of the television system. The number of lines required is equal to twice the number of points it is desired to resolve along the polar radius. If this were 400 points, for example, an 800 line system with a bandwidth of 8·0 Mc/s is required. Despite this disadvantage the method is convenient in that the display equipment is cheaper and local multiple viewing is easy. The wider bandwidth, though, is very inconvenient for transmission over long distances. This method was shown in Paris at the 1955 International Aeronautical Exhibition.[7] A storage tube was used as the conversion device and the results were quite impressive.

Another method of co-ordinate conversion experimented with is that of viewing the radar display picture with a television camera. The results of this have been rather poor. Some measurements carried out by the authors using a photoconductive type of camera tube with a long persistence showed that a display has a brightness range of about 20 lumens/ft^2 on the scan trace to 0·5 lumens/ft^2 after decay on strong echoes, and proportionately less for weaker echoes. The camera had to be adjusted to work on the lower figure and the sensitivity of the camera was not adequate. The camera persistence was of the same order as the display, and gave an equal contribution to the output signal. The level of the output signal after the maximum decay was comparable to the unevenness of the black level, and charge spreading on the target surface was magnified so that a resolution of 800 lines obtained at high light level was reduced to 200 lines. A sensitivity of the order of 10 times greater without overloading on high intensities was required.

The polar to rectangular co-ordinate transformation is not the most efficient means in terms of bandwidth. This can be seen from the ratio of the number of elements in the respective displays. This is $90/D\varphi$ where D is the number of discrete points along the radius and φ is the beamwidth. A square display of sides equal to twice the polar radius is assumed.

This objection is overcome if a spiral scan is used. If the definition of the radius is taken as 400 points and the beamwidth is 1 deg then a rectangular scan based on television standards would require a bandwidth of 1·8 Mc/s. However, the synchronizing of displays is more difficult.

At the present state of technical development each of the methods so far discussed has some disadvantage associated with it which limits its general application. The conventional approach, that of transmitting the radar information in such a way as to operate remotely the normal radar display, is still the most general solution as it enables the usual operational routine to be carried out without loss of facilities. The difficulties of this method are discussed in full in the next section.

5. Direct Transmission

In this section we shall describe an equipment which has been designed to transmit to a remote point radar information at the original bandwidth and processed so that it is capable of feeding the standard plan-position indicator used with the radar set.

In order to reconstruct the radar picture at a remote site it is necessary to transmit at least the scanner angle, the synchronizing pulse and the video signal. Auto-alignment or heading markers have to be transmitted where such circuits are fitted.

This presumes that the radar display can be readily separated from the radar modulator and aerial; in the majority of cases this is true but in some cases the radar modulator also generates range markers and strobing pulses, and arrangements must be made to generate these at the receiving site as it is unnecessary to transmit them.

For complete operational use within a system other quantities for monitoring, identification of targets, etc., may have to be transmitted to and from the local and remote sites.

Early warning radar sets form a class the requirements of which are fairly standard. The pulse repetition frequency ranges from 200 to 650 c/s, pulse length from 0·5 to 5 microseconds, and aerial rotation rate from 0–10 revolutions per minute. On these sets anti-jamming and anti-clutter circuits are incorporated, and duplicates may have to be included in the transmitter of the linking system.

Short range high definition sets are difficult to deal with because of the very wide bandwidths involved. The pulse repetition frequency is from 1000 to 3000 c/s, pulse length varies from 0·02 to 0·2 microseconds, and aerial rotation rates from 20–60 rev/min.

Marine radars must be included because a number of these types have been used for other purposes, and there is always a possibility of being required to operate with one. These usually have p.r.f. rates from 500–1000 c/s, pulse length from 0·1 to 2 microseconds and aerial rotation rates of between 20 and 30 rev/min.

The majority of radar sets use selsyn or magslip systems or 50 c/s generators and synchronous motors to transfer the scanner angle to the display, and the transmission of this angle to the remote display is one of the more difficult problems.

The requirements of height finder radar sets are more complicated. The method of operation is different in that only one target is handled at a time, this target having associated with it its elevation angle as well as the azimuth angle. To operate a remote display without modification the extra information of elevation angles and elevation markers must be transmitted.

Special purpose radar equipment such as moving target indicators, etc., are probably the most difficult types of equipment to deal with, and in most cases remote equipment has to be specially developed . The m.t.i. equipment, for example, will require the simultaneous transmission of two or more sets of video information.

5.1. *Transmitting the Radar Video Data*

Except for the requirement given in the last paragraph, transmission of the video presents few new problems: the bandwidth required is determined by the radar set and it is sufficient that the amplitude/frequency response of the linking system extends to the 3 db point of the radar response. Alternatively, the bandwidth should be at least $3/4\tau$ where τ is the pulse width. This bandwidth will give the optimum signal/noise ratio.

In order to obtain maximum sensitivity it is usual to incorporate a limiter so that the transmitted radar pulse/radar noise ratio may be adjusted.

5.2. *Transmitting the Scanner Azimuth Bearing and Associated Markers*

The radar scanner bearing can either be transmitted as a phase of an a.c. waveform relative to a reference voltage or as an angle in terms of its sine and cosine components: both methods require two separate signals to be transmitted. In the first method a phasing device is attached to the radar scanner whose output is $V \sin(\omega t+\varphi_0+\varphi_s)$, where φ_s is the scanner angle. This voltage and the reference $V \sin(\omega t+\varphi_0)$ are then transmitted. At the receiver the output shaft has a similar device which is supplied with the reference voltage; the output phase is then compared with the transmitted phase and the difference is used to drive the output shaft to the correct position. The output angular error is composed of three components: phase errors in the transmission channels, angular errors in the phasing device, and misalignment error due to the finite gain and stability of the servo mechanism. The most difficult to maintain of these is the phase stability of the transmission channel.

Interfering tones can have a profound effect on the performance. For example, if the phase signal is $V \cos(\omega_1 t+\varphi)$ and the interfering signal is represented as $nV\cos(\omega_1 t + (\omega_1 - \omega_2)t)$ where $(\omega_1 - \omega_2)$ falls within the response time of the system and can be considered as a continually increasing phase addition to ω_1 the combined signal is

$$E = A\omega(\omega_1 t + \alpha)$$

where $A = V\sqrt{\left\{(1 + n^2) + 2n\omega[(\omega_1 - \omega_2)t + \varphi]\right\}}$

and $\alpha = \tan^{-1}\dfrac{\sin\varphi + n\sin[\omega_1 - \omega_2]t}{\cos\varphi + n\cos[\omega_1 - \omega_2]t}$

The amplitude component A can be removed by a limiter but the additional angle variation will cause the output shaft to vary at a period $(\omega_1 - \omega_2)$.

If for transmission purposes these signals are modulated on subcarriers it can easily be shown that a non-linear phase characteristic or differential time delay with frequency can also cause variations in the output angle; this is the principal weakness of the method as it is very vulnerable to disturbances in the characteristics of the transmission path.

In the second method the scanner angle is conveniently obtained from a two-phase magslip resolver attached to the radar scanner: the rotor is supplied with $V\sin\omega t$ and the outputs are $V\sin\omega t\sin\varphi$ and $V\sin\omega t\cos\varphi$. These are transmitted and at the receiver are fed into the stator windings of a similar magslip, the rotor of which is attached to the output shaft. The output of the rotor is phase rectified and is applied to a servo mechanism which turns the shaft for a null. This method is subject to four types of errors: amplitude non-linearity of the transmission channel, differences of gain of the channels, residual errors in the magslip elements, and misalignment of the servo-mechanism due to finite gain and stability of the servo amplifier.

The angular error of the output shaft relative to the input shaft when the amplitude of the sine and cosine channels are V_1 and V_2 respectively is

$$\cos^{-1}\frac{(1+n) + (1-n)\cos 2\varphi}{2\cdot\frac{1}{2}(1+n^2) + \frac{1}{2}(1-n^2)\cos 2\varphi}$$

where $n = \dfrac{V_2}{V_1}$ and φ is the input angle.

This error is the usual type of quadratic error for small amplitudes.

The error due to amplitude non-linearities is of a similar type but if the amplitude curve is a non-symmetrical curve about the axis, i.e. the slope is continually increasing or decreasing, over the range of values of interest, the magnitude of the error will be different in each quadrant. In the first and third quadrants the sine and cosine are both positive or negative and traverse the same part of the curve and the error is small, but in the second and fourth quadrants the sine and cosine are of opposite signs and will have the maximum difference in magnitude and error. The error curve will also show variations of higher period than 2φ but these are usually negligible.

The magslip resolvers available have an accuracy of ±6 minutes over a frequency range of 50 c/s to 2000 c/s, and with careful design the following accuracy of servo-mechanisms can be made comparable. If the channel linearity can be held to 0·5 per cent. an angular accuracy of ±0·25 deg can be obtained by either method, and such accuracies have been obtained in the laboratory. For a production equipment designed for field use an accuracy of ±1 deg is probably the best that can be guaranteed as for consistent results this requires a test rejection limit of ±0·5 deg.

If a better angular accuracy than this is required the scanner rotation can be multiplied by gearing up the selsyn or magslip before transmission and so dividing the error by the amount of the gear ratio.

As power selsyns have accuracies on load of only ±3 to 5 deg this multiplication is frequently used in radar sets to ensure that the displays follow the scanner with negligible error. As an ambiguity is introduced it is usual to arrange that a marker is produced whenever the scanner passes a reference heading, this marker aligning the display automatically.

This method is very convenient for link transmission as the linearity of modulators and demodulators can be reduced. The speed of realignment after a fade in a radio path is very much slower as the scanner must rotate at least once before the error can be detected. This is a serious disadvantage when transmitting a height finder azimuth angle as the scanner may only pass through the reference heading at infrequent intervals.

If we consider the case of a radar set with an aerial rotation of 6 rev/min, and multiplied by 30, a standard figure, then a radio path fade of only 1/6th sec duration occurring just after heading is passed will cause a loss of synchronization which cannot be detected by automatic alignment for 1 revolution, and requires a further revolution or part of a revolution to correct, a time between 10 and 20 seconds. Even an interruption of similar duration at 1 minute intervals would cause serious disruption and in the case of non-video blanking displays would cause intolerable smearing. Many older radar sets have no automatic alignment, and in this case an interruption of one fade every 10 or 15 minutes would cause chaos.

Microwave radio transmission is frequently used and an examination of literature concerning fading at these frequencies shows that fades of 20 db to 30 db occur, particularly on paths over water. These fades are not usually of very frequent occurrence, of the order of 1·0 to 0·1 per cent. of the operating time (depending on path length, Fresnel zone clearance, etc.), except over sea, but they would constitute a nuisance.

These considerations show that a system designed to work under arduous conditions of service and with minimum signal to noise ratios should preferably incorporate a bearing system which transmits the radar angle unambiguously and with the fastest possible recovery time after interruption. This is possible if the limit of an overall operating accuracy of ±1·0 deg is acceptable, and for the vast majority of operating situations, airfield use, harbour use, simple early-warning, this appears to be entirely adequate.

The angle signals so far described have been in the form of a modulated low frequency wave, and this is inconvenient for transmission over a radio link system. It is usual to further modulate these signals on to subcarriers inserted at a convenient frequency in the video bandwidth, or alternatively to express them as the time interval between a pair of pulses inserted in the video at a convenient time.

The use of frequency modulated subcarriers is very convenient and the techniques are well established. The main disadvantage is that the subcarriers share the transmitter power and the system must be carefully examined to exclude the possibility of interference from cross-modulation and beat notes which may fall on or near the subcarriers.

The authors have used the second method in the equipment described later. In this method the angle is impressed on pulses inserted in the blank space at the end of the longest range in use. The use of a sine interval and a cosine interval is the most convenient method and as negative time intervals are not permissible the angles are expressed as $t_1+t\sin\varphi$ and $t_2+t\sin\varphi$ where t_1 and t_2 are time intervals greater than t. At the receiver the values t_1 and t_2 must be subtracted to obtain the negative values, and incorrect subtraction is a further source of possible error.

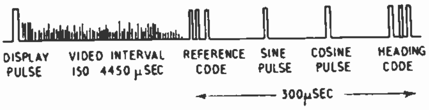


Fig. 1. Typical modulation waveform for transmission by microwave link.

As the azimuth angle is expressed as pulses it is natural that any markers should also be transmitted as pulses and a typical modulation waveform is shown in Fig. 1. The sequence commences with the display trigger pulse followed by the radar video, then a three pulse code is used to denote the commencement of the angle and marker period, followed by two pulses each time modulated with the sine and cosine of the angle, and lastly a separate three pulse code which is transmitted whenever the radar scanner passes the reference heading.

The pulse method has a considerable advantage over a c.w. subcarrier method in the superior signal/noise ratios obtained. This arises because all the transmitter power is available to use for an exchange of bandwidth against noise.

The improvement over the detector signal/noise ratio at video bandwidth for the pulse time modulated signals is given approximately by

$$\text{signal/noise improvement} = 160\,(Bt_m)^2\,\frac{\text{PRF}}{f_m}$$

where B = video bandwidth

t_m = peak modulation bandwidth

P.R.F. = pulse repetition rate

f_m = highest modulating frequency

This improvement can be still further increased by including suitable gating circuits which exclude noise in the time outside the angle period.

Similarly, a very high immunity to interfering pulses and spurious signals can be obtained.

6. R.F. Transmission

In the transmission of very wide video bandwidths a correspondingly wide radio frequency spectrum is occupied and with the present-day frequency congestion only the super high frequencies are available.

As part of the initial development it was required to transmit the information of a high definition harbour radar; this used an i.f. bandwidth of 25 Mc/s and the frequency band 3600–4200 Mc/s was chosen.

The subject of microwave transmission is well treated elsewhere and only the relevant formula will be quoted here. It can be shown that the received signal/noise ratio under free space conditions is given by

$$\frac{\text{signal power (r.m.s.)}}{\text{noise power (r.m.s.)}} = \frac{P_t\, G_1\, G_2\, \lambda^2\, M^2}{F\, k\, T\, B\, 16\pi^2\, d^2}$$

where

P_t = transmitted power

$G_1 G_2$ = gain of receiving and transmitting aerials

M = modulation index or improvement factor

F = noise figure

T = temperature in degrees K.

k = Boltzmann's constant

B = bandwidth

d = distance.

At these frequencies very narrow beamwidth aerials with high gains and reasonably small physical dimensions are easily constructed, and the experimental work was carried out using 4 ft paraboloids with a gain of 31 db. These were replaced by 6 ft types in the later engineered versions of the equipment.

The possible distance of transmission is given by the longest reasonable line of sight path to be encountered. Referring to Fig. 2 on which are plotted the heights of masts required against distance, a path of 40 statute miles requires 300 ft masts for Fresnel zone clearance, over level ground, and this would be costly. Experience shows that a more economic height is about 160 ft, giving a range of 24 statute miles, and it is necessary to take advantage of high ground wherever possible to extend the range. For this type of system the maximum economic distance is therefore about 40 statute miles. This distance can be extended by means of repeaters, the limit being given by the transmission characteristics of the system and the operating and maintenance facilities incorporated. As the number of repeaters is increased so are operating and maintenance difficulties, and long distances demand unattended equipment, standby, and automatic changeover facilities with remote indication of serviceability.

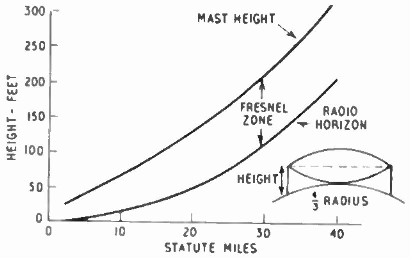


Fig. 2. Mast height required.
(Equal mast height at transmitter and receiver.)

The present design has been limited to a maximum of four repeaters in tandem to reduce the equipment complexity.

With high gain aerials the required microwave power is of the order of 0·5 W and this is obtained from a Heil tube velocity-modulated oscillator, type V233A/1K suitable for amplitude modulation. The decision to use amplitude modulation was made to keep the transmitted bandwidth as narrow as possible and occupy the least frequency space, and to enable i.f. amplifiers to be designed using the techniques and valves then available.

All microwave valves have poor amplitude modulation linearity but as the signal is a series of pulses this was not a serious defect.

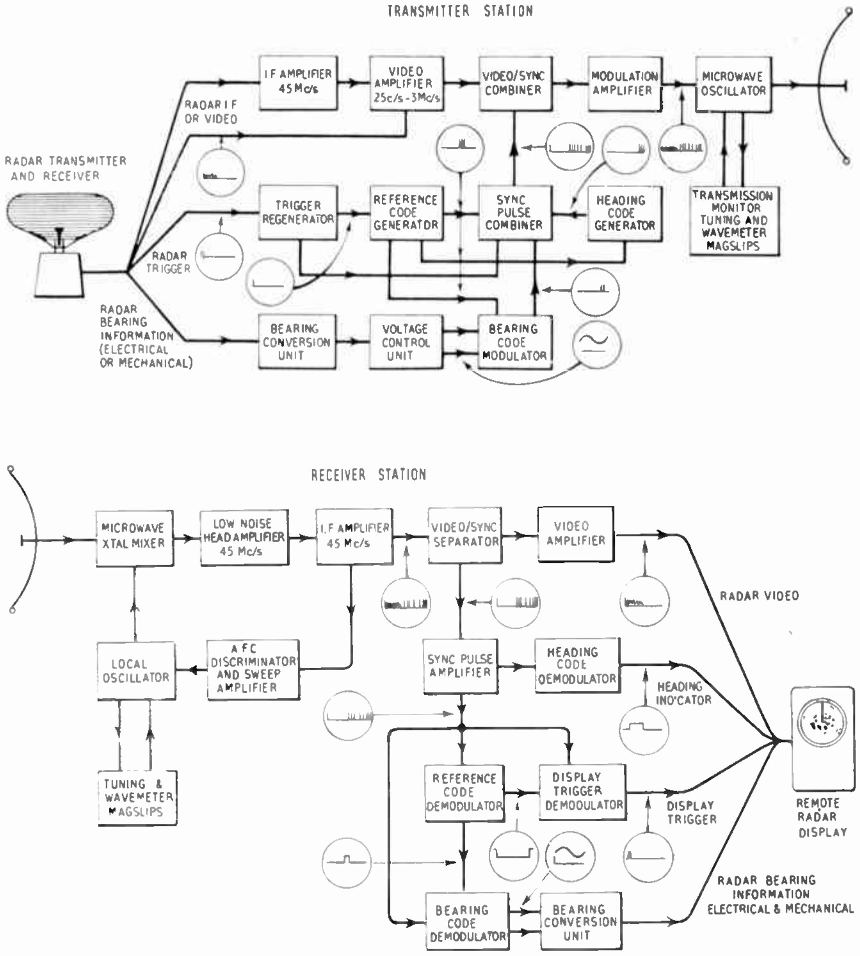


Fig. 3. Schematic of a complete microwave radar link equipment.

7. The Complete Equipment

In Fig. 3 is given a block diagram of the complete equipment. In its final form the equipment has been designed mainly to cater for radars within the pulse range of 0·3 to 0·5 microseconds and longer, pulse repetition frequencies between 200 and 2000, and aerial scanning rates from 0–30 rev/min. The equipment has an overall bandwidth of 2·5 Mc/s, and a signal power to noise power ratio of 41 db (referred to d.a.p. signal waveforms and r.m.s. noise) at a distance of 40 statute miles, thus providing a fading margin of 24 db.

The signal/noise ratio tolerable on a display is lower than that for a television system and it can be shown that signal/noise ratio of 14 db (d.a.p./r.m.s.) will only decrease the sensitivity of the radar set by less than 1 db. The bearing circuits have a threshold at 17 db and this is the minimum usable signal/noise ratio.

The modulation waveform is as shown in Fig. 1: the reference code is a group of pulses of approximately 1·0 μsec width spaced apart by 2·5 and 4·5 μsec, and the marker (heading) code is a similar group spaced by 3·5 and 5·5 μsec. This modulation waveform can be compressed, expanded and limited within wide limits without affecting the accuracy of the radar angle, synchronizing, and markers, and is therefore independent of the method or linearity of modulation on the microwave carrier.

7.1. *Transmitter Equipment*

The blocks marked pulse time modulator unit, video and control unit, and bearing conversion unit, and their associated power supplies, are located in a cabinet on the ground, usually at the foot of the mast, and the transmitter r.f. head unit is located in a casting at the rear of the parabola.

The sequence of events commences with the arrival of the radar trigger pulse. This pulse operates a gating circuit which opens up the video channel to the incoming radar information. At the end of the required longest range in use this gate will close and a pulse is sent to a delay line from which the reference code is abstracted. The last pulse of the code starts the operation of the sine and cosine modulator circuits. These circuits are controlled in the time of emission of their pulses by d.c. voltages generated by phase-sensitive rectifiers, which rectify the output of a two-phase magslip geared to an input three-phase selsyn, the gearing being adjusted to bring the rate of rotation of the two-phase magslip equal to the rotation of the radar scanner. When the radar heading is received a further code is formed and inserted in the period after the cosine pulse. The synchronizing pulses and the radar video are combined and then sent to the transmitter r.f. head where they are amplitude-modulated on the oscillator. The microwave valve is modulated negatively to approximately 80 per cent. depth of modulation and transmits a mean of 300 milliwatts through a monitoring coupler to the dipole. Both the microwave oscillator and wavemeter associated with it are tuned by magslip links from the ground cabinet.

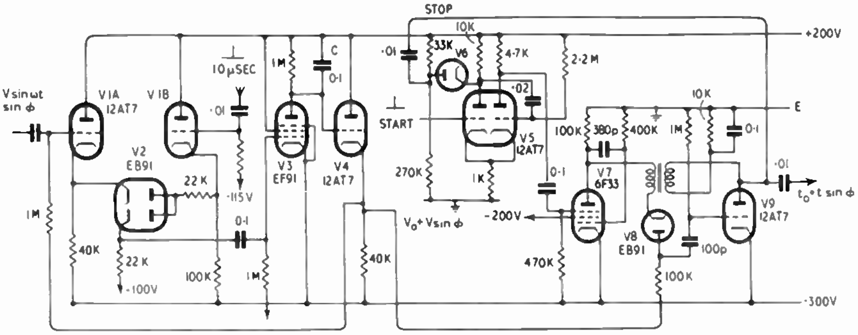


Fig. 4. Transmitter pulse modulator.

7.2. *Receiving Equipment*

The receiver r.f. unit is located in a casting behind the parabola in a similar manner to that of the transmitter. This feeds the signals down to the controlling cabinet containing the i.f. and video unit, the pulse time demodulators, and receiver bearing conversion unit. The r.f. signal feeds into the mixer and the resulting i.f. is amplified and passed to the main unit on the ground.

The local oscillator frequency and the wavemeter associated with it is again controlled remotely. The signal from the i.f. unit passes to two amplifiers, one of which supplies the video via a distribution unit to the displays; the other amplifier, incorporating differentiating and limiting networks, supplies the pulse time demodulator. The i.f. unit also provides a.f.c.

The operation of the pulse time demodulator is considerably more complex than that of the equivalent unit at the transmitter. Initially the whole differentiated and limited signal is passed into the reference code decoder. The reference pulse is sensed but as the possibility exists of a false code appearing in the radar video a gate is erected against this as soon as the first display trigger pulse appears in the right sequence. This synchronizing sequence depends on the existence of both the reference code and the display trigger; any incorrect sequence set up is unstable and the timing is such that the false code is closed out within

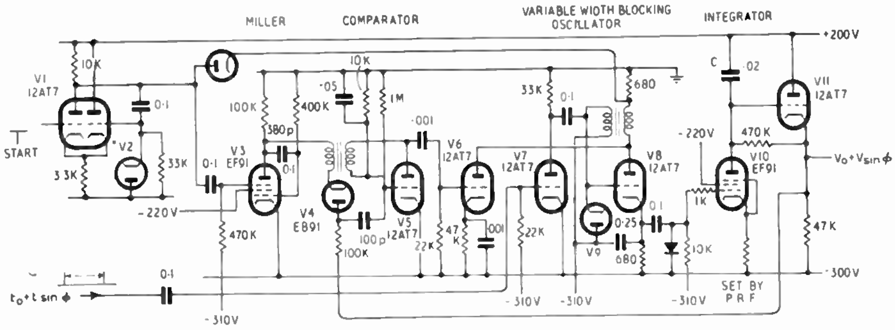


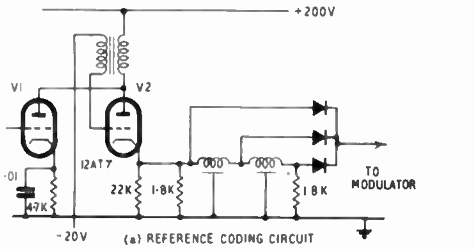
Fig. 5. Receiver pulse demodulator.

about five cycles, whereon correct sequence is established.

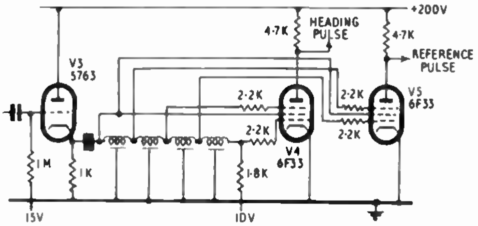
This sequence is established to ease the problem of separation of radar video and synchronizing pulses. Any attempt to separate these by methods involving d.c. restoration introduces cross-modulation between the sine and cosine, therefore the synchronizing pulses are sliced between 50 and 70 per cent. amplitude. Without this sequence radar video breaking through would cause interference and the ratio of sync to video would probably be very critical; this is avoided, and in fact, the radar video can be nearly 100 per cent. of the height of the synchronizing pulses without any effect.

A simplified schematic of the bearing circuits is given in Figs. 4 and 5. Referring to Fig. 4, V1 to V4 is a phase sensitive rectifier circuit which rectifies the output of the scanner resolver. $V \sin \omega t \sin \varphi$ and produces $V_0 + V \sin \varphi$ with very high linearity. The wave $V \sin \omega t$ is sampled at its peak by a a 10 microsecond pulse from V16 and the output pulse from the diode amplitude comparator V2 is integrated by V3. The output voltage from V4 is fed back to V1A and controls the mean value of $V \sin \omega t$ and so amends the amplitude of the pulse from V2. An equilibrium is reached when the amplitude of the pulse is just sufficient to replace the discharge current from C. Any change in the peak value of $V \sin \omega t$ is immediately followed by a change in the output voltage to restore the balance, and the output voltage therefore follows the variation $\sin \varphi$ of the input voltage. V5 to V9 form the pulse modulator. V7 is a Miller sawtooth generator gated by V5. When the voltage at the anode of V7 equals the input voltage diode V8 conducts and V9 produces a pulse.

Figure 5 shows the equivalent demodulator. V1 to V5 is similar to the pulse modulator. V6. V8 and V9 is a variable pulse width blocking oscillator and V10 and V11 is a pulse integrator. V1 is triggered by the decoded reference pulse and the potential at the anode of V3 commences to fall. When it equals the value of the voltage at the cathode of V11, V5 produces a pulse which triggers the blocking oscillator V6 and V8. The next input pulse stops this blocking oscillator via V7. The resulting pulse is integrated by V10 and V11 to produce the output voltage. The action of the circuit is most easily visualized by presuming C to be discharged. The first cycle of operation will produce a long interval pulse from V8 and this will charge C negatively, the second cycle will produce a shorter interval pulse and C will charge negatively by a smaller amount, this will continue until the interval pulse is just sufficient to maintain the charge flowing out of C and the output voltage is nearly equal to the input voltage of the modulator. If the time spacing of the incoming pulses changes the output voltage will take up a new value. A gate valve, not shown, is included as a precaution to prevent the output voltage falling so low that the interval pulse is generated after the arrival of the interval pulse as, under this circumstance, the variable



(a) REFERENCE CODING CIRCUIT



(b) REFERENCE AND HEADING DECODING CIRCUIT

Fig. 7. Coding and decoding circuits.

blocking oscillator will not be stopped but will continue to produce the maximum length of pulse and force the output voltage still further negative.

The output voltage $V_0 + V \sin \varphi$ is then passed to the servo system shown in outline in Fig. 6. The voltage amplitude modulates a 2000 c/s square wave and this is fed to the sine winding at a two-phase magslip resolver. The cosine circuits, which are identical to those illustrated, feed the cosine winding. The stator voltage is phase discriminated and the servo amplifier and motor turn the stator shaft for a null, coupled to the shaft is a similar three-phase selsyn to that on the radar scanner and the voltages from this are passed to the display.

The coding and decoding arrangement is shown in Fig. 7, and, as can be seen, is quite simple. Discrimination against incorrect codes is very good, a discrimination of better than 0·2 microsecond being obtained. The delay line length is 9·0 microseconds and has a cut-off of about 800 kc/s.

7.3. *The Repeater Equipment*

The repeater equipment consists of a number of common parts of a transmitter and receiver. The transmitter and receiver r.f. units are identical with the terminal units. The receiver i.f. and video units are similar.

However, because of the non-linearity of the microwave oscillator and the close spacing of the reference and heading codes, the synchronizing pulses are abstracted, regenerated, and reinserted in the modulation waveform. Provision is also made for a small amount of limiting to be introduced on the video, if desired, to maintain the radar video/noise ratio.

The pulse regenerator has a similar gating sequence to that of the receiver pulse time demodulator, the output of the gated amplifier now driving a blocking oscillator which produces a new train of pulses of between 0·8 and 1·0 microseconds width.

7.4. *Use with Different Radar Sets*

As described, this arrangement is suitable for long range surveillance radars, the i.f. amplifiers and video strips giving a bandwidth of 2·5 Mc/s, one pair of terminals transmitting a minimum pulse of 0·35 microseconds. To

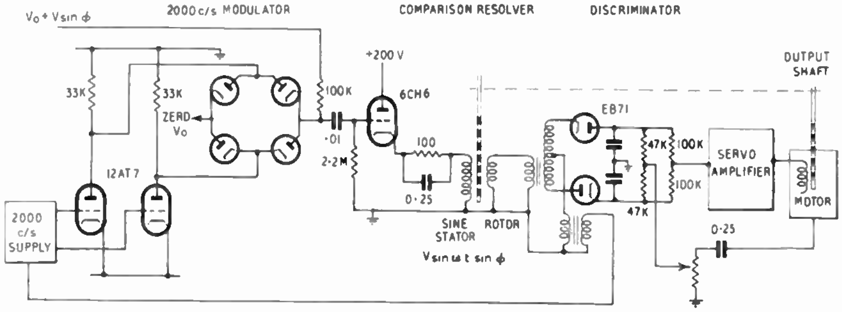


Fig. 6. Amplitude modulator and servo system.

accommodate different bearing system it is only necessary to change the input and output selsyns.

A small point arises when transmitting radar pulses shorter than the synchronizing pulses. In this case the display trigger pulse which normally occupies the first 150 metres of the radar range would be a nuisance. It is therefore necessary to use a small delay, obtained with cables, in the radar trigger at the transmitter and a compensating delay at the link receiver.

In order to operate with radar sets with pulse widths of 0·1 microsecond, the i.f. and video units can be changed to widen the bandwidth to 8·0 Mc/s to 3 db points overall.

7.5. *Mechanical Arrangement*

The general mechanical arrangement can be seen from Fig. 8 showing the transmitter. The top left-hand drawer in each terminal holds the pulse circuits. In the transmitter cabinet the top right-hand drawer contains the radar i.f. unit, video unit, bearing phase sensitive rectifiers, and microwave controls, and in the receiver cabinet it contains the i.f. and video units and microwave controls. The power units are in the two lower drawers. The repeater has a similar layout.

Very careful thought was given to the problem of obtaining maximum access to components and in each drawer the circuits are wired in vertical panels, the valves being on the inner side of the panel and components on the outer. Each drawer slides out on runners until it is completely clear of the cabinet, thus all components and valves are immediately accessible. A large funnel is formed in the centre giving very free air circulation. The r.f. unit (Fig. 9) has been made as small and as compact as possible and fits in the casting at the rear of the parabola (Fig. 10).

It is required that the microwave circuitry be lightweight and as small as possible, and so a coaxial arrangement was adopted throughout. Coaxial components are more compact and flexible than waveguide, the penalty being that it is more difficult to obtain a good match at each component, and that production tolerances are in general tighter. These penalties are offset by the simpler mechanical arrangement.

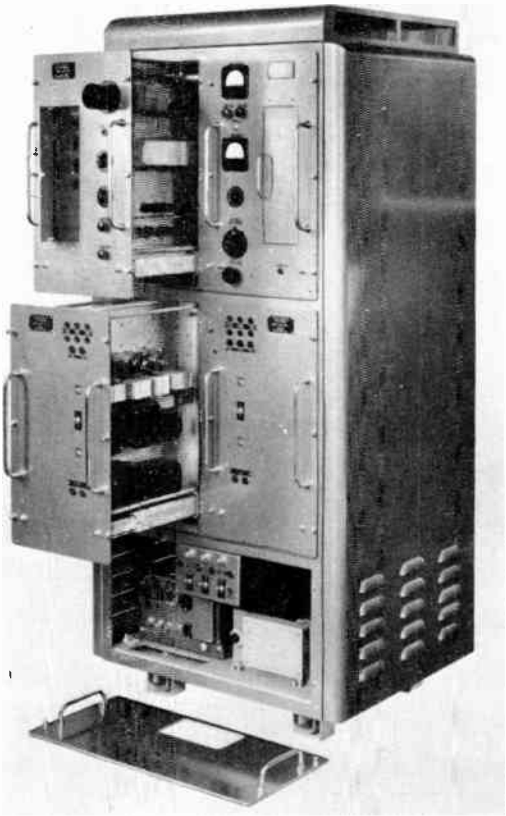


Fig. 8. Transmitter cabinet.

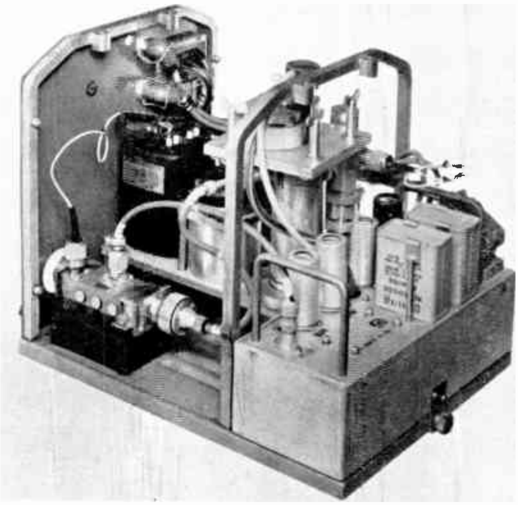


Fig. 9. Transmitter r.f. unit.

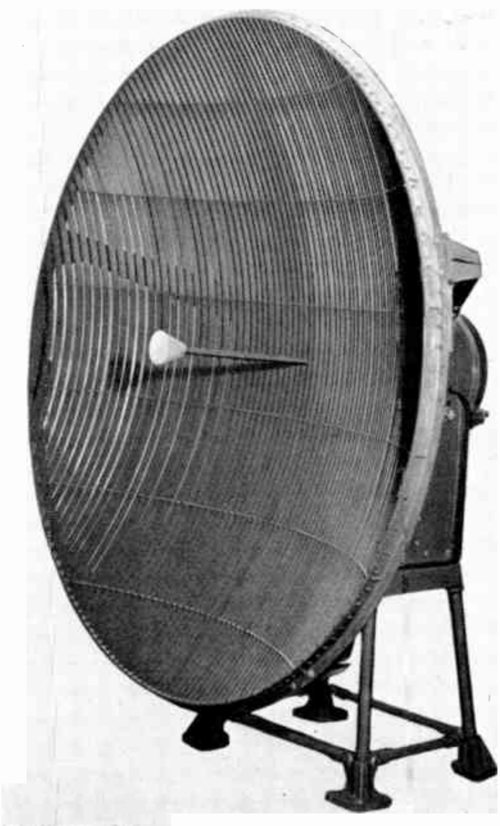


Fig. 10. Transmitter parabola with r.f. head just visible.

As the length of feed from oscillator to dipole is relatively short the match of components can be relaxed a little without affecting performance. The transmitter cavity with its magnet mount and Heil tube can be seen in the centre; this is tuned by the associated magslip link; by its side is the wavemeter cavity and its tuning magslip. The microwave power is taken from a loop into a coupler lying horizontally at the front. This couples a small amount of power into a thermistor and to a crystal, the output of the unit passing to the dipole via a flexible lead. The modulating amplifier is the end unit. The unit tunes directly over the bands 3600–3900 Mc/s or 3900–4200 Mc/s with suitable valves; the dipole head must be changed for each band. The unit fits into a casting at the rear of the parabola and can be partly withdrawn for servicing without interrupting transmission. The unit can be tuned, the frequency and power measured, and the modulation depth examined, from the ground cabinet: the only occasion on which it would be necessary to climb the mast would be on complete failure of the unit.

The receiver r.f. unit is similar in construction with a mixer in place of the coupler: this uses a reflex klystron, type CV2116, as local oscillator. The overall noise figure is, on the average, about 14 db.

The parabola is shown in Fig. 10. It is of slatted construction to reduce windage; the figures for this compared with a solid parabola are:—

With slats vertical, windage is	70%
With slats horizontal, windage is	31%

up to a wind velocity of 100 m.p.h.

The results of measurements made on the parabola are given in Fig. 11: (*a*) gives the resultant horizontal force with the slats horizontal, (*b*) with the slats vertical, and (*c*) the resultant horizontal force on an equivalent solid parabola. It can be seen that the wind force on the solid parabola is high over an arc of 90 deg front and rear with a consequent high turning moment (up to 640 ft-lb) for side winds.

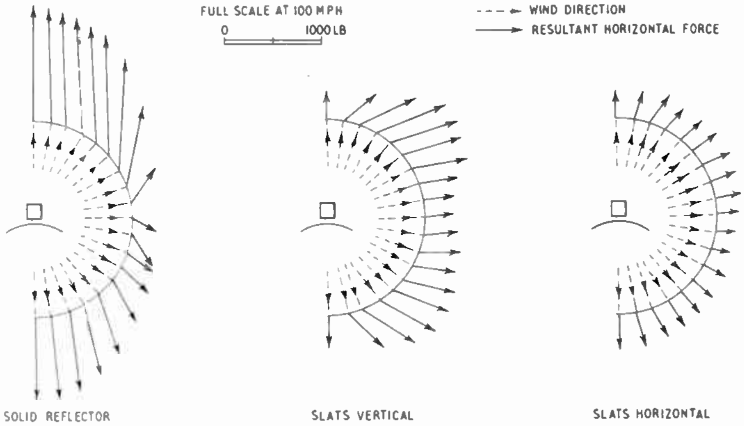


Fig. 11. Resultant horizontal force on parabolic reflectors. Wind blowing outwards along radii.

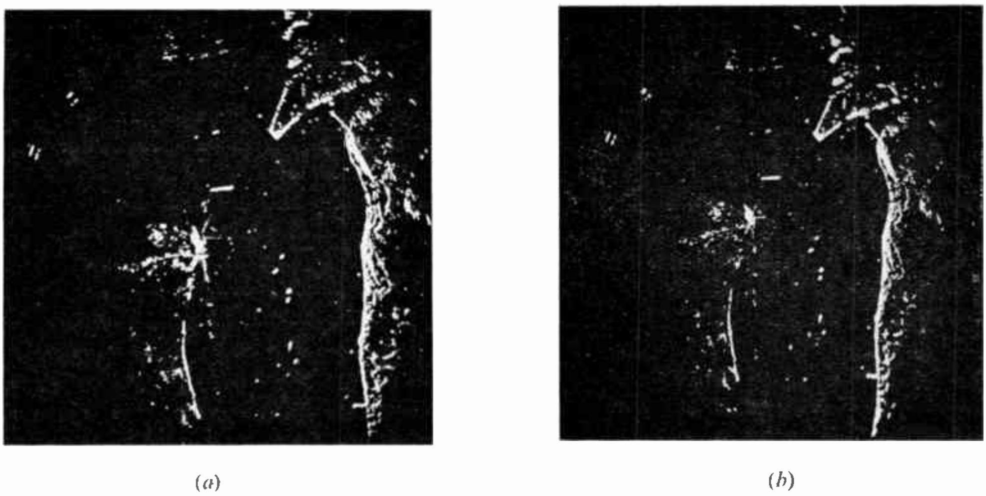

(*a*) (*b*)

Fig. 12. Transmission between Hythe and Warsash.
(*a*) Harbour radar at Hythe. (*b*) Remote display at Warsash.

whereas on the slatted parabola the wind force is more uniform with wind direction, the best and most even force being obtained with the slats horizontal. The measured maximum turning moment in this case is only 66 ft-lb for a horizontal resultant force of 316 lb.

The beamwidth is 3 deg. and sidelobes, with a dipole feed, are rather high. The original 4 ft solid parabola had sidelobes at ± 9 deg of − 25 db, the best figure obtainable. The slatted parabola has sidelobes of − 18 db due to the form of construction. Outside ± 9 deg all other sidelobes are better than − 35 db.

8. Measurements and Performance

Figure 12 shows photographs taken of the prototype developed for the Harbour Radar when it was installed at Southampton. The transmitter is located at Hythe opposite Southampton Docks, and the receiver is located at Warsash on the River Hamble, 3 nautical miles away. The docks can be seen on the upper left-hand corner of the photograph. The

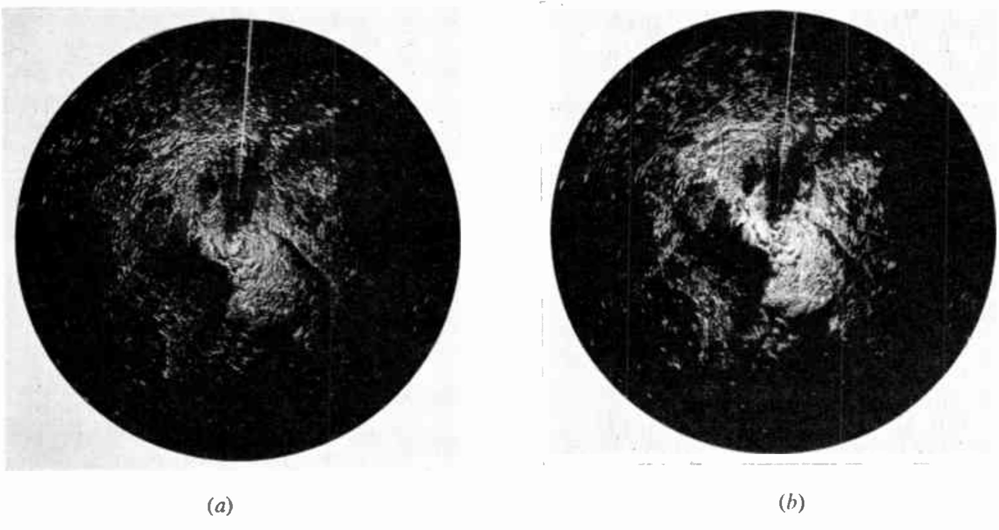

(*a*) (*b*)

Fig. 13. Pictures transmitted between Crystal Palace and Brixton Road.
(*a*) Crystal Palace radar p.p.i. (*b*) Brixton Road p.p.i.

receiver is located just off the photograph on the opposite shore to the right. The local and remote discrimination was similar (about 25–30 feet). The pulse length is 0·06 microsecond and the display range is 4 nautical miles.

Figure 13 shows photographs taken when a production equipment, modified with the 15 Mc/s receiver, was installed between Crystal Palace and Brixton, a distance of 4½ nautical miles. The radar set and link transmitter were located at the top of a water tower at a height of about 120 feet. The receiver aerial was placed on the flat roof of a building in Brixton Road. Despite the height of the radar there is quite an amount of shadowing on the picture. The Thames can be seen in the middle of the photograph. The pulse length is 0·1 microsecond and the display range is 10 nautical miles. The measured angular accuracy of both these was better than ±1 deg. The performance of the equipment operating with high power long range radars is comparable with the previous examples.

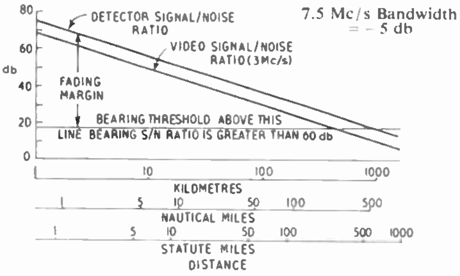


Fig. 14. Transmission performance of the microwave radar link type 2.

The graph of Fig. 14 gives the performance of the 6 Mc/s i.f. bandwidth equipment as a function of range, and is based on measured results. These figures are actually 4 db down on predicted performance, but the height of the transmitter was about 40 ft and that of the receiver about 15 ft above the ground, this accounting for the difference.

A series of trials were carried out by tracking aircraft to the point where they became undetectable, using a transmitter and a receiver, with direct telephone connection. In every case, if the echo appeared on the primary display it was equally apparent on the remote display. Later a repeater was inserted and similar trials were carried out with the same result.

The effect of repeaters is to establish a lower threshold and an upper threshold, and as the number of repeaters is increased the threshold limits move together. The position of these thresholds on the signal can be varied by the gain and limiter controls at the transmitter. Any signal passing the threshold will be repeated to the final display. One would expect that after, say, four repeaters, the remote display would present echoes on a black background speckled by coarse noise which has equal amplitude, the density of noise being dependent on limiter adjustment at the first transmitter.

Photographs of a system using one repeater showed the commencement of this effect and it is expected that after four repeaters the threshold, on an input radar signal/noise ratio of 5:1, would be established at a level of just above the noise shoulder, representing a radar sensitivity loss of about 1 to 2 db. Measurements were made at the same time to establish whether the range discrimination was affected, but no significant deterioration of discrimination was found, this depending mainly on the bandwidth which was adequate.

Measurements have been made of the effects of fades and interference on bearing accuracy and synchronization. The transmission was deliberately interrupted and restoration of correct operation was obtained within five seconds in the worst case of 180 deg. Similarly, interruptions of one second duration at random rates were corrected within one second. No appreciable smearing of the display was caused and the picture was fully usable in the unaffected sectors. Faster interruptions than 0·5 sec had no effect other than blanking of the displays. The synchronizing circuits pulled in within five p.r.f. cycles in every case.

9. Conclusions

We have given briefly some of the methods which may be used and are being used for transmission of radar information, and work on these lines is being pursued, notably in France, Germany and the United States of America. Since writing this paper it is interesting to note that a system using the principles described in Section 4 has been developed in Germany. This system was described in a paper by Pederzani read at the Marine Radio Aids to Navigation Convention held in Hamburg under the auspices of Auschuss für Funkortung. In this paper Pederzani describes a storage tube developed for line by line storage and integration and by this means a bandwidth reduction of up to 25 times is claimed. This, when applied to the Hamburg wideband high definition harbour radar system, will enable a simple coaxial line system to be used for linking the whole harbour radar system together.

10. Acknowledgments

Thanks are due to the Directors of Decca Radar Limited for permission to publish this paper, to Mr. K. I. Khoury who designed the microwave equipment, and to Mr. H. McDermott, Mr. J. Norman, and the other engineers associated with the project.

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DIPLOMAS IN TECHNOLOGY

First Courses Recognized

The National Council for Technological Awards has recently announced the first courses which have been recognized as leading to the Diploma in Technology. The Colleges which are conducting courses with opportunity for specialization in electronics or radio communication are: Full time—Battersea Polytechnic; Sandwich courses—Acton Technical College, Battersea Polytechnic, Birmingham College of Technology, Woolwich Polytechnic.

The National Council has also approved five new courses proposed by Colleges but these do not include courses in Electrical or Electronic Engineering.

The Future of the Dip.Tech.

The Vice-Chairman of the National Council for Technological Awards, Sir Harold Roxbee Cox, spoke on the subject of Diplomas in Technology when addressing the Annual Assembly of the Nottingham and District Technical College. Courses so far approved should result in some 50 Dip.Tech. awards in 1958 and nearly 100 in 1959.

Sir Harold discussed the advantages of this new qualification which he considered would take its place beside University degrees as a first rate qualification. He pointed out that the bright boy or girl from the lower income groups could get a grant which would take him or her to a university and that the child of wealthy parents was equally privileged. There were, however, many children whose parents had incomes considered by educational authorities as being too big to qualify for any pecuniary aid, but whose assessment by the Inland Revenue was such that they would not afford to send children to a university *without* pecuniary aid. These children would now be able, if they wished, to take the Diploma in Technology.

Referring to the standards which were required by the National Council for Technological Awards, Sir Harold said that the Council found serious deficiencies in most of the Technical Colleges they had visited. These were not only in halls of residence, common rooms, libraries or playing fields, but in the laboratory and lecture theatre accommodation. Almost everywhere, laboratories, scientific libraries and provision for private study left much to be desired, but the Council had been practical and recognized courses where the requisite academic standards were met. He warned the Colleges, however, that in five years' time when the renewed recognition would be required the Council would not countenance any deficiencies in residential accommodation and provision for broadening the background of academic study.

Sir Harold also stressed that approved courses would not be restricted to the Colleges of Advanced Technology. A Regional College or an Area College would be considered equally for recognition if the course offered was one that the Council wanted.

Hostels for Technical College Students

Lord Hailsham, the Minister of Education, has asked local education authorities to consider the provision of hostel accommodation at certain technical colleges, particularly at the Colleges of Advanced Technology or those providing courses leading to the Diploma in Technology.

At present there are very few hostels attached to these Colleges and more must be established. They are needed to give some of the more advanced students the experience of a period of residence at College as recommended by the National Council for Technological Awards.

The initial aim should be to allow each student at a College of Advanced Technology to be in residence for at least a year of a full-time course or for one academic session of a sandwich course. Hostels catering for between 50 and 150 students are recommended, each under the supervision of a resident warden.

Some employers have given generous help towards the cost of hostels for technical Colleges. Though the duty of providing such hostels lies clearly with local education authorities, the Minister hopes that firms which send substantial numbers of students to particular Colleges will consider giving financial help towards the cost of hostels there.

A CONTRIBUTION ON THE TRIODE SYSTEM OF THE CATHODE RAY TUBE ELECTRON GUN*

by

M. E. Haine, M.Sc.†

SUMMARY

By analysis of published experimental data it is shown that the triode system of the conventional electron gun is very inefficient from an electron-optical viewpoint. It is deduced that the deficiency arises from spherical aberration arising from the strong curvature of field immediately in front of the cathode, essentially still in "object space." It is shown that the elimination of this defect would allow very appreciable reduction in the final beam angle, but that only partial advantage could be taken of this because of beam spreading due to space charge. A large reduction in cathode loading is then theoretically possible.

LIST OF SYMBOLS

ρ	beam current density
ρ_c	cathode current density
β	brightness (current density/unit solid angle)
α	beam semi-angle
E	beam voltage
k	Boltzmann's constant $\frac{1}{11{,}600}$ eV/°K)
T	cathode temperature (°K)
b	grid-cathode spacing
d	grid hole diameter
t	grid thickness
f	grid-anode spacing
$-E_g$	grid-cathode p.d.
E_A	anode-cathode p.d.
I_A	total emission current
E_c	cut-off voltage
$E_d = E_c - E_g$	drive voltage
y	radius of emitting area on cathode
r_s	radius of "virtual source"
θ	semi-angle of ray cones
l	beam convergence length
r	radius of focused spot

1. Introduction

A large number of papers have appeared on the subject of the cathode-ray tube and its associated electron optics. Even so, there is apparently still considerable confusion concerning the exact mechanism of beam formation in the triode accelerating system. Comparatively recent papers[1,2] refer to the possible presence of aberrations in this part of the gun and published correspondence shows that no general agreement has yet been reached as to whether the focused spot is an image of the crossover or the cathode or merely some other beam cross-section of minimum diameter.

The present paper will attempt to analyse the triode efficiency from basic laws and published experimental data and make some deduction regarding the mechanism of beam formation.

2. Analysis

The maximum current density possible in the spot is given by:

$$\rho = \beta\pi\alpha^2$$

where α is the semi-angle of the beam, and β is the beam brightness or current per unit solid angle, which, as was shown by Langmuir[3] cannot exceed a value given by

$$\beta = \frac{\rho_c eE}{\pi kT} \quad (eE \gg kT) \quad \ldots\ldots\ldots(1)$$

ρ_c being the cathode emission density and eE

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the beam energy at the point under consideration, k is Boltzmann's constant in electron volts per deg K ($=1/11{,}600$ eV/°K), and T the cathode temperature.

If this is applied to the final beam in a tube operating at 10 kV with 1 mA in a 1-mm spot and a cathode operating at 1000°K loaded to 0·5 amp/cm², the value of α comes out to be 0·0016 rad (0·09°) which is many times smaller than is obtained in typical television tubes. Indeed, one of the important problems in such tubes is to accommodate the large angles usually obtaining. The fact that the beam angle is greater than it theoretically need be is presumably widely known; the deficiency has, nevertheless, not been stressed in the literature. For example, Moss, who derives an empirical expression for the angle[1,2] and even applies the Langmuir relation, does not evaluate his data far enough to show the "apparent" departure from the ideal theory. That it is, to a certain extent, only apparent, will be shown.

In order to show how the deficiency arises Moss's empirical relations for a triode gun will first be summarized.

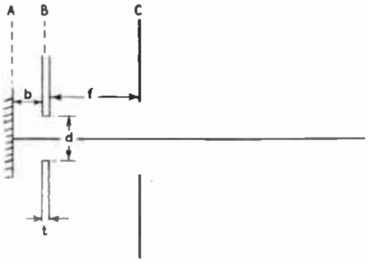

Fig. 1. Diagrammatic representation of triode electrode gun.

Referring to Fig. 1, A is the flat cathode, B the grid spaced b from A and with aperture of diameter d and thickness t, C is the first anode spaced f from the grid.

The systems investigated by Moss were not quite so idealistic as this but there is every reason to suppose his results will apply to this system within the error of his experimental measurements and the usual constructional inaccuracies involved in manufacturing such guns. The cathode is assumed always space charge limited and voltages $-E_g$ and E_A are applied between grid and cathode, and anode and cathode respectively. The total current flowing is I_A. The cut-off bias (E_g when I_A goes to zero) is E_C and the drive voltage (E_d) is $E_C - E_g$.

Moss shows experimentally that, over the normal range of operating conditions and dimensions used, the cut-off voltage is inversely proportional to f and b and proportional to E_A and d^3:

$$E_C \propto E_A d^3/bf$$

He then deduces from dimensional analysis that t must occur in this proportionality as t^{-1}. In fact, it seems unlikely that the cut-off voltage will vary as t^{-1}. Looking into Moss's analysis, one finds that the cubic relation between E_c and d is deduced from two points and the origin on a curve. It is much more likely that t occurs associated with d as $(d-Ct)$ where C is a constant, since as $t \to 0$, E_c should not become infinite. If this is assumed and applied to Moss's data, C is approximately equal to unity and the proportionality becomes

$$E_C \propto \frac{E_A(d-t)^2}{bf}$$

The constant of proportionality (again from Moss's data) is 0·034 so that:

$$E_C = 0{\cdot}034\,\frac{E_A(d-t)^2}{bf} \qquad \text{.........(2)}$$

The current at zero bias was found by Moss to obey the law

$$I_0 = 3\times10^{-6}E_C^{3/2} \qquad \text{.........(3)}$$

The current at a drive E_d was found to be proportional to $E_d^{7/2}$. Combining this proportionality with (2), bearing in mind that $E_d = -E_C$ when $I = I_0$

$$I = 3\times10^{-6}E_d^{7/2}/E_C^2 \qquad \text{...........(4)}$$

3. Emitting Area and Cathode Loading

Moss showed by experiment that the radius (y) of the emitting area is proportional to d and to E_d/E_C the proportionality constant being 0·5, hence

$$y = 0{\cdot}5d\,(E_d/E_C)$$

The mean loading ρ_c is then given by

$$\rho_c = 3{\cdot}8\times10^{-6}\times E_d^{3/2}/d^2 \qquad \text{.........(5)}$$

The distribution of current density over the cathode was shown to be approximately Gaussian so that the peak loading is given approximately by

$$\rho_{c(\max)} = 14 \times 10^{-6} E_d^{3/2}/d^2 \qquad \text{.........(6)}$$

4. Angular Divergence of Beam

The angular divergence of the beam leaving the triode was found to be proportional to $f^{-3/4}$, d and E_d/E_C. It was shown to be almost independent of b. The dependence on t is not considered by Moss, though, from dimensional considerations, there must be some other dependence on a [length]$^{-1/4}$. Since the power of this is so low, it will have little effect and can be neglected over a suitably restricted range of parameters. The proportionality constant deduced from Moss's data is 0·3 for the dimensions in cm, hence

$$\alpha = 0{\cdot}3(d/f^{3/4})(E_d/E_c) \qquad \text{.........(7)}$$

5. "Crossover Size"

Knowing the emergent beam angle and total beam current, Moss proceeds to deduce the crossover size. The argument is based on the invariance of brightness in the optical system which, Moss points out, is maintained if no space charge effects or aberrations are present. In fact, the brightness is invariant under any conditions except in the presence of absorption. More of this will be said later.

It is somewhat academic to consider the actual crossover since if this occurs at all, it is positioned inside the region of accelerating field. On the other hand it is relevant to consider the "virtual source" size. By virtual source is meant the minimum area virtual cross-section of the beam obtained by continuing backwards the electron trajectories leaving the triode system into field free space. Moss equates the brightness here to the maximum theoretical value given by (1):

$$\frac{I}{\pi r_s^2 \pi \alpha^2} = \frac{\rho_c e E_A}{\pi k T}$$

where r_s is the radius of the virtual source.

After substituting values of I from (4)), ρ_c (from (6)) and α (from (7))

$$r_s = \frac{1{\cdot}6(kT)^{\frac{1}{2}} f^{\frac{3}{4}}}{(e\,E_A)^{\frac{1}{2}}}$$

or for $T = 1000$°K

$$r_s = 0{\cdot}47\, f^{\frac{3}{4}}/E_a^{\frac{1}{2}} \qquad \text{.........(8)}$$

Moss demonstrates, from experimental data, the proportionality of r_s with $f^{3/4}$ and $E_a^{-1/2}$ and independence of r_s on E_d and d. He does not, however, evaluate the proportionality constant nor any typical values for r_s. It will be seen that for typical values such as $f = 0{\cdot}4$ cm and $E_a = 2000$ V, r_s is equal to 20×10^{-4} cm, very much smaller than is, in fact, obtained in practice. It should be mentioned that though this result has been deduced from Moss's semi-empirical relations, a similar result follows from other published data or by taking spot points from Moss's curves. If Moss had made this evaluation, he would presumably have deduced that the strong aberrations must be present and the application of the brightness relation was not justified. There are two objections to this: firstly, as has already been stated, contrary to Moss's assertion, brightness is invariant even in the presence of aberrations; and secondly, if aberrations are present, why is it that in some plane following the triode there is found a well resolved image of the cathode? These two aspects will now be discussed in detail.

6. The Brightness Relation

The brightness or current density per unit solid angle is invariant throughout any system in which no absorption occurs. This invariance is not affected by the presence of aberrations or space charge. This invariance arises from thermodynamic considerations. The error arising in Moss's paper, and similar errors have occurred in other papers, is due to a wrong application of the brightness invariance principle. The brightness refers to conditions at a point. Thus, the brightness in the virtual source may be obtained by considering the presence of a minute aperture in this source and dividing the current passing the aperture by its area and the solid angle of the beam emerging from the aperture. This angle is not necessarily equal to the total angle of the beam from the whole of the virtual source, since each point may pass a narrow beam whose mean direction varies with the position of the source. This condition is illustrated in Fig. 2. Each point of the cross-section at A emits into a semi-angle β but the mean direction varies with distance from the axis. If the direction of the elementary beams varies in proportion to the radial distance from the centre then, continuing the rays backwards will result in a smaller beam cross-section at B. Hence, this condition is simply that corresponding to an out of focus spot. It will be noted that the spot now emits at every point into a beam angle equal to the total beam angle (α).

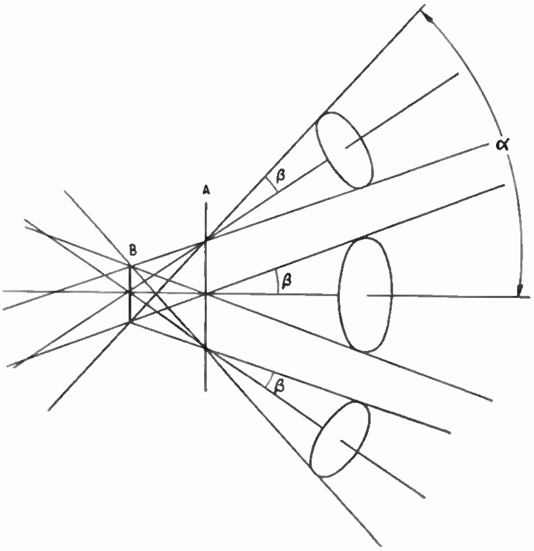

Fig. 2. Illustrating the brightness in a virtual source

If the beam contains aberrations the mean direction angle of the individual beams in any plane will vary other than linearly with the distance from the axis (for example, as the cube for spherical aberration.) If now as before the rays are continued to find the minimum beam cross-section it will be found that each point in this section emits into an angle smaller than the total beam cross-section. In fact, the solid angles take up peculiar shapes at various points, from hollow cones for points on the axis to narrow arc-like beams near the periphery. If these solid angles are used in determining the local brightness, the Langmuir value must always result, but if the total beam envelope angle is used a lesser value results. The factor $I/\pi^2r^2\alpha^2$ where α is the total beam angle, might be called the *total beam* brightness. If this is then less than the brightness given by $\rho_c E/\pi kT$, aberrations must be present.

It may thus be concluded that the triode system of the electron gun does suffer from severe aberrations. Whether these aberrations result from the electrostatic field distribution alone or are introduced by space charge effects is not immediately important. It is, however, important to explain how a good image of the cathode can follow a system which suffers severe aberrations. To do this, the crossover formation is studied in more detail.

A crossover smaller than the image is formed in an imaging system where each image point is formed by a very narrow cone of rays. Such a system is shown in Fig. 3. For simplicity, the rays are here presumed to travel from the object, O, via a lens, L, to an image, I, through space which, except for the lens, is of constant refractive index. Each object point emits only into a small cone in a mean direction parallel to the axis. In the back focal plane (F) of the lens, the ray cones cross to form the crossover of diameter $2f\theta$, where f is the focal length of the lens and θ the semi-angle of the ray cones.

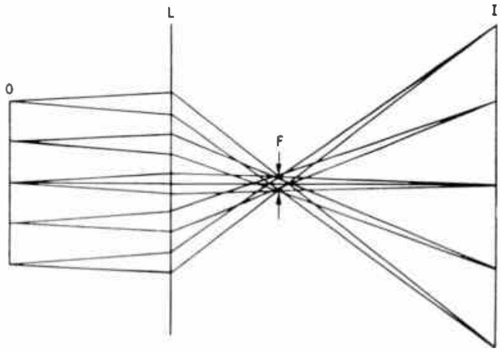

Fig. 3. Formation of crossover smaller than the image.

If aberrations are present in the lens, the image will be spoiled. If, however, an optical element (S) such as a lens with strong aberrations or a fourth-order plate (an element deflecting rays in proportion to the cube of their distance from the axis) is placed immediately in front of the object the crossover is destroyed or spoiled, but, since only the emission direction of the rays from the object is affected, the image is unspoiled. This condition is illustrated in Fig. 4.

Such an effect as above described then explains the apparent anomaly in the triode gun if such an aberrating effect takes place immediately in front of the cathode. It has been pointed out by Haine and Einstein[4] that just such an effect takes place in the temperature limited electron gun used in the electron microscope. It is well known that the modulation of the triode results partly from the enforced change in emission area resulting from the movement of the intersection of the zero equipotential surface and the cathode as the bias is changed. The shape of the equipotential lines immediately in front of the cathode is strongly concave and causes the electrons emitted away from the axis to be strongly refracted towards the axis immediately after emission when their velocity is low. The effect is more marked the greater the radial position of the emission point. In the several attempts, described in the literature, at plotting the trajectories in the triode system, approximations have been made about the field immediately in front of the cathode and hence this very important effect has been missed. For example, Einstein and Jacob fit an analytic expression to the measured axial field distribution and then calculate trajectories after obtaining the off-axis field by the well-known expansion formula. The application of this formula to regions near the cathode would require the inclusion of very many terms to give accurate results. In fact, only a small number were taken.

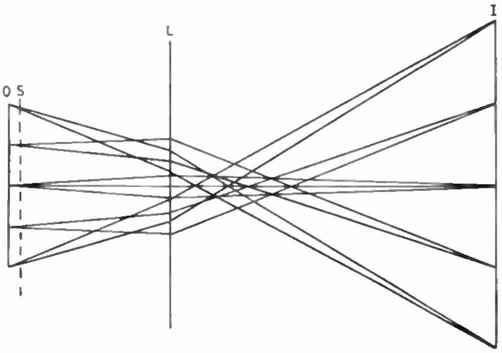

Fig. 4. The effect of aberrations immediately in front of the object.

It is probable that the effect of space charge is not very large in the triode system, especially near the cathode where the cathode surface provides a strong shielding action.

In the electron microscope electron gun a hairpin tungsten wire cathode is used; the tip of this is approximately spherical and, with a suitable bias, a beam is produced with a total beam brightness equal to the Langmuir brightness. This apparently results when the zero equipotential surface intersects the cathode on the side of the sphere in such a way as to minimize the aberrations. In this case, the spot is usually an image of the cathode; no crossover appears to occur in this type of electron gun. It seems possible that shaping the cathode into the form of a small sphere might reduce the aberration in the space charge limited cathode ray tube gun.

7. Space Charge Limitation at the Screen.

It is well known that the size of focused spot at the screen is limited by space charge spreading due to mutual repulsion between the electrons. It can be shown that for a given spot radius (*d*) this effect is negligible if the current is less than a value given by[5]

$$I = \frac{1{\cdot}4\ 10^{-5}\ E_0^{3/2}\ \alpha^2}{\log_{10}(l\alpha/r)} \text{ amperes } \qquad \ldots\ldots\ldots(9)$$

where E_0 is again the final electron energy in electron volts, α the final beam semi-angle and l the distance from focusing lens to screen. The logarithm in the denominator varies only slowly with l, α and r and hence putting in approximate values for these parameters gives a good approximation for the limiting current. For example, if $l = 25$ cm, $\alpha = 0{\cdot}01$ and $r = 0{\cdot}05$ cm, the inequality becomes approximately

$$I < 10^{-5}\ E_0^{3/2}\ \alpha^2 \qquad \ldots\ldots\ldots(10)$$

It will be noted that the expression is now independent of the "throw" and spot size. The significance of this lies in the fact that above a certain current the beam "blows up," i.e., its size increases very rapidly with current.

If the electron optical system is free from aberration the current in the spot will be given by

$$I = \beta \times \pi\alpha^2 \times \pi r^2/4 \qquad \ldots\ldots\ldots(11)$$

where β, as before, is the Langmuir brightness.

If this value is substituted into the preceding inequality and β put equal to $\rho_c eE_0/\pi kT$, an expression is obtained for the maximum diameter of spot which can be used without space charge repulsion limiting the performance:

$$r<[0\cdot3\ 10^{-5}\,E_0^{1/2}\,kT/\rho_c]^{1/2} \qquad \ldots\ldots(12)$$

putting $T=1000°\text{K}$ and $\rho_c=0\cdot5$ amp/cm²

$$r<0\cdot7\times10^{-3}\times E_0^{1/4}\ \text{cm} \qquad \ldots\ldots\ldots(13)$$

e.g. for $E_0=10{,}000$ volts
$r<0\cdot007$ cm

It is thus seen that no practical cathode-ray tube with conventional spot size can make full use of the theoretical optimum gun performance because of beam spreading due to space charge. This does not mean, however, that reduction of the gun aberrations are not worth while. In the first place some reduction of beam angle is possible before the space charge limitation becomes operative and after this the remaining reduction of aberration can be made use of in reducing cathode loading. For a given peak current the minimum beam angle is determined by (10). Combining this with (11) and (1) the minimum cathode loading is obtained as:—

$$\rho_{c(\text{min})}=0\cdot3\times10^{-6}\times E_0^{1/2}/r^2\ \ \text{amp/cm}^2$$

for $T=1000°\text{K}$.

Thus for a 0·1 cm diameter spot and an electron energy of 10 keV the cathode loading becomes 0·011 amp/cm². The final beam semi angle is given from (10) as

$$\alpha=320\,I^{1/2}/E_0^{3/4}$$

For $I=1\text{mA}$, $\alpha=0\cdot01$ rad ($\cong0\cdot6°$)

For 25 cm throw, the beam diameter at the lens will be 0·5 cm. Both these figures represent a considerable improvement over present cathode ray tubes.

The use of such low cathode loading would necessitate a rather large cathode. For example, for the example quoted 3·5 mm.

These derivations do not of course specify the intermediate optics which must be chosen to give the desired magnification.

8. Conclusions

From available experimental data and the application of basic laws it is apparent that the triode system of the space charge limited cathode ray tube suffers from severe spherical aberration. It is deduced that this aberration must arise from the field in immediate proximity to the cathode. It appears by no means impossible to eliminate this aberration.

Even if the aberration could be eliminated, space charge spreading due to mutual electron repulsion would prevent full use being made of the triode performance, but a significant reduction in beam diameter should be possible, coupled with a large reduction in cathode loading which should considerably improve cathode life.

9. Acknowledgment

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THE CHARACTERISTICS OF MAGNETIC RECORDING HEADS AND TAPES*

by

H. P. Spring (Associate Member)†

SUMMARY

The paper deals with the functions, operating conditions and characteristics of magnetic heads and tapes. It is shown how a recording by magnetic means is made, retained on the tape and finally reproduced. The erasing of a magnetic tape by means of a steady or an alternating magnetic field is explained. The recording process is considered together with the effects caused by a.c. biasing. Formulae for obtaining the output voltage from any given head are discussed. Demagnetization, gap functions and the various losses encountered in tape reproduction are also dealt with. Tape characteristics are discussed together with comparison graphs for different tape characteristics. Some recording heads, which differ from conventional designs, are described and their applications for various types of magnetic recordings considered. Finally, the effect of head and tape wear on the frequency response of a recorded tape are discussed quantitatively.

1. Introduction

The recording of sounds or signals on magnetic tapes need not remain confined to the recording of music or speech only and in recent years a great number of developments have taken place to utilize this relatively new medium for the recording of signals perhaps not immediately concerned with either the entertainment world, profession or for private amusement. Magnetic recording has begun to play also a very important part in industry and is now being exploited for the automatic control of machine tools, the storing of information or similar purposes besides the main uses with which everybody now seems to be quite familiar. The design and development of magnetic recording heads and the design and manufacture of tapes suitable for receiving and retaining magnetic impulses have become quite an art in the electronic industry. A great number of facts directly concerned with magnetic recording are quite basic, but only the observation of all facts will enable a recording head or tape to be designed to specification.

2. Fundamentals

The following sub-sections will deal almost exclusively with the basic principles of magnetism and magnetization as far as they are required for the recording and reproduction of audio-frequency signals, with the generation of magnetic fields, their measurements and the laws governing magnetic induction.

2.1. *Permeability*

If certain kinds of materials are brought into a magnetic field, the number of flux lines through any one cross section of such materials may be much greater than through a vacuum or air. Elements or materials with such properties are said to have a high permeability. The permeability of a vacuum or air is denoted by the symbol μ_0 and shows the ratio between induction and field strength,

$$\mu_0 = \frac{B\ (\text{gauss})}{H\ (\text{oersted})}$$

The definition of the permeability of a material or elements is also the ratio of induction to field strength and is noted by the symbol μ_{abs} which is the absolute permeability. It is usual to put the magnetic permeability of a material into a direct relationship to that of a vacuum or air. (The permeability of air differs only very little from that of a vacuum.) This is then the relative permeability, or for short the

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permeability of the material.

$$\mu = \mu_{rel} = \frac{\mu_{abs}}{\mu_0} = \frac{B_{material}}{B_{vacuum}}$$

This ratio now becomes a relative figure and means that the material (μ_{mat}) has a permeability which is a certain number of times greater than that of a vacuum or air. The unit of permeability is the permeability of the vacuum and it equals to $\mu = \mu_0 = 1$. Materials having a permeability which differs only a little from that of air are called para-magnetic materials and those of a permeability of less than unity are dia-magnetic materials. Ferromagnetic materials are those with a permeability very much greater than that of air, and their permeability values may differ by a very great extent. The permeability for transformer laminations may be 500, that for a mu-metal 30,000, and for the material "1040," a Permalloy, it could be more than 60,000. The definition of permeability for ferromagnetic materials should be studied a little more closely, since this is not a constant value. The ratio between induction (B) and field strength (H) is not linear, but is dependent on the field to which the material had been subjected previously. What is normally understood as the permeability of a material for a given value of H is the ratio $B:H$ when the material has no previous magnetic history. If H, the field strength, is increased in one direction from zero and the induction measured, it will be found that the induction for small field strengths will increase slowly but in proportion to the field. The B/H curve will begin to rise more quickly, will then slow down again until a point is reached at which any further increase in the field will produce no further increase in the induction. This point is called the saturation induction. If the material has never been subjected to magnetic fields before, the curve traced will be the normal magnetization curve. It is very similar to the characteristic of a triode valve. Very close observation of the curve shows that this is by no means a steady line in itself, after the field has reached a relatively low figure. If the measurements are taken with sufficient accuracy, it will be found that the normal magnetization curve has a great number of small steps in itself which according to Barkhausen are caused in the following manner: The molecular magnets are not freely suspended in the material and are not able to move freely as the field increases. If the field increases, the resistance of the molecular magnets will be overcome and they will, perhaps quite suddenly, jump into their new position. A further very small increase in the field will cause no change in the molecular structure until the field has again gained sufficient magnitude for a number of the bar magnets to assume a new position. The application of a field of certain magnitude will finally move all molecular magnets into one direction which is parallel with the field lines and no further increase of induction is then possible. When this happens the saturation point has been reached.

The Barkhausen effect, as this is often referred to, can be shown experimentally by a piece of ferro-magnetic material on which two separate windings are suspended. One winding is then fed to an amplifier and loudspeaker and direct current is passed through the other winding. If the current is now very gradually and steadily increased, a crackle can be heard which takes place when the molecular magnets move into a new position. It is essential, of course, that the current is increased very slowly. Since it is both impractical and inconvenient to measure a field strength of zero, in practice a value $H = 5$ millioersteds is taken as unit permeability. Input transformers of voltage amplifiers, i.e. microphone input transformers, operate under such conditions.

2.2. *Remanence*

For the following observations a toroidal type of coil should be considered. If the field is increased until the induction reaches its point of saturation, then this induction is denoted by the symbol B_s. If the field is now reduced to zero, the induction does not disappear altogether but takes on a value which is the limit remanence, provided of course, the field was increased up to the point of saturation. The relationship between B and H is shown in Fig. 1. If the material is magnetized to a value which is below the point of saturation, the remaining induction is called remanence. The limit remanence is therefore the maximum remanence which a material can possess after the application of a field. If the induction of a core is to be reduced to zero, a magnetic field must be applied which is opposite in direction to the original field causing the saturation. This takes place along the curve c-b. If a field is removed at the points 1, 2, 3 or 4, then the induction will reduce to the corresponding points B_1, B_2, B_3 or 0 on the B-axis.

2.3. *Coercivity*

The remanence of a ferro-magnetic material is not only dependent on the strength of the field but to a perhaps greater extent on the previous magnetic history of the material. If therefore magnetic fields of the strength H_1, H_2, H_3 or H_4 are applied to a magnetic neutral core, values of remanence of B_1', B_2', B_3' and B_4' are obtained which, as far as their value or their direction are concerned, are quite different from points B_1, B_2, B_3 or 0. The amount of field strength necessary at which the induction of a material previously magnetized to saturation, disappears, is called the coercivity of such a material. The coercivity is therefore a measure for the energy which is applied by the material against demagnetization and which, together with the limit remanence, constitutes one of the most important characteristic properties of a material. The value of the coercivity of the material which has previously been saturated is the distance along the H-axis from the zero point at which the induction disappears.

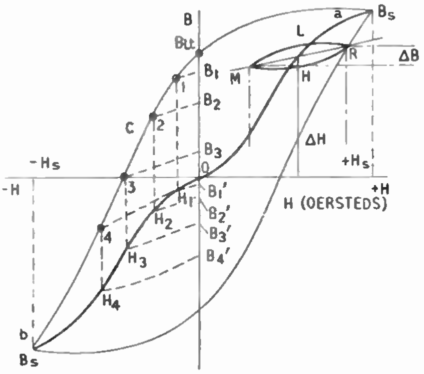


Fig. 1. Basic B–H relationship.

2.4. *Hysteresis*

If a field of a value of $+H_s$ is applied so that the induction reaches saturation, and if the field is now reduced, reversed and increased again to $-H_s$, then the induction resulting from such fields will follow the curve a–c–b and if the field is again reduced, reversed and made to increase, the induction will now follow the curve b–d–a. This curve, closed back into itself is called the hysteresis loop of the material. If the ferro-magnetic material is subjected to an alternating field of sufficient magnitude, then the resulting induction will follow this curve in sympathy with the frequency of the alternating current. When changing the magnetic polarity of the induction, or when changing the induction in magnitude or value, work is done which is converted into heat. Such losses are called hysteresis losses of the ferro-magnetic material. A measure for such losses is the area enclosed by the hysteresis loop. The work F done for the change of induction from the positive saturation point to the negative saturation of 1 cm^3 of iron is equal to $F = 4\pi / A$ ergs, where A is the area enclosed by the hysteresis loop in the gauss-oersted scale. Since hysteresis losses are caused by either an increase or a decrease of the field, they are proportional to the frequency of an alternating field applied to some ferro-magnetic material. To keep the losses small, materials having a low coercivity are normally used but optimum conditions would only exist if a material having no coercivity whatsoever could be obtained. If a ferro-magnetic material is considered, to which a field is applied, then the induction will rise to a point B_x. If the field is now made to change in a sinusoidal fashion, then the material will operate on what is termed a minor hysteresis loop (M-H-R-L in Fig. 1). The effective permeability of the material at this point is then approximately proportional to the slopes of the axis of the minor hysteresis loop, and can be expressed as $\mu_e = \Delta B / \Delta H$.

2.5. *Magnetic Resistance*

The magnetic conductivity or permeability of a material can be compared with the conductivity of electric circuits. It can be shown that the magnetic resistance or reluctance of the material having a constant cross-section is equal to

$$R_m = \frac{l}{\mu \cdot q} \left(\frac{1}{\text{cm}}\right)$$

or in practical units

$$R_m = \frac{l}{\mu \cdot q} \cdot \frac{10^9}{4\pi} \left(\frac{1}{\text{henry}}\right)$$

(q denoting the cross-sectional area in cm^2)

Table 1[1]

The Conversion of Electrical and Magnetic Units

Definition	Sym	Formula	C.G.S. System	Sym	Practical Units	Sym
Electrical current	I	$I=\frac{dQ}{dt}$	1 e.m.u. 10^{-1} e.m.u.	—	1 ampere =1 coulomb sec 1 ampere	A
Potential difference (*a*) by change of field (*b*) by movement of conductor in field	E	$E=-w\cdot\frac{d\varphi}{dt}$ $E=B\cdot l\cdot v$	1 e.m.u. $=\frac{1\text{ maxwell}}{\text{sec}}$ 10^8 e.m.u.	—	10^{-8} volt 1 volt	V
Resistance Ohm's Law for electric circuits	R	$R=\frac{E}{I}$	1 e.m.u. 10^9 e.m.u.	—	$10^{-9}\text{V/A}=10^{-9}\text{ohm}$ 1 ohm	Ω
Magnetic Flux	φ	$\varphi=B\cdot q$	1 maxwell $=1$ gauss-cm^2 10^8 M	M	$10^{-8}\text{Vsec}=10^{-8}\text{weber}$ 1 weber	Wb
Magnetic Potential	E_m Θ	$E_m=H\cdot l=I\cdot w$	1 gilbert $=1$ oersted-cm $\frac{4\pi}{10}\cdot\text{Gb}$	Gb	$10/4\pi$ ampere turn 1 AT=1A	AT
Magnetic Reluctance Ohm's Law for magnetic circuits	R_m	$R_m=\frac{E_m}{\varphi}=\frac{L}{\mu_{abs}\cdot q}$	$1\text{ e.m.u.}=\frac{1}{\text{cm}}$ $4\pi\cdot10^{-9}$ e.m.u.	—	$\frac{10^9}{4\pi}\frac{\text{AT}}{\text{V sec}}=\frac{10^9}{4\pi}\frac{1}{\text{henry}}$ $1\frac{1}{\text{henry}}$	—
Magnetic Induction Number of lines cut per unit cross section	B	$B=\frac{\varphi}{q}$ $=\mu_{abs}\cdot H$	1 gauss 10^8 G	G	$10^{-8}\frac{\text{V sec}}{\text{cm}^2}$ $1\frac{\text{V sec}}{\text{cm}^2}$	—
Magnetic Field Strength Magnetic Force	H	$H=\frac{I\cdot w}{l}$ $=\frac{B}{\mu_{abs}}$	1 oersted $\frac{4\pi}{10}$ oersted	—	$\frac{10}{4\pi}\frac{\text{AT}}{\text{cm}}$ $1\frac{\text{AT}}{\text{cm}}=\frac{1\text{A}}{\text{cm}}$	$\frac{\text{AT}}{\text{cm}}$
Permeability Magnetic Conductivity of vacuum Magnetic Conductivity (absol.) of material	μ_0 μ_{abs}	$\mu_0=\frac{B_{vacuum}}{H}$ $\mu_{abs}=\mu_{rel}\cdot\mu_0$ $=\frac{B_{material}}{H}$	$1\frac{\text{gauss}}{\text{oersted}}$ $\frac{10^9\text{ G}}{4\pi\text{ oersted}}$	—	$\frac{4\pi}{10^9}\frac{\text{V sec}}{\text{A cm}}=\frac{4\pi}{10^9}\frac{\text{henry}}{\text{cm}}$ $1\frac{\text{henry}}{\text{cm}}$	—
Relative Permeability Ratio of permeability of material to permeability of vacuum	μ_{rel}	$\mu_{rel}=\mu=\frac{\mu_{abs}}{\mu_0}$ $=\frac{B_{material}}{B_{vacuum}}$	$\mu=1$ (for vacuum)	—	$\mu=1$ (for air)	—
Inductance E.m.f. induced in conductor for change of current in unit time	L	$L=E\frac{dt}{di}$ $=w^2\frac{\mu\mu_0\cdot q}{l}$ $=\frac{\varphi\cdot w}{I}=\frac{w^2}{R_m}$	1 e.m.u.$=1$ cm $\frac{10^9}{4\pi}$ cm	—	$4\pi\cdot10^{-9}$ henry 1 henry	H

w = number of turns l = length of conductor q = cross-sectional area

Table 2[1]

The Calculation of Unknown Units from Known Units

to calibrate ↓ from →		Current I		Voltage E		Induction B		Field strength H		Inductance L		
Field strength	H	$\frac{w\cdot I}{l}$	$\frac{A}{cm}$	$\frac{10^9}{4\pi}\cdot\frac{E}{\mu\cdot qw\cdot\omega}$	$\frac{V}{cm^2\,sec^{-1}}$	$\frac{10}{4\pi}\cdot\frac{B}{\mu}$	G	H				$\frac{A}{cm}$
		$\frac{4\pi}{10}\,\frac{w\cdot I}{l}$	$\frac{A}{cm}$	$\frac{10^8\cdot E}{\mu\cdot w\cdot q\cdot\omega}$	$\frac{V}{cm^2\,sec^{-1}}$			H				—
Induction	B	$\frac{4\pi}{10}\,\mu\,\frac{w\cdot I}{l}$	$\frac{A}{cm}$	$\frac{10^8\cdot E}{w\cdot q\cdot\omega}$	$\frac{V}{cm^2\,sec^{-1}}$	B		$\frac{4\pi}{10}\cdot\mu\cdot H$	$\frac{A}{cm}$			G
Permeability	μ	$\frac{10^9}{4\pi}\cdot\frac{E\cdot l}{w^2\cdot q\cdot\omega\cdot I}$	$\frac{V\cdot cm}{cm^2\,sec^{-1}\,A}$			$\frac{10}{4\pi}\cdot\frac{B}{H}$	$\frac{G}{A\,cm^{-1}}$,	$\frac{B}{H}$	$\frac{gauss}{oersted}$	$\frac{10^9}{4\pi}\cdot\frac{l\cdot L}{w^2\cdot q}$	$\frac{cm\cdot H}{cm^2}$	—
Inductance	L	$\frac{E}{I\cdot\omega}$	$\frac{V}{A\cdot sec^{-1}}$	$\frac{E}{I\cdot\omega}$	$\frac{V}{A\cdot sec^{-1}}$					$4\pi\cdot 10^{-9}\cdot w^2\cdot\frac{\mu.q}{l}$	$\frac{cm^2}{cm}$	H
Current	I	I		$\frac{E}{\omega L}$	$\frac{V}{sec^{-1}\,H}$	$\frac{10}{4\pi}\cdot\frac{B.l}{\mu\cdot w}$	G·cm	$\frac{H\cdot l}{w}$	$\frac{A}{cm}\cdot cm$	$\frac{E}{\omega L}$	$\frac{V}{sec^{-1}\,H}$	A
								$\frac{4\pi}{10}\cdot\frac{Hl}{w}$	Oe·cm			
Voltage	E	$\omega L\cdot I$	sec⁻¹·H·A	E		$10^{-8}\cdot B\cdot wq\omega$	G cm² sec⁻¹	$4\pi\cdot 10^{-9}H\mu wq\cdot\omega$	$\frac{A}{cm}$ cm² sec⁻¹	$I\cdot\omega L$	A sec⁻¹ H	V
								$10^{-8}\cdot H\mu\cdot w\cdot q\cdot\omega$	Oe cm² sec⁻¹			

w = number of turns
l = length of conductor
q = cross-sectional area

Since μ alters with the field H, the magnetic resistance will also depend on H. It is therefore important to know the relationship of the permeability μ to the field H and in some cases also the frequency. For a ring of a high permeability material of (say) 120 cm mean diameter, a permeability of 12000, a cross section of 1 cm², $R_m = 120/12000 \times 1 = 0{\cdot}01$. If now an air-gap is inserted anywhere in the ring and parallel with its cross-section, then the reluctance of the core itself remains unchanged. The total reluctance of the completed magnetic circuit is the sum of the reluctances of core and air-gap. The reluctance of the air-gap if this is assumed to be (say) 0·1 mm is $R_{m\ \text{air}} = 0{\cdot}1/1 \times 1 = 0{\cdot}1$.

2.6. *Ohm's Law for Magnetic Circuits*

Ohm's law can be made to apply to magnetic circuits if the voltage E is replaced by a unit E_m; the resistance R by the magnetic reluctance R_m, and the electric current I by the magnetic flux φ. The unit for the magnetic potential is the magnetomotive force (M.M.F.) and is defined as the power which is able to induce a flux line in a magnetic circuit having unit reluctance. The unit of this "magnetic voltage" is the gilbert (1 oersted × 1 cm) or in the practical system 1 ampere-turn. Ohm's law for magnetic circuits can therefore be defined as

$$\varphi = E_m / R_m$$

It is more usual to calculate in ampere-turns and the formula is then

$$\varphi = \frac{4\pi \,.\, I \,.\, t}{10\, R_m} \quad (M)$$

where t = number of turns. It follows that one gilbert is $4\pi/10$ ampere-turns and the values for the conversion can be obtained from Table 1. Table 2 shows all formula for the conversion of electrical units to magnetic units and vice versa. If voltage and current measurements are taken on a toroidal type of coil, Table 2 will enable the magnetic values of that coil to be obtained.

2.7. *De-magnetization*

All the hysteresis loops so far considered consisted of a coil wound on to a closed core. The permeability in such a magnetic circuit is equal along the full length of the core. If now an air-gap is contained in the core, the flux in the gap will be smaller than that in the ferromagnetic material. According to Ohm's law for magnetic circuits the magnetic potential must remain constant and the flux must therefore be small for the larger reluctance. It follows, since the magnetic potential $E_m = \varphi \,.\, R_m$ remains constant, φ must become smaller for the greater reluctance, and, since $B = \varphi/q$, the induction will also become smaller for a given field H. The result, as can be seen from Fig. 2, is a flattened or stretched out hysteresis loop and is called shearing or de-magnetization.

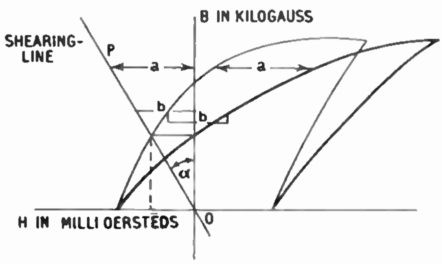


Fig. 2. De-magnetization or shearing line[1].

The line O–P is called the de-magnetization line or shearing line and its slope or angle with the B axis can be determined as follows: Due to the air-gap, if the effective gap width is considered to be equal to the length of the gap, the same number of flux lines must pass through the gap as are passing through the core of the coil: $\varphi_{\text{air}} = \varphi_{\text{core}}$. If the cross-section of the core is denoted by q_c and that of the gap by q_a and if we express the flux by the induction in the circuit we obtain the equation

$$B_c \,.\, q_c = H_a \,.\, q_a \qquad \ldots\ldots\ldots(1)$$

Provided the cross-sections are equal, the induction in the gap is equal to the induction in the core itself. Since the sum of the magnetic potentials over the closed magnetic circuit must always be 0, we obtain:

$$(H_c \,.\, l_c) + (H_a \,.\, l_a) = 0 \qquad \ldots\ldots\ldots(2)$$

l_c denoting the mean length of the core and l_a denoting the length of the gap. If equation (1) is divided by equation (2), we obtain

$$\frac{H_c}{B_c} = \frac{q_c}{q_a} \cdot \frac{l_a}{l_c}$$

or if the cross-sections in core and gap are equal:

$$\frac{H_c}{B_c} = \tan \alpha = \frac{l_a}{l_c}$$

When there is no air-gap ($l_a=0$), α will be zero. An increase in the length of the air gap will cause the slope of the shearing line to increase and with it the de-magnetizing function of the gap. The induction in the gap can be calculated from equation (1) and is:

$$H_a=B_c \cdot \frac{q_c}{q_a}$$

Since the flux lines will not leave the core at right angles to its cross-section only, a constant σ is introduced to denote the apparent widening of the gap. The effective gap width is always larger than its actual width. The slope of the shearing line now becomes

$$\tan \alpha=\frac{q_c}{\sigma \cdot q_a} : \frac{l_a}{l_c}$$

and the induction in the air-gap is now equal to

$$H_a=B_c \cdot \frac{q_c}{\sigma \cdot q_a}$$

It is possible to construct the hysteresis loop for a core with an air-gap from that of the closed core by taking the distance of a number of points along the shearing line from the B axis and subtracting it from the normal hysteresis loop. This procedure is indicated in Fig. 2. The slope of the shearing line is often called the de-magnetization factor of the material. De-magnetization not only occurs in magnetic constructions consisting of a core with an air gap, but also in bar magnets and in the recording medium itself. For very long bar magnets, the effect of the de-magnetization is very small, but it will increase as the magnets are shortened and for very small bar magnets, the de-magnetization can become equal to $\sigma=5$.

2.8. *Ferro-Magnetic Materials*[4]

For the recording or reproduction by magnetic means, two different types of ferro-magnetic materials are of great importance. For the erase head, recording head and the reproduction head, a "magnetically soft" material is required. This is a material having a high permeability and a very low coercivity. The permeability must be high in order to produce a flux density of sufficient magnitude in the air gap, whereas the coercivity should be kept small to reduce the energy required for a particle of the material to be moved from a positive to a negative induction when the field changes from a positive to a negative value. This has already been discussed under hysteresis losses. Magnetically soft materials range from soft iron with a coercivity of approximately 1 oersted and maximum permeability of 5000 to materials with a coercivity of 0·009 oersted and a maximum permeability of 300,000. It is quite usual to use mu-metal for the core of recording heads with a coercivity of approximately 0·03 oersted and a permeability of about 70,000. To obtain such magnetic properties, materials used for the construction of heads are normally subjected to special treatment. The high value of the permeability is obtained by submitting the material to an annealing process in a hydrogen atmosphere. The material is heated to approximately 1000° C and the whole process lasts from 3-16 hours. The cores of magnetic heads nearly always consist of laminations which, to avoid eddy-current losses, are insulated from each other. This is in most cases done by oxidizing the surfaces of the laminations. Some materials also require the subjection to a magnetic field whilst being annealed in order to achieve a maximum value of permeability.

The erase and bias frequencies in magnetic recording normally range from 30-100 kc/s. Such relatively high frequencies cause heavy current losses in the laminations of the cores of the heads, reducing their effective permeability. The losses for a given frequency depend on the thickness of the laminations and on the specific electric resistance of the material used. The frequency at which the permeability of the material becomes negligible is called limit frequency and its value may be determined by:

$$f_u=\frac{4\rho_E}{\pi \cdot \mu_0 \cdot \mu \cdot q_L^2}$$

where f_u denotes the limit frequency, ρ_E the specific resistance of the material (Ω/cm), μ the permeability, μ_0 the permeability of a vacuum$=4\pi \times 10^{-9}$ and q_L the thickness of the laminations in cm. The relationship is shown in Fig 3. It should be noted that the effective permeability is reduced if the frequency is increased, since this plays a decisive part in the recording and reproduction of high frequencies.

Magnetically hard materials are used as recording media, since they are required to retain their magnetism when relatively high counter-magnetizing forces are present or when the individual magnets are so short that the flux lines must close through substantial air paths. They possess a high coercivity which reduces de-magnetizing influences such as, for instance, are caused by mechanical stresses, changes of temperature, stray a.c. fields and air-gaps. The values for their coercivity lie between 50 oersteds for carbon steel and approximately 2500 oersteds for platinum-cobalt alloys. The optimum values for magnetic tapes or carriers appear to lie between 200 and 600 oersteds. The value of remanence for the more suitable type of material, approximately 12,000 gauss.

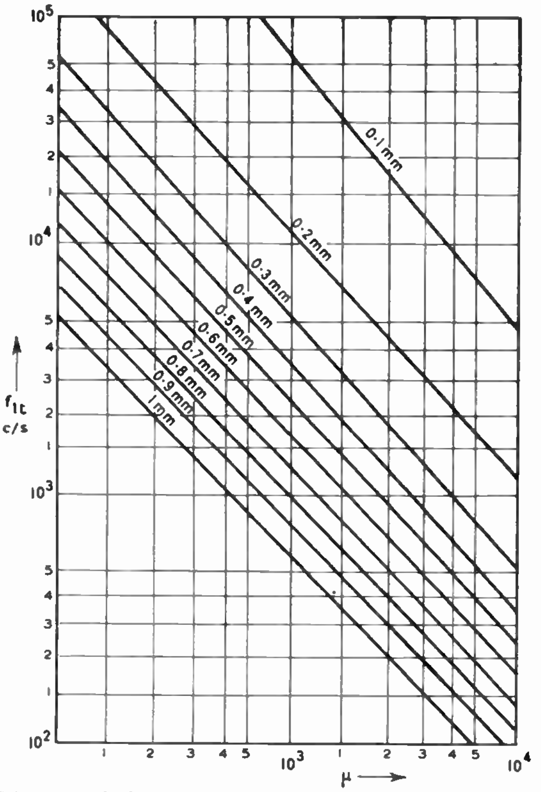


Fig. 3. Limit frequencies for different thicknesses of laminations.

3. Principal Functions of Magnetic Heads and Tapes

In tape recording, the relative positions of the magnetic medium and the magnetic tapes continuously alter. It is unimportant, basically, whether the medium is moved past the heads or whether the heads are moved past the medium. For reasons of mechanical simplicity however, it is usual to move the recording medium (the tape) past the magnetic heads. This must take place at a very constant speed which is usually a fraction or a multiple of 15 inches per second. If the signal amplitude alters as a function of time, the intensity of the recorded signal will alter as a function of tape length. For a constant frequency at a constant tape speed V the recorded wavelengths will be:

$$\lambda = V \,.\, t = \frac{V}{f} \quad \left(\frac{\text{cm . sec}}{\text{sec}}\right)$$

The recording magnetic head will always basically consist of a ring type core, having an air-gap in its face and perhaps a second air-gap at the back. It carries a winding through which the audio-frequency current is fed. Recording heads have also been constructed on entirely different principles and they will be referred to later. The two pole-pieces forming the air-gap are very often cone-shaped in order to concentrate the flux lines at this point and to force them outwards through the recording medium. The magnetic flux lines emanate from the ends of the pole-pieces and close through the magnetic medium, hence magnetizing the iron oxide particles of that particular portion of the medium. When this part of the tape has left the influence of the gap, the magnetic induction of the tape will decrease along the hysteresis loop until it reaches the remanant induction which depends on the magnetic properties of the medium. The flux lines which leave the bar magnets of the medium and which are forming their magnetic circuits, constitute the surface induction of the medium. They can be made visible if some emulsion carrying small iron particles is brought in contact with a recorded tape. Fig. 4 shows the relationship between external and

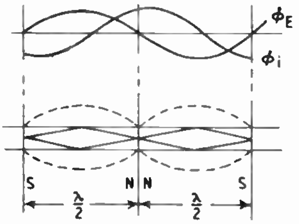


Fig. 4. Relationship of external and internal flux density.

internal flux density spread over a short portion of the medium.

In Fig. 4, φ_i depicts the flux in the medium whereas φ_E depicts the external flux. At the points where the external flux is at a maximum, the flux density also has its maximum. These points will show an accumulation of iron particles if the aforementioned test is applied. The internal flux disappears since all lines have left the medium and have completed the magnetic circuit. The internal flux is at a maximum at all the points where no lines leave the small bar magnets and these are also the points where the external flux disappears. The field distribution is also very similar to that of a bar magnet, the length of which is equal to one half of the recorded wavelength. The bar magnets are always joined with their equal poles and their cross-section is equal to the cross-section or thickness of the medium.

When playing back, the medium is moved past the playback head which could be the same as the recording head and in which case we are dealing with a combined recording/playback head. The outer surface induction now forces the field into the gap of the playback head and through the core of the head which can be looked upon as a short circuit for the field since it will only have a relatively low magnetic resistance. The field now produces a flux in the playback head which induces a voltage in the windings of the core. The voltage which is generated can be expressed by:[2]

$$E = \frac{w \cdot d \cdot \varphi_h}{dt} \times 10^{-8}$$

in which φ_h denotes the flux in the core and E the induced voltage. w denotes the number of turns in the core and d their diameter.

To erase a recording it is only necessary to remove the remanence left on the tape either by de-magnetization or by saturation. This can be achieved by several means; either the recorded tape on its spool is brought into a very strong a.c. field which will magnetize the medium up to its points of saturation and on removal from the field the induction of the tape will pass through magnetization curves (small hysteresis loops) which become smaller and smaller as the distance from the a.c. field increases. The other method is to bring the pole of a magnet in close contact with the tape and to move the tape past it. The medium will again be magnetized into one of its points of saturation but after removal from the influence of the d..c. magnetic field, a remanent magnetization will remain on the tape. In practice a special head is normally used, the erase head, which is fed with a relatively heavy erase current and which saturates the medium as this is running past it.

All three types of magnetic heads will now be dealt with in detail.

4. Erasing

Erasing is possible by means of a d.c. or of an a.c. field. If d.c. is employed, each particle of the medium is saturated to one point of saturation from any point of its previous inductance and after leaving the field of influence a remanent inductance will remain on the tape which is equal for all parts of the tape. When a.c. is being used, each particle of the medium will be magnetized to the two points of saturation and as the field decreases hysteresis loops will be described which will become smaller and smaller until no remanent induction remains.

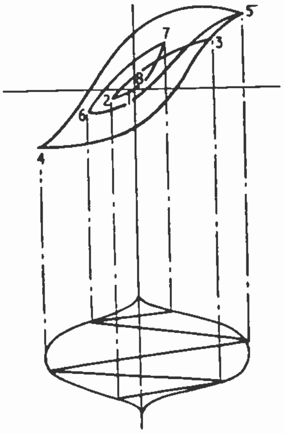


Fig. 5. Erase field and hysteresis loops.

This is only possible however if sufficient reversals take place whilst the particle is in the field of influence. The distribution of the field in the gap is advantageous for this since it is similar to the shape of a bell.[2] If the slopes of the two sides are kept relatively flat, which is identical with a wide gap, then the particle will pass through a field which is gradually increasing, reaching a maximum and then slowly decreasing again (see Fig. 5).

Basically, the frequency of the a.c. field would be of little importance provided the particle on the medium can be passed through sufficient reversals whilst passing through the influence of the gap. If the gap is of sufficient width, 50 c/s currents could be used but at the tape speeds with which we are dealing this would lead to such great dimensions of the erase head that this is impracticable. It is therefore the usual trend to use a relatively high erase frequency which is normally between 30 and 60 kc/s. The choice of the erasing frequency is a matter which requires some definite consideration. For economy reasons it is often desired to use the same oscillator for the provision of the recording bias and the erase current. The application of such comparatively large alternating magnetic fields to the medium becomes more difficult when the effects of the hysteresis and eddy current losses are taken into account. These losses increase rapidly as the erase frequency is increased and the efficiency of an a.c. erase head is relatively low when compared with that of a d.c. erasing head. For a given mechanical gap width of 0·5 mm, the ampere-turns per cm should be approximately 2·7. This would correspond to an erase current of 120 mA through 150 turns.[1] It is usual to fit a small piece of beryllium copper into the gap as a protection against the accumulation of iron oxide in the gap which would result in the short circuiting of the core and also to create eddy currents. The eddy currents also produce a field which opposes the field through the core. The field lines through the core therefore choose the path of least resistance and pass through air. They are also leaving the core or pole pieces sooner than would be otherwise the case. Eddy currents also produce heat in the gap which may have a bad effect on the medium, especially if its base is of plastic. This creation of heat mainly determines the upper limit of the erase frequency but normally the greater part of the heat is conducted away through the fixing arrangements of the head. If the movement of the tape is stopped whilst erase current is applied to the erase head, the heat can burn either the base of the medium or the medium itself. It is quite usual to find that the heat in the gap is up to 170° F when using 160 mA erase current and an erase frequency of 60 kc/s.

5. Recording

When recording, the variations along the recording medium take the form of variations in its remanent magnetization. It is the object of magnetic recording to produce a remanent magnetization in the medium at any point which is directly proportional to the instantaneous value of the signal strength corresponding to that point. Fig. 6 shows the three different ways in which magnetic recording is possible if the medium is moved in one given direction. The system now in common use is the longitudinal way. Perpendicular and transverse recording is also possible but if wire is used as the recording means, transverse and perpendicular recordings are of course identical. The field lines, leaving the core, magnetize the medium in the direction of movement. It must be noted that the flux density in the tape is greater near the surface which makes contact with the gap than at any part further away from the gap but still in the medium. In the longitudinal recording, a certain component of perpendicular recording is also present and this is indicated in Fig. 6 (*a*). The smaller the gap the greater the component of perpendicular recording and this is often to blame if a recording cannot be fully erased. The effect is caused by the field distributions in the gap of the erase head and in the gap of the recording/playback head being different. The perpendicular part of a

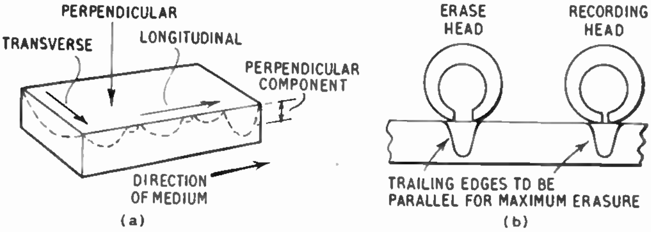


Fig. 6. (*a*) Illustrating the three directions for magnetic recording.
(*b*) Illustrating the position of the heads for maximum erase.

recording cannot be erased by the erase head even if the erase current is very much increased. If it is considered that normal recording amplifiers show a top lift of 6 db per octave, it will be appreciated that it is quite simple to over-modulate a recording, causing increased components of perpendicular recording which cannot be fully erased. Due to the lower slope angle of the field in the gap of the erase head, the erase current cannot fully erase a perpendicular component. Maximum erase conditions only exist where the trailing edge of the erase field is parallel with the trailing edge of the recording field (see Fig. 6 (*b*)).

The recording process will now be considered under the following conditions: Each particle of the medium shall pass the gap at uniform speed, the flux densities considered will follow a sine law, the velocity of the medium and the frequency to be recorded shall be great and the gap width shall be small relative to each other. This will result in the particle being subjected to a small change of field whilst it moves through its influence, and the magnetization of each particle will then be approximately equal to the maximum field in the centre of the gap. After the particle has left the influence of the gap, the remanent induction will be reduced to a value B_r and this is now the function of the field strength H in the core which again is proportional to the magnetizing current. The resulting curve is the dynamic magnetic characteristic which will be different from the static characteristic. It shows the relationship between field strength and the induction present at any given moment. This characteristic is no absolute physical characteristic since it is also dependent on the thickness of the medium and on the frequency to be recorded. The dynamic characteristic is therefore mainly dependent on whether the particle reaching the effect of the gap has had some previous magnetic history or not. Somewhat better conditions exist if the medium was erased by means of an alternating current and now reaches the recording head in neutral condition. Magnetization then takes place along the normal magnetization curve (see Fig. 7) but the great irregularities of this curve lead to strong non-linear distortion, mainly of the third harmonic order.

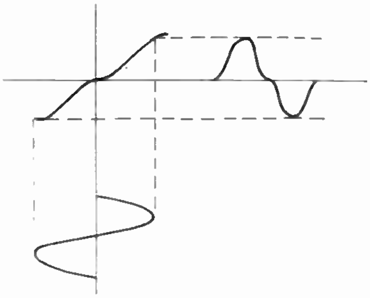


Fig. 7. Normal magnetization curve.

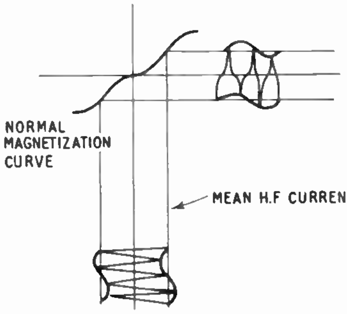


Fig. 8. Recording with h.f. bias.

For a number of years d.c. biasing was employed which shifts the operating point along the normal magnetization curve into one of the more linear portions. The quality of such recording however cannot be termed as good, since it then becomes essential to reduce the signal amplitude to a very small figure if one wishes to operate on a relatively linear portion of the transfer characteristic. When applying an h.f. recording bias, it is important to ensure that its amplitude increases and then decreases as the particle of the medium is moved through its field of influence. To avoid or decrease tape noise, a sufficient number of reversals must be possible which, at a given tape speed, determines the frequency of the recording bias. A.c. biasing moves the dynamic magnetization curve to the right or left on to the straight portion of the hysteresis loop and can be considered analogous to a minor hysteresis loop as shown in Fig. 1. Fig. 8 also shows that the h.f. amplitude must be given a certain figure in order to operate at the optimum operating point. If the h.f. amplitude is too small, very great non-linear distortion will occur. The same happens if the h.f. oscillator exceeds its optimum value. This will also lead to distortion. Fig. 10 shows the relationship between distortion factor and audio amplitude[4] and this differs for different types of media and with their speeds. After the signal has been recorded, de-magnetization takes place which is especially noticeable at the higher frequencies. This is due to the de-magnetizing effect of the bar magnets by virtue of the fact that their poles of equal polarity are almost touching. (Fig. 9.)

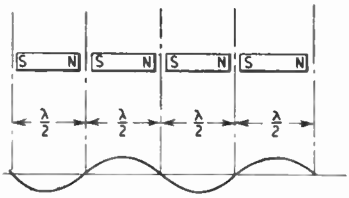


Fig. 9. De-magnetization due to poles of equal polarity almost touching.

Since the signal amplitude can be considered as varying along the length of the tape or medium, the number of flux lines within the medium must also change. All flux lines form closed circuits and one refers to the internal flux which exists within the medium and the external flux which leaves the medium and completes its path outside the surface of the medium. If the recorded frequency was a sine wave, then the flux density in the medium must be:

$$\varphi = \varphi_{\max} \,.\, \sin 2\pi ft$$

where φ depicts the number of flux lines on the surface of the tape and where $\varphi_{\max}$ depicts the maximum value of φ during one period. If the flux density on a point x along the medium is φ_x, then the surface density must be proportional to the changes in the flux density at this point, which must be equal to $d\varphi_x/dx$. If the signal frequency is substituted by the recorded wave length, the product of velocity × time by the distance x on the medium, we obtain:

$$\varphi = \varphi_{\max} \,.\, \sin 2 \,.\, \frac{vt}{\lambda} = \varphi_{\max} \,.\, \sin 2 \,.\, \frac{x}{\lambda}$$

The surface density at any point x on the medium is the number of flux lines per unit length at this point and is therefore proportional to the first derivative of the flux with respect to x:

$$B = \frac{d\varphi_x}{dx} = \frac{2\pi}{\lambda} \,.\, \varphi \cos 2\pi \frac{x}{\lambda}$$

or expressed by the frequency

$$B = \frac{2\pi}{v} \varphi \cos 2\pi ft$$

This means that the number of flux lines per unit length of the medium is proportional to the recorded frequency. Since the geometrical pattern of the flux distribution will be equal for both the low and the high frequencies, it can be seen that it is important for the medium to make close contact with the head. Where this is not the case, the signal amplitude of the top frequencies will be lost, but considerably less effect will be noticed at the lower frequencies.

6. Reproduction

If we consider a medium (tape) on which is recorded a sine wave, then the internal flux density must also be distributed in a sine fashion along the tape. The distribution of the external flux follows a cosine law, since the points of maximum density of the internal flux coincide with the minimum points of the external flux, i.e. they show a phase shift of 90 deg. If a single conductor is placed at right angles to the direction of movement and touching the tape, then it will be cut by lines of the external flux only and a voltage will be induced in it. Due to the external flux, an induction exists on the surface of the medium, and this will be approximately equal to:

$$B = \frac{d\varphi_E}{dx} = \frac{2\pi f}{v} \,.\, \varphi_{E\,(\max)} \,.\, \cos 2\pi ft \text{ (gauss)}$$

where f depicts the recorded signal frequency, v the velocity of the medium and $\varphi_{E\,(\max)}$ the maximum value of the external induction. The induced voltage can now be calculated as:

$$E = B \,.\, v \,.\, l \,.\, 10^{-8} \text{ volts}$$

$$= 2\pi f \,.\, l \,.\, \varphi_{E\,(\max)} \,.\, \cos (2\pi ft) \times 10^{-8} \text{ volts}$$

where l is the length of the conductor which is cut by the flux. In the case of tape recording, this is equal to the width of the track. If the tape is reproduced at a different speed than that at which it was recorded, then the ratio between the recorded and the reproduced frequency will be equal to V_1/V_2. It is also evident that the induced voltage will be proportional to the width of the track if a playback head is used in place of a single conductor, the formula still holding good with the exception that w is now the number of turns of the coil in the head and the voltage will be w times greater. In addition we have a constant factor k which is dependent on the geometric proportions or dimensions and the magnetic properties of the core. We now obtain

$$E = w \,.\, k \,.\, l \,.\, 2\pi f \,.\, \cos 2\pi f \,.\, t \times 10^{-8} \text{ volts}$$

or if we consider that $2\pi/\sqrt{2}$ equals 4·44:

$$E = 4{\cdot}44 \,.\, w \,.\, k \,.\, l \,.\, f \times 10^{-8} \text{ volts effective.}$$

In this equation w depicts the number of turns of the playback head, l the track width in mm, f the signal frequency in c/s, k the maximum value of the external induction referred to a track width of 1 mm and inducing a voltage E in the head. To determine the constant k the above mentioned equation can be used and the induced voltage can be measured using a frequency of approximately 100 c/s. A low frequency must be used in order to keep the damping effect and the gap effect at a minimum.

6.1. *De-magnetization*

Measurements of the voltage induced in a playback head have shown that this voltage rises in a linear fashion only up to approximately 200 c/s at 7·5 in./sec. It then approaches a maximum and cuts off quickly after a certain higher frequency. This reduction in output level is the self-demagnetization which is due to the wavelengths on the medium becoming shorter and it is equal to:

$$D = \exp(-f/f_1)$$

where f_1 is the frequency at which the external induction of the medium is reduced to $1/e = 37\%$. Our formula for the reproduction of the signal can now be extended to: $E = 4{\cdot}44\, w\, k\, l\, f \exp(-f/f_1) \times 10^{-8}$ volts effective. This takes into account losses due to self-demagnetization.

6.2. *Gap Function*

Since the gap in the playback head has a definite width (g), the magnetic modulation on the tape is not picked up from point to point but with the full width of the gap. This means that at any given point x the mean value of the induction φ, must be considered and its value is arrived at by taking the mean value of induction between the limits x_1 and x_2. The field distribution is:

$$\varphi_E = \varphi_{E(\max)} \,.\, \sin 2\pi \,.\, v/\lambda$$

Applying the limits x_1 and x_2 we obtain[2]:

$$\varphi = \frac{1.}{g} \int_{x1}^{x2} \varphi_{E(\max)} \,.\, \sin 2\pi \,.\, \frac{x}{\lambda} \,.\, dx$$

$$= -\varphi_{E(\max)} \cdot \frac{\lambda}{2\pi g} \cos\pi \,.\, \frac{x_2}{\lambda} + \varphi_{E(\max)} \cdot \frac{\lambda}{2\pi g} \cos 2\pi \frac{x_1}{\lambda}$$

Putting the limits $x_1 = x - \frac{1}{2}s$ and $x_2 = x + \frac{1}{2}s$, then we will obtain

$$\varphi_{\text{mean}} = \varphi_{E\max} \cdot \frac{1}{\pi} \cdot \frac{\lambda}{s} \,.\, \sin\left(\pi \,.\, \frac{s}{\lambda}\right) \sin\left(2\pi \,.\, \frac{x}{\lambda}\right)$$

If now $\pi s/\lambda$ is replaced by α and x/λ by $v \,.\, t/\lambda = f \,.\, t$, then the equation will read:

$$\varphi_{\text{mean}} = \varphi_{\max} \cdot \frac{\sin\alpha}{\alpha} \,.\, \sin 2\pi f t$$

which is a function well known in sound film technique. It becomes clear, that for a ratio $g/\lambda = 1, 2, 3, \ldots$ minimum points will occur. The output from the head will then again increase, decrease and will once more reach a minimum point. It would therefore be possible to record wavelengths which are smaller than the effective gap length. Since each successive minimum becomes smaller and smaller, advantage is hardly ever taken of such an effect. Including the function for the gap effect the final formula for magnetic recording now becomes:

$$E = 4{\cdot}44\, w\, k\, l\, f \exp(f/f_1) \frac{\sin\alpha}{\alpha} \times 10^{-8} \text{ volts}$$

where α is $\pi \,.\, g/\lambda$.

6.3. *Reproduction of Low Frequencies*

The playback e.m.f. rises with frequency by 6 db per octave. In practice, however, lower frequencies do not conform to this rule. The effect is entirely due to the physical dimensions of the playback head. The external flux emanating from the tape will at high frequencies, i.e. short wavelengths, be entirely shunted by the pole-pieces of the head. At a certain low frequency, the value of which depends entirely on the parts of the pole-pieces which are in contact with the tape the output will decrease since not all the flux lines are shunted by the pole-pieces which have a permeability different from air.

Since this loss of bass frequencies depends on the wavelength as well as on the dimensions of the pole-pieces, it becomes less important at slower tape speeds and larger contact surface of the pole-pieces.

7. Tape Characteristics

The manufacture of tapes has now reached a standard which is much above that of the early recording media. Specifications of tapes for industrial and broadcast purposes have become very much more stringent. Whereas recording media were designed in the early days to provide as much output as possible, tape manufacturers have now begun to produce tapes of quite different specifications so as to make them suitable for many different purposes.

Two types of basically different recording media can be produced, homogeneous and non-homogeneous media. Homogeneous media may consist of steel or vicalloy and were in use during the early days of magnetic recording. Steel wire is still in use at the present time since it exhibits some properties which are advantageous or indeed essential for a limited number of applications. Most homogeneous tapes consist of approximately 30 per cent. iron oxide by weight or 10 per cent. by volume and can be produced to have an extremely smooth surface—an important point where heads and tape guides are to last as long as possible. Non-homogeneous tapes consist of a separate carrier or base on which a coating of iron oxide is formed. The coating consists of an average of 70 per cent. iron oxide by weight or 40 per cent. by volume. The higher the content of iron oxide the better is the electrical performance normally. The abrasive properties of the iron oxide, however, cause wear of the heads by the tape and it is the responsibility of the tape manufacturer to arrive at a convenient compromise. The permeability of homogeneous media is usually about 1·5 to 2·5, that of non-homogeneous media about 2·0 to 5·0.

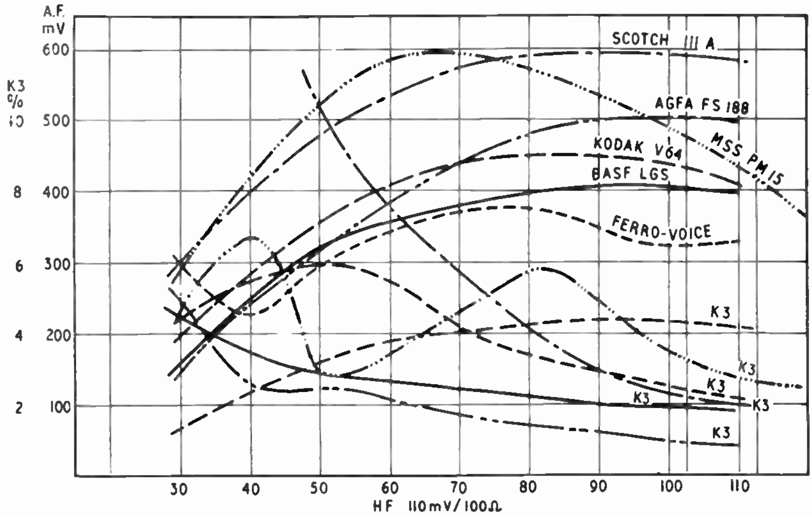


Fig. 10. Relationship of distortion factor k_3 and audio output for different types of tape and different values of h.f. current.

Conditions:
Head—2500 turns 0·05 enamelled copper.
A.F.—1000 c/s 0·1 mA constant.
H.F.—45 kc/s.

For all types of recording tapes it is of course of great importance to ensure that the size of the granules is as small as possible.

Figure 10 was prepared to show the characteristics of some well-known tapes. The relationships are given for audio-output and distortion factor at a constant input and when varying the h.f. bias current.

8. Special Types of Recording Heads

With the progressing technique of magnetic recording the shortcomings of the equipment in present use become more and more apparent. One of the weakest links is the recording or playback head used. A great deal of time has already been spent on research to produce heads of an entirely different design and with properties which would either make such a head more reliable or tend to simplify the whole process of magnetic recording. One American company has recently produced a playback head[5] from which the output is no longer proportional to the playback speed of the medium. The head consists of a very small cathode-ray tube in a more or less conventional type of core with an air-gap. Two wing-shaped electrodes in the tube are so arranged that the deflection of an electron beam, which is produced in the usual manner, alters the potential between them. (See Fig. 11.) The magnetic flux lines emanating from the tape deflect the beam in relation to their density and the potential across the two electrodes alters in sympathy. The limit of the frequency which can be reproduced is only dependent on the width of the gap, since even no tape movement at all would produce a deflection of the electron beam.

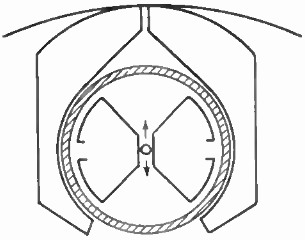


Fig. 11. "Electron beam" playback head.

In earlier sections it was explained how the frequency response alters during playback. The output increases with frequency at a rate of 6 db per octave until de-magnetization and gap effect cause a reduction of the output. This means that both bass and top frequencies have to be lifted in the playback amplifier if one aims at a level response. H. Leitener^5 of Germany recommends a playback head which overcomes this often difficult problem. The permeability of a material is not a constant value and depends on the amount of magnetization. Fig. 12 shows a typical permeability curve. It should be noted that this curve shows two rather straight portions and the operating point may be chosen on either of them by means of d.c. biasing. If the core of the head is now subjected to an h.f. current, then the permeability will change around the operating point and in sympathy with the high frequency, i.e. the magnetic resistance alters with the applied high frequency voltage. The signal on the medium will however also alter the magnetic resistance and the result is a field which generates in the windings of the playback coil an h.f. voltage modulated by the audio-frequency signal. Fig. 13 shows the layout of such a head. The core has a playback gap and is of conventional design. A magnetic short circuit is included, however, and this carries a winding L1. L2 and L1 are in series and are fed with an h.f. current. The windings are balanced so that no voltage is induced in L3. The presence of the audio signal now disturbs the existing balance in coils L1 and L2 and in L3 an h.f. voltage, modulated in sympathy with the audio-frequency signal, is induced. The magnitude of the induced field depends on the number of flux lines cut per unit time, but this is mainly determined by the h.f. field so that the frequency of the audio signal is of very little importance. According to Leitener the output from such a head is very much greater than that of conventional design. It is necessary to note, however, that the modulation obtained is without a carrier and it would appear advantageous to couple a carrier of correct phasing to the modulation.

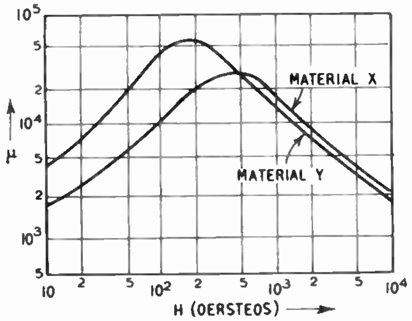


Fig. 12. Arbitrary relationship between permeability μ and field *H*.

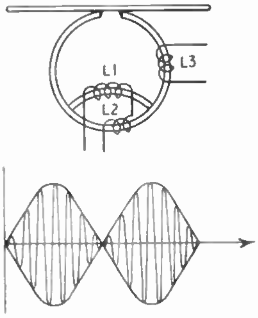


Fig. 13. Playback head of novel design.

If the gap in the playback head is not exactly parallel to the gap of the recording head, damping of the higher frequencies will occur. The damping is equal to $(\sin x)/x$

or in decibels: $20 \,.\, \log_{10} [(\sin x)/x]$

where $x = (\pi \,.\, \tan \alpha)/\lambda$.

In practice a tilting of the gap of one-quarter of the gap width of the playback head is normally accepted as permissible. The effect of the damping caused by such tilting can be used to contain two separate recordings on one track without an appreciable amount of cross-talk or interaction between the channels. Since the system would appear to be highly suitable for stereophonic reproduction, this would be of little importance in any case. Heads recommended by F. Krones[1] for this purpose would contain an X or V gap and would be fitted with two separate windings. The possibility therefore exists of utilizing the full width of the tape as against less than one-half in conventional double track recording systems, resulting in a gain of output level of 6 db. If the gaps were considered to be at 45 deg. to the edge of the tape, their length would be extended by 1·44 and the output increased by 3 db. The overall gain would then show a rise of 12 db if account is taken of the fact that no safety margin, usually one-third of the tape width, is required, a worthwhile proposition. Fig. 14 shows the design of such heads.

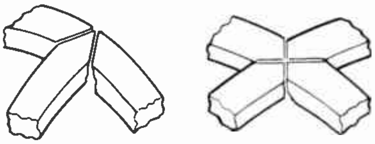


Fig. 14. Designs for heads suitable for stereophonic recording.

9. Alterations of the Characteristics of Recording/Reproducing Heads with use

A recording or reproducing head in use will be subjected to certain changes. These become apparent after periods of time which vary considerably and which depend on the type and construction of head, the material used, the abrasive properties of the tape, tape speed and tape pressure. Recording heads and reproducing heads are nearly always treated after manufacture and after assembly in specific ways to ensure that their active surfaces are smooth, their gap is uniform and clean and that they will make good contact with the medium during operation. Such treatment may consist of a special finishing process after which the head is highly polished ready for incorporation on to the recording apparatus. It will be found, however, that the physical contact between tape and head gap is not yet quite ideal and is dependent on the alignment of the head or the medium or both. Due to the abrasive properties of the tape a "bedding in" process takes place during the first few hours of operation. In cases where fresh tape is used as well as a newly manufactured head, this process is even more pronounced, not only because of the higher abrasive properties of such tape, but also because wear takes place which will remove superfluous particles of iron oxide from the tape This brings the mass of the tape into closer contact with the head gap. The active part and pole-pieces of the head are subjected to further polishing at the same time until the tape makes good physical contact with the gap over its full width and with even pressure. The result is an improved top response of the arrangement and must be taken into account when setting the frequency response on new equipment provided of course such accuracy is required. Since wear on the head is dependent on both tape speed and time, it can only be expressed as a function of tape length. Wear on the tape, however, depends on the number of times on which a point on the tape has passed the head and can only be expressed as number of playings.

In the following measurements a tape of 1,200 feet in length was used which was pulled across the face of the head at a constant speed of 3·75 inches per second; the direction was reversed after every 1,200 feet. The head is of a type similar to those used in a number of current recording machines. It must be borne in mind, however, that the final results depend on the exact type of head and tape used in the experiments. Figure 15 shows the relationship between frequency response and tape length moved across the head at a constant pressure of the tape against the head of 25 grammes, 50 grammes and 75 grammes. It will be observed that after a very short time—regarding the amount of tape passed in units of time—the top response of the recording equipment has reached a peak value which is then maintained for some span of time. The response then begins to fall off at a steadily decreasing rate. This takes place after the initial bedding-in process is completed and is due to a widening of the gap due to wear. The author is also of the opinion that changes in permeability take place in the core of the head, although no concrete figures are available to confirm this theory. The drop in frequency response is not steady and decreases since the conventional construction of a recording head offers an enlarged surface to the medium as wear progresses. In Fig.15 the curve for a tape pressure of 75 grammes shows a marked increase of level after approximately 100 feet of tape have passed the head. This it not only due to an increase in top response because of the better physical contact between tape and head but is also due to a general increase in noise level.

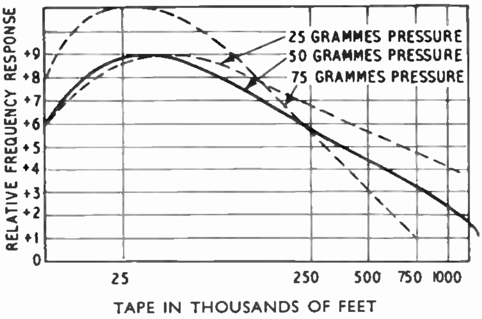
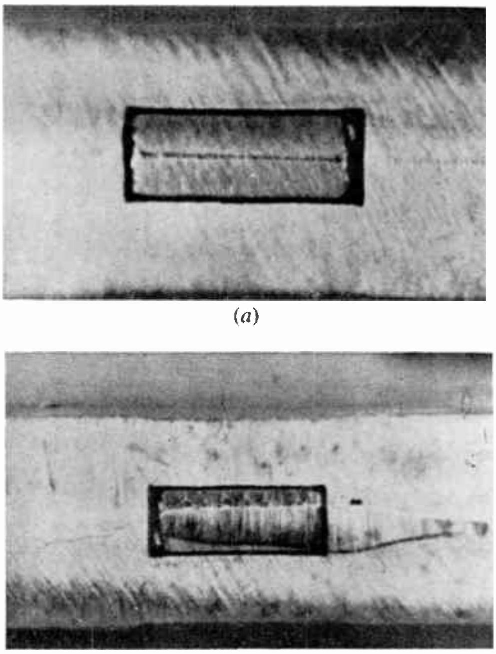


Fig. 15. Typical relationship between head/tape wear and frequency response.

To observe the effects of general tape wear, a loop of recording tape, carrying a recording of 10,000 c/s sine wave is played back continuously and the output measured across the head. With a new head and new tape, a bedding-in process will again take place, as previously described. The output at the frequency considered will however show only a very small increase which reaches its peak after about 10-15 playbacks. The response will then remain unaltered for about a further 20 playbacks and will then gradually decrease. The decrease is due to particles of iron oxide wearing off due to friction between head and tape. As has already been shown, a very short recorded wavelength will not penetrate the medium to an appreciable amount and it is mainly the surface of the coating which is saturated. Due to particles being worn off the surface, the mean value of remanence per unit cross section will also decrease and hence the output will drop. (See Fig. 16.)

10. Conclusions

Tape recording systems have reached a very high standard as compared with their forerunners. Their development however is by no means complete and sufficient scope is left for new designs and new methods to make the apparatus more efficient or more reliable. This paper has dealt with all principal and basic requirements encountered when designing magnetic recording or reproducing equipment, although final production methods are often kept exclusive by the actual manufacturers.


(*a*)

(*b*)

Fig. 16. (*a*) Shows a new recording/playback head. (*b*) The same head after 2,000,000 feet of tape have been passed over it with a pressure of 25 grammes.

11. References

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APPLICANTS FOR ELECTION AND TRANSFER

As a result of its March meeting the Membership Committee recommended the following elections and transfers to the Council.

In accordance with a resolution of Council and in the absence of any objections, the election or transfer of the candidates to the class indicated will be confirmed fourteen days after the date of circulation of this list. Any objections or communications concerning these election should be addressed to the General Secretary for submission to the Council.

Direct Election to Member

ATKINSON, Brigadier Leonard Henry, O.B.E., B.Sc. *High Wycombe.*
RUDD, Group Captain Sydney Charles William, R.A.F. *Hatch End.*

Transfer from Associate Member to Member

PITTENDRIGH, Lenus Walter Duff. *Bromley.*
WHITAKER, Captain Geoffrey Charles Francis, R.N. *Melbourne.*

Direct Election to Associate Member

BABB, Alfred Thomas Symonds, B.Sc.(Hons.). *Wembley.*
BARLOW, Michael William Salanson, M.A. *Great Baddow.*
BRASH, Robert Alexander, B.Sc. *Gerrards Cross.*
DUNCAN, Sydney Spencer. *Welwyn Garden City.*
HICKS, Thomas Partridge. *Egham.*
KEMP, Sqdn. Ldr. Edward William Wynn, R.A.F. *Malvern.*
LYNCH, Commander Hugh James Alexander, R.N. *London, W.13.*
OVENS, Ralph Clifford, B.Sc. *Johnsonville, New Zealand.*
PYE, Wg. Cdr. Alexander Edward George, R.A.F. *Chigwell.*
RAJU, T. A., M.Sc. *Madras.*
ROSNER, Paul. *Kiryath-Yam, Israel.*
SHANNON, Robert Edward, B.Sc.(Hons.). *Hemel Hempstead.*
SPRIGGS, Thomas Frank. *Iver.*
STEARNS, Major Terence Kenneth, R.E.M.E. *Piddington, Oxfordshire.*

Transfer from Associate to Associate Member

HALVORSEN, Hedge Sigurd. *Fredrikstad, Norway.*
ORSBORNE, Charles Lawrence. *Christchurch, Hants.*
RAYMOND, Anthony Miles. *Slough.*
WATKINS, Allan. *Wolverhampton.*
WIGNEY, Lieut. Com. Peter Greig, R.N. *Fareham.*

Transfer from Graduate to Associate Member

ADAMS, Hubert Charles Barton. *London, N.14.*
ARMITAGE, Norman. *Hatfield.*
BRIDGER, Sqdn. Ldr. Alwyn Richard, R.A.F. *London, W.4.*
CHAPMAN, Roy Kenneth. *Canterbury.*
CONLON, James. *Southall.*
CUNDY-BORGE, Roy. *Plymouth.*
LAND, Lieut. Leonard Ernest, B.Sc., R.N. *London, S.W.1.*
McILROY, Flt. Lt. William Alexander, R.A.F. *Henlow.*
MILNE, James. *Hamilton, Ontario.*
MORRIS, Gordon William. *Penarth.*
MOTHERSOLE, Peter Leonard. *Harley.*
MUTTIAH, Eliathamby. *Colombo.*
PANTON, Victor Alphonso. *Kingston, Jamaica.*
PARK, Alexander. *Woking.*
POWELL, John, B.Sc. *Woking.*
SIMMONS, Henry Robert William. *London, W.4.*
TOLL, John Walker. *Hitchin.*

Transfer from Student to Associate Member

ANAND, Captain Tejinder Singh, Corps of Signals. *New Delhi.*
SMITH, John Douglas, B.Sc. *Bournemouth.*

Direct Election to Associate

ELLIOTT, Flg. Off. Peter Muir, R.A.F. *Dundee.*
KING, Gordon John. *Kidlington, Oxford.*
MULGREW, Peter David. *Lower Hutt, New Zealand.*
PORTANIER, Joseph Anthony William. *London, S.W.8.*
REYNOLDS, John Alexander. *Cardiff.*
STAINTON, Donald. *Coventry.*

Transfer from Student to Associate

JAMES, William. *Tollerton, Notts.*
MASON, Eric Boyle. *New Jersey, U.S.A.*
RUBENSTEIN, Gerald. *Wembley.*

Direct Election to Graduate

ALMANDIL, Barak, L.C.D. *London, N.16.*
BARBER, Flt. Lt. Kenneth, R.A.F. *Bebington, Cheshire.*
BRADNAM, Ronald Hastings. *Bexhill-on-Sea.*
CURRAN, Arthur Joseph. *Montreal.*
DOWSON, Frederick Henry. *London, N.13.*
ELTON, Sub-Lieut. Michael John, R.N. *London, E.4.*
FOSTER, Alan George Lindup. *London, W.14.*
GRUNDY, Gerald Francis Nicholls. *Norwich.*
JACKSON, Peter, B.Sc.(Hons.) *Gillingham.*
MANDL, Vladimir. *Milan.*
MORWOOD, James Watt, B.Sc. *Stoke-on-Trent.*
MUKUTMONI, Plt. Off. Manas, M.Sc., I.A.F. *West Bengal.*
MURPHY, Patrick Emmett. *London, S.W.15.*
PAO, Joseph Yee-Ching, Dip.El. *Sidcup.*
PATTEN, Roy. *London, S.W.20.*
URBAN, Charles Edward. *London, N.6.*

Transfer from Student to Graduate

ACHUTHAN, Madras Gopalan. *Madras.*
ASLAND, Greggar. *Bergen, Norway.*
BRACE, William James. *Newport, Mon.*
CHANNING, Ronald Francis. *London, N.W.3.*
DHALL, Raj Kumar. *Ambala.*
DOBBIN, Robert George. *London, S.W.16.*
FRANCIS, Keith Donald. *London, S.W.11.*
GOGATE, Bhalchandra Damodar. *Gurgaon.*
HADJIDEMETRIOU, Demetrious. *Athens.*
NARENDRANATHAN, Ponnudurai, B.Sc. *Wellawatte, Ceylon.*
ONN, Peter. *London, W.5.*
SMITH, Charles Edward. *London, N.W.10.*
STICKLER, Gordon Alan. *Newport, Mon.*
ZAIKOS, Demetrius. *Athens.*

STUDENTSHIP REGISTRATIONS

AHMAD, Ghulam. *Lahore.*
ANANDA, Surapur L.V., B.Sc. *Bangalore.*
BLACK, John Alexander Webster. *Bexleyheath.*
BLAKE, Frank George. *Dagenham.*
CHATTERJEE, Jatindra Mohan, B.A. *Kanpur.*
CORBEN, Clifford Bernard. *Portsmouth.*
DUTHIE, John. *Luqa, Malta.*
EVANS, Ronald Brian. *Poynton, Cheshire.*
FINN, Peter Miles. *Woldingham.*
FLORIDES Linos Petrou. *Athens.*
GOVINDARAJULU, R. G., B.A. *Madurai.*
HOWES, Bentley Arthur. *Thornton Heath.*
HOWKINS, William Edward. *Kings Lynn.*
JAFFAR, Malik Ghulam. *Lahore.*
LEWCOCK, John Alfred. *Johannesburg.*
LUFF, William. *Boreham Wood.*
MYNETT, Anthony John. *Grimsby.*
NEIL, Flt. Lt. James Bruce, R.A.F. *Marham.*
PARROTT, Edward James. *London, S.E.15.*
PRIOR, Keith Edwin. *Lowestoft.*
SARMA, Garrimella S. S., B.Sc. *Madras.*
SCHOFIELD, Keith. *Edinburgh.*
SIDAWAY, Derek. *Dudley.*
SNOW, J. W. *Coventry.*
VAN RENSBURG, Christoffel Raymond. *Johannesburg.*

THE RADIO TRADES EXAMINATION BOARD

Chairman's Report for the year ended 31st August, 1956

This report is published for the interest of members in view of the active work of the Institution in the formation and operation of the Board.

INCLUDING the year under review, the total entries for the examinations conducted by the Board since 1944 reached 4,221. This figure is the most significant indication of the work done by the Board in serving the radio industry and in providing active co-operation between industry, technical colleges and recruits to trade and industry.

The Memorandum of Association of the Board dated 30th December, 1955 (Incorporation Certificate No. 559393) expresses in legal terms the objects for which the Board was originally formed in 1942. The country was then at war and the shortage of technical manpower in all branches of the radio industry emphasized the need for more technical colleges offering courses of study in radio, especially at the craftsman and technician level.

Much attention was then being given to the question of post-war employment and in our own field this meant the civilian employment of the very large number of men absorbed in the Services on radio and radar work. The three Services were, therefore, particularly interested in the work which had been started by the Board. The co-operation which has existed between the Board and the three Services over the last 14 years has been of tremendous value—especially in providing a suitable civilian qualification for men who have been employed on radio and allied work during their Service lives.

Procurement of incorporation under Section 19 (1) of the 1948 Companies Act was the result of a great deal of work undertaken by the secretaries of the constituent associations, which still remain as:—

The British Institution of Radio Engineers.
The Radio Industry Council.
The Radio and Television Retailers' Association (R.T.R.A.) Limited.
The Scottish Radio Retailers' Association.

The principal object for which the Board is established and incorporated is:—

> "The promotion of a high standard of skill and efficiency in the technique and work of persons employed or otherwise engaged as radio mechanics, technicians and tradesmen in the radio and allied trades."

The analysis of examination results, appended, shows how well the Board has succeeded in procuring a high standard of skill and efficiency. From the pre-war state of there being several local examinations in radio service work, the Board has progressed to the stage of having attracted during the last year no less than 822 applications to enter for the Radio Servicing Certificate Examination and a further 138 for the Television Servicing Certificate Examination. In addition to the written examinations which are compulsory in both cases, each one of the 960 candidates took a practical test on an actual radio or television receiver chassis. These practical examinations were held at 38 centres in Great Britain.

Entry for the Television Servicing Certificate Examination is not permitted unless a candidate has previously succeeded in the Radio Servicing Certificate Examination. In the early years, it was not possible, for obvious reasons, to hold a Television Servicing Certificate Examination throughout Great Britain, and until 1954 the examination was largely limited to the London area. With the extension of television services, however, it is anticipated that there will be a steady increase in the number of candidates; already there are 1,636 who have passed the Radio Servicing Certificate Examination. These are eligible for admission to the Television Servicing Certificate Examination and in fact 342 have already secured the Television Servicing Certificate.

The continual increase in the number of candidates throws an ever-increasing burden on the Examinations Committee of the Board. The results are considered by a Moderating Committee set up between the Board and the City and Guilds of London Institute—the latter body having the prime responsibility for conducting the written examination.

The Radio Industry Council, one of the founders of the Board, has given every co-operation in securing the necessary number of chassis. Indeed, the Board's work would be severely handicapped if it were not for the ready co-operation of manufacturers who loan receivers on which the practical tests are carried out.

Much attention has been given to ways and means of economizing in the number of receivers required; it has meant staggering the attendance of candidates for the practical examination and the increased employment of examiners in re-setting faults in receivers.

Extension of the Board's Activities—Having established a sound basis for the training of craftsmen and technicians, the Board has under consideration the desirability of extending its work into fields other than domestic radio and television as, for example, in the growing field of electronic application.

In the main, the work of such technicians will be on the maintenance of user's equipment. For the present, however, it should be made clear that the Board does not wish to see any duplication of efforts which are already being made to stimulate technical efficiency in the maintenance and repair of electronic equipment. During 1957, the City and Guilds of London Institute will be conducting for the first time an examination for electronic technicians where the study of electronics is part of a four-year part-time course for electricians. This examination will not, of course, include a practical test but the required training does involve some practical work.

These various examinations also show that the field of employment for mechanics and technicians in radio and electronics is steadily increasing. It may well be thought the Radio Servicing Certificate Examination conducted by the Board is a necessary basis for most, if not all, of present and future examinations of this character, and the Board will bear all these developments in mind before recommending any steps for the establishment of additional technician examinations.

A Membership Association—Suggestions have been made that the Board might encourage the formation of an Association to which successful candidates might belong. The obvious advantages are to provide, if required, a means of introducing candidates to prospective employers and to arrange meetings to enable holders of certificates to keep abreast of new techniques in servicing and maintenance.

Such an Association would require central organizations which the Board cannot, at present, provide. Nevertheless, the idea has many commendable features and the possibilities are still being examined by the Board.

Acknowledgments—In this first report since the incorporation of the Board, opportunity is taken to thank all those who have assisted in achievement of the Board's objects.

The happy arrangements which exist between ourselves and the City and Guilds of London Institute have made it possible to establish nationally recognized schemes of training courses and examinations. Particular comment must be made on the co-operative work which resulted in the compilation of a teachers' syllabus—a most valuable contribution in promoting sound training schemes.

The technical colleges also deserve our thanks for the way in which they have co-operated with us as well as the City and Guilds of London Institute, in introducing courses for our examinations and providing facilities for the holding of the examinations.

We also express thanks to the very many individuals who serve on Committees of the Board and on the joint Committees of the Board and the City and Guilds of London Institute and to those who are especially responsible for providing examination papers and the schemes and for acting as examiners.

We continue to remember that the Board's activities could not in any way be continued if it were not for the generous subsidy contributed in equal part by the Radio Industry Council, the British Institution of Radio Engineers and the Radio Retailers' Associations.

Finally, the Board wish to record sincere regret that illness has prevented Mr. R. P. Browne, Secretary of the Radio Industry

Council, from taking such an active part in the Board's affairs during the past twelve months. Mr. Browne was an original member of the Board and has at one time or another served on all the Committees of the Board and the relevant Committees of the City and Guilds of London Institute. In recording our appreciation for all that he has done for us, we express the sincere hope that he will soon make a return to more normal health.

Appendix: Analysis of Examination Results

Table 1

Radio Servicing Certificate Examination

Year	Entered	Sat	Passed	In one Sitting	Having been Referred	Referred	Failed	% Pass
1944	55	42	19	19	—	7	17	45
1945	61	58	28	24	4	12	18	48
1946	74	68	44	38	6	6	18	65
1947*	69	65	44	41	3	2	19	69
1948	108	96	65	62	3	15	16	68
1949	167	153	96	89	7	24	33	63
1950†	264	255	137	122	15	45	73	54
1951	396	292	196	177	19	46	50	67
1952	314	302	152	133	19	69	81	50
1953	323	309	126	96	30	87	96	41
1954	378	370	144	116	28	96	130	39
1955	533	523	263	213	50	167	93	50
1956	822	802	322	261	61	185	295	40
Totals	3,474	3,335	1,636	1,391	245	761	938	49

Table 2

Television Servicing Certificate Examination

Year	Entered	Sat	Passed	In one Sitting	Having been Referred	Referred	Failed	% Pass
1950	30	30	16	16	—	12	2	53
1951	306	292	196	19	6	16	16	33
1952	135	131	66	57	9	43	22	50
1953	140	135	64	40	24	36	35	47
1954	107	104	55	36	19	20	29	53
1955	113	110	56	43	13	12	42	51
1956	138	134	60	54	6	51	23	45
Totals	747	722	342	308	90	212	211	47

* First Examination held jointly with the City and Guilds of London Institute

† First Television Servicing Certificate held.

THE 1957 PHYSICAL SOCIETY EXHIBITION

GOVERNMENT research bodies were well represented at this year's exhibition. A universal missing pulse ratio meter developed by the Radar Research Establishment measures the extent to which a radar transmitter produces pulses deficient in amplitude or duration due to disturbances, for instance in the magnetron oscillator. It counts as missing any r.f. pulse whose energy in a given frequency band is more than $2 \pm 0{\cdot}2$ db below a level representative of the preceding normal pulses occupying within a period adjustable from 0·1 to 3 seconds. The number of missing pulses is totalled over an interval of either 1 or 5 minutes $\pm 2\%$. The instrument can be used at any p.r.f. between 100 and 10,000 pulses/sec and can also measure the p.r.f. with an accuracy of $\pm \frac{1}{2}\%$. The missing pulses are counted by means of dekatron counter tubes.

The Signals Research and Development Establishment demonstrated a sound spectrograph for the production of frequency/time analyses of speech, etc. Recorded sound samples are repeatedly played back through a band-pass filter whose centre frequency is varied automatically over the range under examination. This is done by modulating the speech signal on a carrier whose frequency is varied step by step. The presentation is on Teledeltos paper and by obtaining differential spectrograms the spectral maxima can be accurately located.

The Aeronautical Inspection Directorate showed a series of exhibits for precision power and voltage measurement. These included the coaxial crystal milliwattmeter for the frequency range of 100 kc/s to 10,000 Mc/s and power levels from 0·2 mW to 0·632 mW; a pair of silicon diodes in a voltage doubler circuit measure the voltage across a load resistor having frequency independent characteristics. A wide-band coaxial compensating network eliminates the effect of crystal capacitance on input impedance and by making allowance for crystal conductance on input, v.s.w.r. greater than 0·995 is achieved up to several hundred Mc/s. The crystals are operated under square law conditions so that the d.c. output is directly proportional to the r.f. load power.

High speed oscillograph techniques formed a large part of the exhibition by the Atomic Weapons Research Establishment and these included time expansion by means of an image storage tube and in another instrument by means of radial deflection of a spiral trace. In an ultra-high-speed oscillograph using a coaxial line deflection system to reduce input capacitance and transit time effects, the signal propagation velocity of the coaxial line is arranged to equal that of the c.r.t. electron beam. The sensitivity is approximately one volt per spot width.

A large number of circuits and complete instruments were shown which utilized transistors. Mullard showed an analogue-to-digital converter consisting of eight digit units operating in conjunction with a comparator amplifier and timing pulse generator. Another demonstration showed the use of transistors to drive a magnetic matrix store and to amplify its output.

A recent variation on the magnetic matrix using small toroids has been the "magnetic cell" formed by drilling a hole in a ferrite block of material having a rectangular hysteresis loop. Standard Telephone and Cables showed the applications of magnetic cell storage to an error-indicating system for use in the transmission of five-unit codes. The code is modified to transmit an additional or check unit indicating whether the number of marks (or spaces) in a character should be even or odd. The five-code units are stored at the receiver end and the net result compared with the check unit.

At the 1956 exhibition Elliott Brothers showed an aerial plotter which recorded amplitude and phase. The electronic techniques of this device in which a signal generated by a klystron is compared with a frequency differing from it by 220 c/s have been adapted to provide an instrument which displays complex impedance continuously on a cathode-ray tube. The equipment has been developed for the examination of microwave components in the 8·3 mm and 3·2 cm bands. The electronics and display units for the two bands are identical and only the r.f. unit is changed. Great savings of time are claimed compared with non-automatic methods.

. . . Radio Engineering Overseas

A selection of abstracts from European and Commonwealth journals received in the Library of the Institution. All papers are in the language of the country of origin of the journal unless otherwise stated. The Institution regrets that translations cannot be supplied.

621.315.592.9

Measurement of the Gauss effect of various semiconductors for 10,300 and 600 Mc/s. P. RAMER, M. J. O. STRUTT and F. K. VON WILLISEN, *Archiv der Elektrischen Ubertragung*, **11**, pp. 1-7, January 1957.

A review of the existing theoretical results concerning the frequency dependence of the galvanomagnetic effects shows that the assumptions on which the corresponding formulas are based unfortunately do not all hold for the semiconductor materials employed. These formulae thus cannot give any useful information on frequency dependence. Measurements on six semiconductor pellets (two of indium-arsenide, three of indium-antimonide, and one of germanium) revealed that, with respect to the reference values at zero frequency, the galvanomagnetic effects decrease at 10 Mc/s slightly, at 300 and 600 Mc/s, however, very distinctly. The measuring methods and error limits are discussed.

621.316.7

Synthesis and design of feedback control systems. W. FINDEISEN. *Rozprawy Elektrotechniczne* (*Warsaw*), **11**, pp. 420-470, 1956.

The paper presents in a uniform and synthetic way some recent methods of synthesis and design of feedback control systems, i.e. regulating systems and servomechanisms. The paper is concerned only with linear systems working continuously. Various quality criteria and methods of system design based on differential equations or transient response are discussed as well as methods based on frequency response. Matters connected with stochastic processes are not included in the paper.

621.317:621.396.673

The measurement of the efficiency of short unsymmetrical metre-wave antennas. M. LOHR. *Nachrichtentechnische Zeitschrift*, **10**, pp. 120-124, March 1957.

A method for determining the efficiency of short unsymmetrical metre-wave antennas is described. The method used for the measurement only involves simple impedance measurements for which a total accuracy of 2 per cent. can be obtained. The determination of the efficiency is explained by means of examples.

621.317.75

Oscillators unaffected by load impedance. E. FRISCH and W. HERZOG. *Nachrichtentechnische Zeitschrift*, **10**, pp. 35-38, January 1957.

Oscillator circuits whose frequency is not affected by load impedances are investigated. Circuits not using transformers, and with grounded cathodes as well as grounded loads are mentioned. The frequency pulling is smaller than 0·1 per cent. for any capacitive, inductive or resistive loading on the oscillator.

621.317.75

Distortion-free reproduction of waveforms with a large bandwidth by means of display units with a small bandwidth—Bandwidth compression. H. RIEDLE. *Nachrichtentechnische Zeitschrift*, **10**, pp. 135-140, March 1957.

The paper describes a unit which is able to display, with practically no distortion, periodic waveforms of pulses with a frequency spectrum of up to 200 Mc/s by means of a simple oscilloscope after frequency compression. After frequency compression the waveform has a frequency spectrum of up to approximately 20 kc/s. The device for frequency compression has been developed as a converter to be used at the input end of simple commercial oscilloscopes.

621.372.2.09

Wave propagation in the disc line. G. PIEFKE. *Archiv der Elektrischen Ubertragung*, **11**, pp. 49-59, February 1957.

The propagation of electromagnetic waves in a disc line is investigated theoretically. A disc line is a stack of round copper discs, perforated at their centres and insulated from each other. This insulating dielectric is very lossy so that any modes travelling between the discs in a radial direction suffer strong attenuation and accordingly no field exists outside the line. The thickness of the copper discs plus dielectric is much smaller than the line wavelength. A hypothetical dielectric constant and permeability are assumed for the insulated copper discs, and represented by tensors. A formula is given for calculating the propagation constants of all possible modes.

621.375.4:681.84.081.48

A transistor pre-amplifier for the magnetodynamic pick-up. G. HUBER and J. RODRIGUES DE MIRANDA. *Philips Technical Review*, **18**, No. 8, pp. 238-242, February 1957.

Describes a pre-amplifier designed for coupling a magnetodynamic pick-up to a normal radio. Its purpose is to amplify the signal voltage to an adequate level (max. 2·5 V r.m.s.) and at the same time to provide a frequency characteristic conforming to the "New Orthophonic" cutting characteristic of gramophone records. The necessary amplification is obtained with one OC 73 transistor with common emitter connection. A thermistor is incorporated to stabilize the working point at differing ambient temperatures (10 to 45° C). The power unit contains a transformer, a germanium diode OA 81 and a smoothing filter. The pre-amplifier proper, together with supply unit, is mounted in a box about 3½″ × 3″ × 2″.

621.385:621.316.54.064

Counters and control circuits with coincidence thyratrons. L. HARTMUTH. *Nachrichtentechnische Zeitschrift*, **10**, pp. 141-144, March 1957.

Coincidence thyratrons of the type ST80T may be used for all types of control circuits as well as for switching operations of up to 50 kc/s. The maximum values for mean anode current, peak anode current and loading factor must not be exceeded in order to attain a mean life-time of 10,000 hours. The loading factor can easily be calculated from the operating values.

621.385.032.213.13:669.27.426

Thin tungsten wire for small radio valves. L. Schultink and P. G. van Zanten. *Philips Technical Review,* **18,** No. 8, pp. 222-228, February 1957.

Filaments for electronic valves were initially made of tungsten. Later this material was superseded by nickel, but in the sub-miniature valves developed in the last two decades tungsten has been reinstated as filament material. The reason for this is the greater tensile strength of this material, thanks to which the filament can be made thinner, whilst a far smaller filament current will suffice. The most commonly employed method for making very thin wire is the electrolytic etching of thicker wire. The principal requirements are high tensile strength and low creep. The wire is coated with a layer of alkaline earth carbonates. The principal method of coating is by means of electrophoresis. During pumping of the valve, prior to sealing, the carbonates are decomposed into oxides by heating the filament. For very thin filament wires the ratio of the diameter of the coated wire to that of the bare core is fairly high. Owing to the difference in temperature thus caused between core and surface, such cathodes will retain their activity far longer.

621.385.1.181.4:621.396.694

Problems in the construction of small radio valves. B. A. Cant. *Philips Technical Review,* **18,** No. 8, pp. 217-222, February 1957.

For the smallest types of so-called sub-miniature valves the old pinch-construction, long since abandoned in the manufacture of normal radio valves, was first employed. More recently sub-miniature valves have been successfully made using a pinch-less construction. For the filaments and grids of these valves extremely thin wires are used. The filament is made of tungsten instead of nickel, which results in a reduction in filament current. By making the electrode system short and by using high-quality springs for stretching the filament, the resonant frequency of the filament can be raised, which gives a decrease in valve microphony.

621.385.213

Dynamic properties of tungsten cathodes. W. Ruppel and H. Seifert. *Nachrichtentechnische Zeitschrift,* **10,** pp. 115-119, March 1957.

Directly heated diodes are considered as low frequency amplifiers for the fluctuations of filament current. The relationship between slope, time-constant and life-time on the one side, and diameter of filament and operating temperature on the other side, have been investigated and the theoretical response curves proved quantitatively by measurements on test valves.

621.395.623.7

A loudspeaker installation for high-fidelity reproduction in the home. G. J. Bleeksma and J. J. Schurink. *Philips Technical Review,* **18,** pp. 304-315, March 1957.

A loudspeaker installation is described comprising a corner cabinet with two bass-note loudspeakers, two separate boxes for the higher frequencies, each containing a double-cone loudspeaker, and filters for splitting up the audio spectrum into two ranges, one below and one above 420 c/s. By appropriately positioning the high-note loudspeakers good diffusion of the sound can be achieved. The so-called hole-in-the-wall effect, which is a drawback of reproduction by a single loudspeaker, is thus eliminated.

621.396.663

Possible applications for goniometers in telecommunications. H. Fricke. *Nachrichtentechnische Zeitschrift,* **10,** pp. 65-73, February 1957.

Goniometers, which have so far been used for the determinations of incident azimuthal angles for electro-magnetic waves, are universal circuit elements in telecommunication engineering. New possibilities for their application exist in radiolocation as well as in other fields.

621.396.67

Problems of antenna pattern synthesis. S. Porgorzelski. *Rozprawy Elektrotechniczne (Warsaw),* **11,** pp. 351-371, 1956.

The problems of antenna pattern synthesis is formulated. Three aspects are discerned: the synthesis of current distribution, the synthesis of the field in an aperture and the pattern transformation. Examples which solve these problems are discussed as follows:

1. The evaluation of the current distribution in the linear antenna which ensures the realization of the given pattern.
2. The evaluation of the field in the aperture cut out in a plane perfectly conducting surface with the given pattern of the aperture.
3. The evaluation of the cross-section of the cylindrical reflector with a perfectly conducting surface.

621.396.677

The gain of a directional short-wave receiving antenna with back-scatter. B. Beckmann and K. Vogt. *Nachrichtentechnische Zeitschrift,* **10,** pp. 90-91, February 1957.

Gain measurements at directional receiving aerials by means of long distance reception in the presence of back-scattering have led to the conclusion that back-scattered radiation is essentially coherent.

621.396.677.75

The shape of dielectric antennas. G. v. Trenntini. *Nachrichtentechnische Zeitschrift,* **10,** pp. 60-64, February, 1957.

The radiation properties of various types of dielectric antennas are investigated by means of experiments. Rods with steps in the dimensions of their cross-sections have produced similar results as those of the usual design in the form of tapered rods with equal length. Plates of suitable dimensions exhibit a stronger beam concentration in one plane and composite systems such as parallel or crossing plates, horns, horns with tubular extensions and variations thereof have a higher gain than concentrically concentrated beams.

621.396.812.5

Forward-scatter observations at 50 Mc/s. K. Bibl, H. A. Hess and K. Rawer. *Archiv der Elektrischen Ubertragung,* **11,** pp. 59-62, February 1957.

Field strength measurements and recordings on v.h.f. scatter propagations at 51·3 Mc/s were performed with a 10-kW c.w. transmitter and a special receiver of 70 c/s bandwidth over two different distances, one of about 500 km, the other of 1000 km. The medium propagation loss (compared with free-space propagation) ranged between 90 and 100 db in either case; short bursts of field strength were caused by meteor trails.