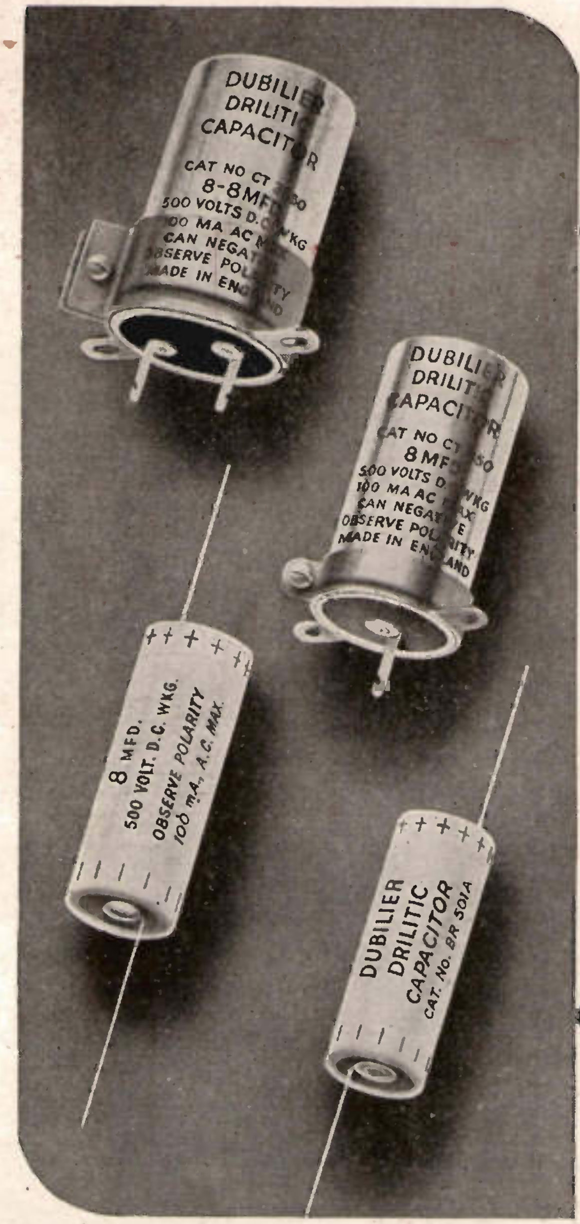
Harry Sutcliffe

Electronic Engineering

INCORPORATING ELECTRONICS, TELEVISION AND SHORT WAVE WORLD

PRINCIPAL CONTENTS

2/- MAY, 1946



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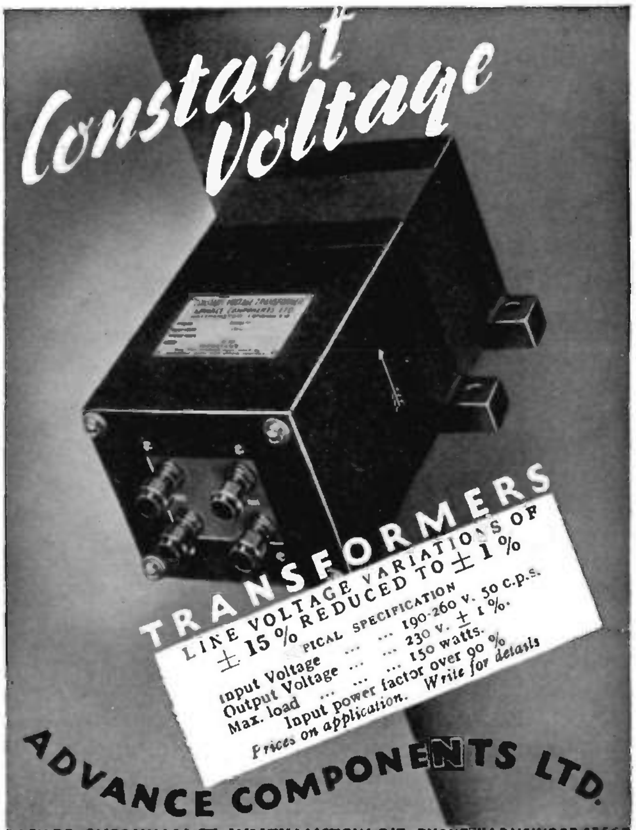

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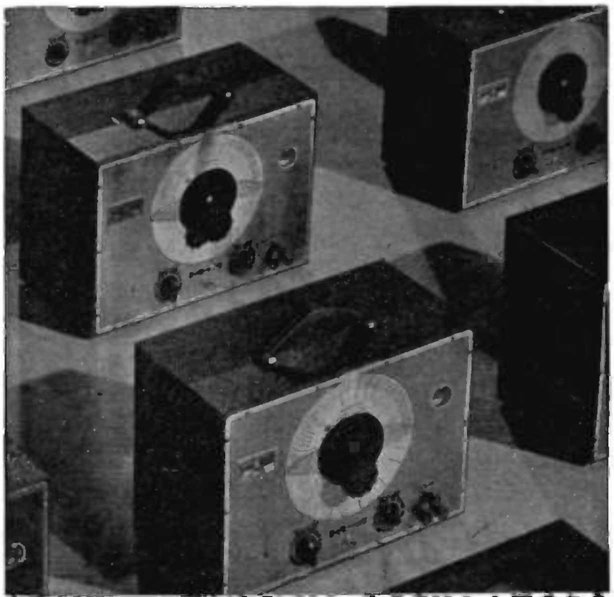

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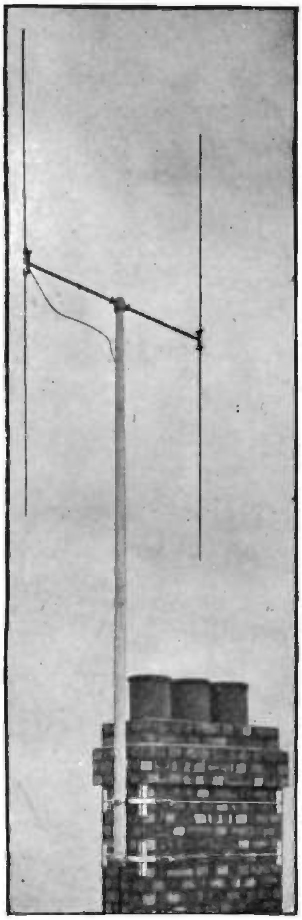
TELEVISION AERIAL 'QUIZ'

Answers to some of the questions we are continually receiving by letter and 'phone



Q.1. *What are the advantages obtained when using a reflector with a dipole?*

A. (*a*) It is necessary in areas of weak field strength to increase the signal input to the receiver.

(*b*) The directional properties can be utilised as a means of minimising interference, particularly so, if the aerial can be installed in such a position that the location of the source of interference is placed behind the reflector in relation to the transmitter.

(c) By rotating the aerial, ghost image can be reduced or eliminated.

Q.2. *What type of feeder should be used with a dipole T.V. aerial?*

A. T.V. Receiver designers still fall into three schools of thought:

(1) Coaxial feeder which needs complicated matching and balancing at the dipole end for best results and minimum interference.

(2) Unscreened twin which is the cheapest but needs a carefully balanced input circuit in the receiver for optimum results and does not provide a screened input to stabilise a super-sensitive receiver.

(3) Screened twin which gives the advantages of both but is a trifle dearer than coaxial.

If the receiver manufacturer makes a strong recommendation for his set it should be adhered to, but otherwise in most localities the cheapest—*i.e.*, the twin unscreened feeder of 70 to 80 ohms impendance, will give no apparent loss even when connected to a coaxial input.

Q.3. *Is it advantageous always to erect the aerial on the highest possible point of the building?*

A. No, not always; sometimes a building can be used to screen against interference.

Q.4. *Does water at the centre of a T.V. dipole affect reception?*

A. No, as this will only produce a parallel resistance across the dipole terminals of several thousand ohms. As an example we may assume that the parallel resistance is 10,000 ohms at 45 Mc/s across a dipole of approximately 70 ohms radiation resistance. From the formula of resistances in parallel:

$$RT = \frac{R1 \times R2}{R1 + R2} = \frac{10000 \times 70}{10000 + 70} = \frac{700000}{10,070} = 69.51 \text{ ohms}$$

It can thus be seen that the reduction in signal is less than 1 per cent. and can be neglected.

. . . . TO BE CONTINUED

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Credits

THE true scientific spirit is recognised by its willingness to assign credit to a colleague for an original discovery or for a piece of prior work, and conversely, to imply a claim to originality by omitting reference to previous workers is looked on with distaste in research circles. It is probable (or it is charitable to assume so) that many omissions occur through oversight, and when they are pointed out the author is usually grateful for the opportunity to make amends. The writer of these notes was guilty of a breach of scientific good taste of this nature some years ago, and although the fault was remedied the memory remains.

It was this memory which prompted the remark on the omission of Dr. A. H. Rosenthal's* name in connexion with the Skiatron in last month's "Convention Comment," and the authors of the paper referred to (Messrs. P. G. R. King and J. F. Gittins) are justifiably annoyed at the implied slur on their scientific accuracy and honesty. There were, in fact, two 'papers' on the Skiatron, one a written paper and the other a "lecturette" summarising the written paper, both read before the I.E.E. Radiolocation Convention. The proof on which the comment was made was that of the lecturette and not that of written paper, and while it is true that the proof made no reference to Dr. Rosenthal by name, full acknowledgment of his work was made by the authors in the original MS and at the meeting. It will, of course, appear in the published I.E.E. paper. So they deserve a retraction which is in as prominent a place as the original criticism.

A second acknowledgment and apology is prompted by a letter from the President of the Council of the Society of Polish Engineers in relation to the article on Land Mine Locators which appeared in the March issue. A paragraph runs:

> "We feel that the article might have pointed out that the original development work and the design of the first of the models in question was done by our member Captain J. S. Kosacki of the Polish Sappers. . . . Capt. Kosacki's model was adopted and became officially known as the Mine Detector, Polish Type. This type was used in large quantities at Alamein, Tunisia, Italy and elsewhere."

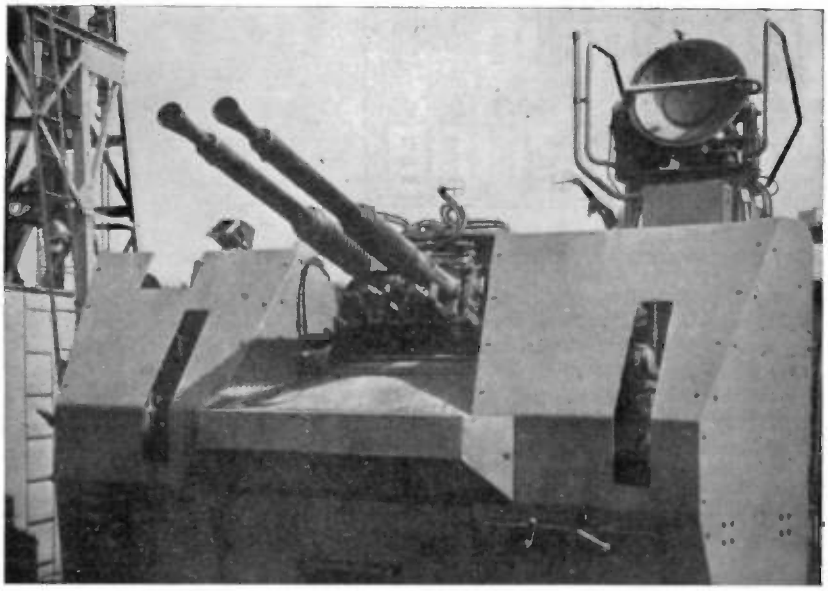
Those who had practical experience of the Model I Mine Locator will be pleased to learn the name of the officer responsible for its development, and will endorse our tribute to this example of allied co-operation.

Finally, we may anticipate a misplacement of credit in future by noting the following letter from Mr. M. G. SCROGGIE :

> "A circuit device that ranks with the cathode follower among the most valuable of recent years is that called the Miller integrator. I suggest that this name is inappropriate and misleading, as although the circuit is related in principle to the Miller effect it is actually due to the late MR. A. D. BLUMLEIN. It would be some small recognition of the many contributions of MR. BLUMLEIN to circuit technique if this circuit were renamed the BLUMLEIN integrator. As the present name has not yet been given much publicity it should not be too late to make the change, which I therefore strongly recommend for your consideration."

We in turn recommend it for the consideration of all readers of this note who are aware of the value of Mr. Blumlein's work in the war effort and remember the unfortunate way in which this work was cut short.

* Worse, by a typographical error, Dr. A. H. Rosenthal of Scophony was confused with Dr. E. Rosenthal, the ceramic expert !



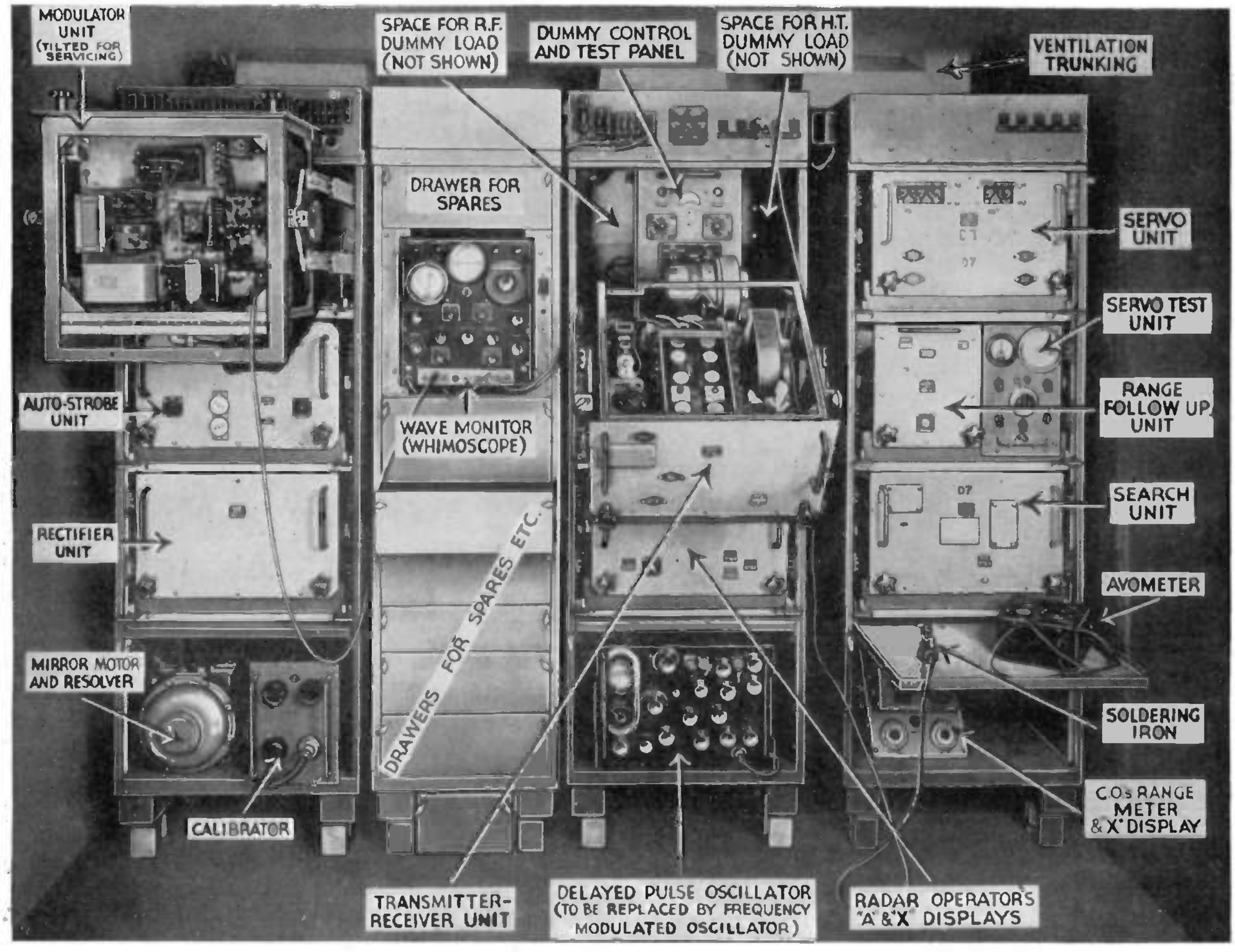
The Autofollower

The naval-fire-control radar equipment shown below was demonstrated at the final session of the Radiolocation Convention. It was developed to provide blind fire with the twin Bofors gun mounting shown on the left.

When a button was pressed the aerial immediately began to search the sky. Within a few seconds it located the target, locked on and from then followed the target, automatically.

The illustration shows the equipment as fitted in test racks in the radio maintenance room. (*Admiralty photograph*).

The apparatus is described in a paper by J. F. Coales, H. C. Calpine and D. S. Watson, of the Admiralty Signal Establishment.



Electronic Flash Tubes

In High-Speed Photography of Explosions

By D. A. SENIOR, B.A.*

This article, slightly condensed from a communication issued by the R.P.L.O., News Division, illustrates one of the many ways in which electronic devices have contributed to the solution of special war problems.

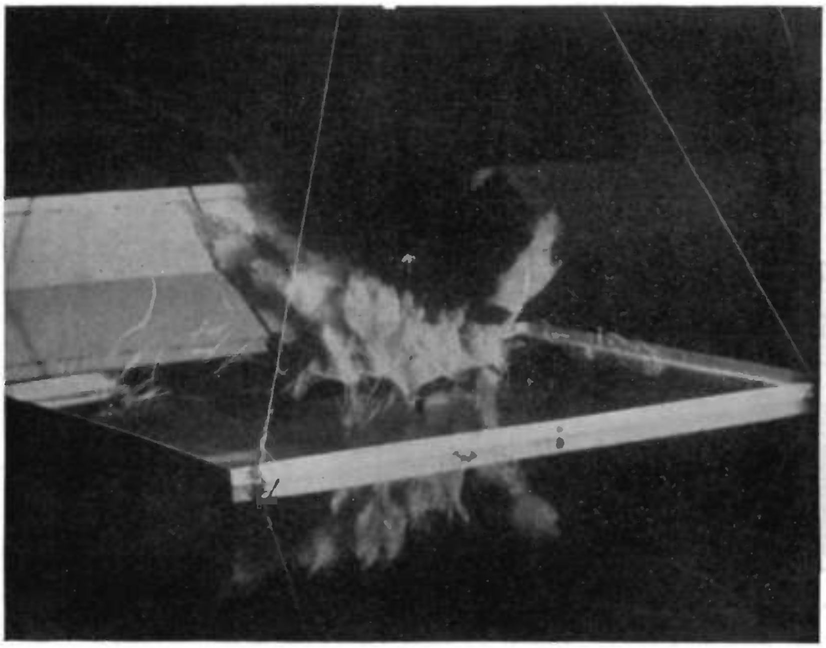


Fig. 2. Rupture of a steel plate on the surface of the water by underwater charge.

DURING the last hundred years there has been a steady increase in the use of submerged explosive charges in the form of mines, and, later, torpedoes and other weapons. Consequently increasing efforts have been made to bring to light the nature of the phenomena involved when explosions take place under water and thus to obtain a better insight into the processes whereby damage is caused. One of the principal difficulties which investigators have had to face is the speed with which explosive phenomena occur, and for this reason the assistance which has been made available by recent advances in high-speed photographic technique has been very welcome. The application of this technique to underwater explosion research dates back little if at all before 1941, but it has facilitated the solution of a number of problems when other available methods would have proved costly, tedious, or impossible.

Two methods of high-speed photography are available. In one, the subject is illuminated continuously and exposure regulated by means of various types of high-speed shutter. This method has been developed to give high-speed cine-cameras operating at speeds up to 8,000 frames per second. In the other, the film is exposed continuously and it is the illumination which is regulated. By means of intense flashes of short duration, good photographs of exposure time less than 5 microseconds can be taken either singly or at speeds up to 1,500 per second.

The flash method is essentially a development of the well-known technique of spark photography which has been in use for many years.

Gaseous Discharge Tube—Single Flash Technique

The required illumination can be obtained without serious increase in the duration of the exposure by the use of the gaseous discharge tube. A condenser is discharged, not through an air gap as in spark technique, but between electrodes in a tube filled with a suitable inert gas mixture. The construction of these tubes and the gas filling are such as to give a longer path between electrodes than would be possible at the same voltage with a spark in air. This results in greater light flux for a given energy of discharge, and flashes can be produced of sufficient intensity for really good reflected light photography of objects at distances up to 15 ft. from the discharge tube, without the use of reflectors.

The capacity of the condenser varies from 0.1 to 4 microfarads and its voltage from 2,000 to 20,000 volts. Both condenser and voltage are thus within the range of fairly simple laboratory equipment.

For the production of one flash at a time, charging takes place quite slowly, through a high resistance; discharge takes place extremely rapidly through the discharge tube—or flash tube as it is generally called—which is connected with the minimum of wiring directly across the condenser terminals.

The flash tube is connected in this manner in order to reduce to a minimum the inductance of the discharge path and thereby the duration of the flash. The duration depends upon many other factors, including the gases used in filling the tube and their pressure, the construction and treatment of the electrode system, the size of the condenser and the voltage at which it is charged. A great deal of work has been carried out with the aim of minimising the duration which with the more recent tubes is about 1 or 2 microseconds.

Synchronisation—Thyratron Trigger Circuit

There now remains the question of synchronising the flash with the event. It is, first of all, essential to be able to initiate discharge of the condenser—or "trigger the flash"—reliably and repeatedly. For this purpose either a triggering band external to the tube or an internal electrode may be used. In either case

* Naval Construction Research Establishment.

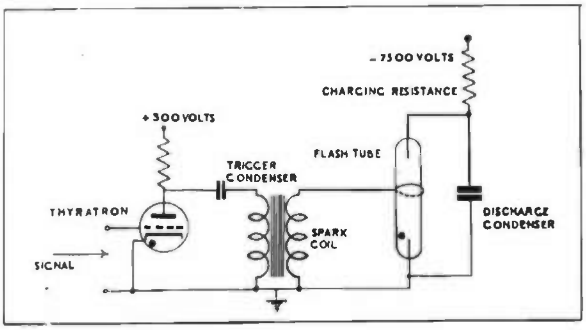


Fig. 1. Circuit of high-intensity flash tube.

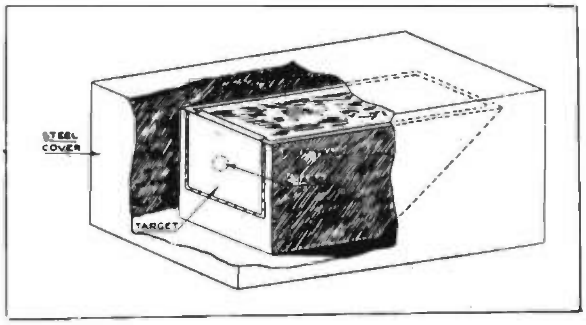


Fig. 3. Model tank for investigating damage to bulkheads.

a voltage—or "signal"—must be generated at the instant when the flash should occur.

The signal, assuming for the time being that one can be obtained, is amplified if necessary, and then applied to the grid of a thyratron valve. This permits the discharge of a small condenser (the trigger condenser) through the primary winding of a spark coil. The secondary winding is connected either as shown in Fig. 1 if an external triggering band is used, or between the starting electrode and one other electrode if the tube is of the three-electrode type. In both cases pilot sparks are produced within the tube. These are followed by the discharge of the main condenser, which produces the flash. With well-designed tubes the interval between the arrival of the signal and the flash is of the order of 5 microseconds and is quite reproducible.

The derivation of the signal from the phenomenon under investigation obviously depends upon the nature of that phenomenon. The closing or opening of an electric circuit produces quite a reliable signal, and this covers most impact problems. Alternatively the generation of a shock wave or sound wave may be used. These may be picked up by means of a microphone or hydrophone, but it must, of course, be remembered that this implies a time delay equal to the time taken for the wave to travel from the source to the microphone. Another method which has been used successfully is the interruption of a beam of ultra-violet light, the signal being given by a photo-electric cell.

Providing that the phenomenon being studied is reproducible and that a signal can be derived representing some "reference event," single-flash photography can be made to cover the remainder of the phenomenon by introducing a known time interval between the signal and the flash. The magnitude of the delay may vary from a few microseconds to several hundred milliseconds, and is generally provided by means of electronic devices, *e.g.*, multivibrator or double thyratron circuits. Thus a set of pictures may be obtained, and the history of the phenomenon pieced together.

Multiple Flashing—Power Stroboscope—High-Speed Camera

Basically the principle is the same as that of the multiple spark; that is, a condenser is repeatedly charged and discharged. Each discharge produces a short-duration flash of light which is utilised to record a photograph upon a strip of moving film.

The Edgerton high-speed camera is of the continuously moving film type. The camera takes 100 ft. of 35-mm. cine-film, which is drawn from one spool to another by a small electric motor, and travels past the lens over a sprocket wheel at governed speeds between 30 and 90 ft. per second.

There is no lens shutter, the spacing of the pictures, or framing, being regulated by timing the flashes of the stroboscopic lamps to occur at equal intervals of film. This is accomplished by means of a commutator which forms an integral part of the sprocket wheel mentioned above.

The mechanism of triggering the flash is essentially the same as that used for single-flash photography, *i.e.*, signals (received from the commutator) operate a thyratron trigger circuit at the appropriate instants.

The interval between the segments of the commutator is so chosen that the frame spacing is the same as that in standard cine-film. The records may therefore be projected at the normal rate (16 frames per second) and the subject "slowed down" 30 to 90 times.

The "power stroboscope" consists of a 2,000-volt power supply together with lamps and trigger circuit. The trigger circuits and lamps work on the same principle as the single-flash equipment described above; certain modifications in the charging and discharging circuits are, however, necessitated by the high rate of flashing (1,000 to 1,500 flashes per second).

Multiple-flash technique has been used on high-speed cine-photography of cavitation phenomena close to yielding structures. While the detail shown in individual photographs is less than that in single-flash photographs, the advantages of recording a sequence of pictures are manifold. Not the least is the fact that the projection of records at normal speed enables a clear qualitative idea of the behaviour of the subject to be gained before analysis is begun.

Single-flash methods have been used at Admiralty Undex Works to study the rupture of steel plates attacked by explosive charges. In one set-up a steel plate was placed upon the water surface, a charge being fitted on the underside of the plate in contact with the centre. The signal from a hydrophone placed 10 ft. from the charge was used to trigger the flash. The resulting photograph (Fig. 2) shows the hole torn in the plate, the white "plume" of water thrown up, and the black cloud of explosion products.

Underwater Protective Systems

The Edgerton power stroboscope and more recently a similar unit built at Admiralty Undex Works have been used in investigation of the mechanism of failure, under explosive load, of the multiple compartment protective system used in some large warships. For the purpose of this investigation a special tank has been constructed, in which an attempt is made to simulate on the model scale the conditions obtaining when a ship is damaged by a contact or near-miss explosion. Targets are built to represent typical ship construction to a scale of one-twelfth, and may consist of one or more bulkheads dependent upon the part of the process of destruction under investigation.

The tank itself, shown diagrammatically in Fig. 3, is constructed from 2-in. armour plate; it is rectangular in section, 6 ft. wide, 5 ft. deep and 11 ft. long at the top, with one vertical and one sloping end. In the vertical end is a rectangular opening 4 ft. 6 in. wide, and 3 ft. 6 in. deep, in which the targets are bolted. The tank is filled with water and explosive charges fired in the water in contact with or at the required distance from the target. Reflexions of the shock wave on to the target are avoided by means of the sloping end mentioned above.

The whole tank is contained within a steel cover which serves both to exclude daylight and confine fragments of such targets as disintegrate.

The water within the tank represents the sea, the space in front of the vertical end of the tank representing the inside of the ship. In this space the camera and associated gear are mounted so as to record the phenomena as seen from inside the ship. Camera, lamps, etc., are suitably protected from the effects of explosive blast and fragments by means of steel covers with armour-plate windows, the lamps being spring mounted.

Silhouette Photography

Depending upon the type of damage being studied, silhouette and reflected light methods have been used. If the bulkhead under observation should rupture, much information may be gained from silhouette photographs.

Here the camera is arranged so as to look at an oblique angle across the target, which is foreshortened into a straight line on the left of the picture. On the side of the target remote from the camera, a frosted screen is erected. This is illuminated stroboscopically from behind. Thus, as the target breaks up, explosion products, fragments of the target and water move across the field of view of the camera, and from the sequence of pictures obtained velocities and displacements may be deduced.

One frame, selected from a record of a shot in which the explosive charge was in contact with a single bulkhead, is reproduced in Fig. 4.

The instant when the bulkhead first ruptures may be deduced from the streak left on the film by the image of the incandescent gases which normally form the explosion bubble in open water. These gases pour through the small hole blown in the bulkhead within a few microseconds of detonation. The hole itself is subsequently enlarged as the bulkhead tears in radial lines and forms " petals " of distorted metal. Simultaneously a mass of water moving with considerable velocity enters through the hole.

The time interval between the first sign of rupture and the flash of light which produced the photograph in Fig. 4 was 1.83 milliseconds. The shape of the water mass can be discerned and the form taken by the " petals." The charge used was ¼ oz. of Polar blasting gelatine, the bulkhead 1/16 in. of mild steel, and the final major dimension of the hole 15 inches.

Some work has also been done on bulkheads with stiffening members. Fig. 5 shows the state of affairs in a typical shot (a) before and (b) 17.5

(*Continued on page 141.*)

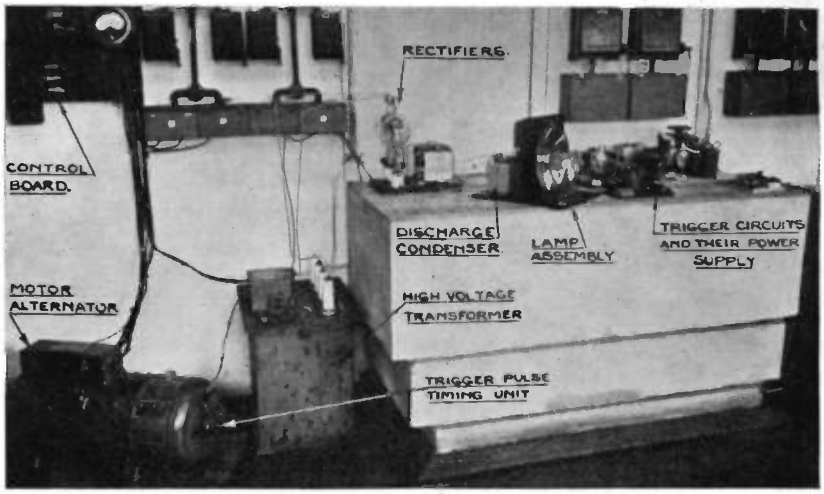
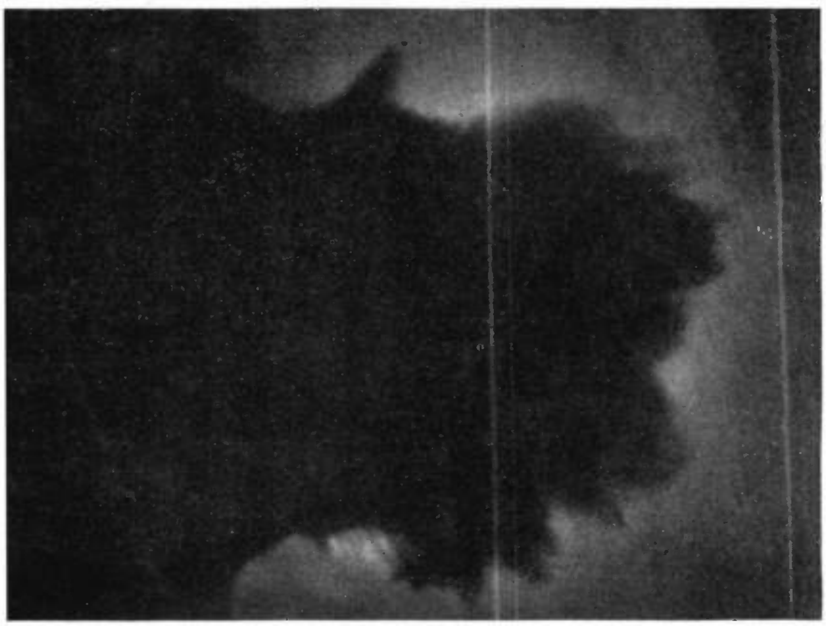


Fig. 6. Improved high-intensity flash equipment giving 1,000 flashes per second.

Fig. 4. Silhouette of rupture of bulkhead showing mass of water entering the hole.



Microphones

Part II—Sound Waves and the Physical Properties of Microphones

By S. W. AMOS, B.Sc.,* and F. C. BROOKER, A.M.I.E.E.*

IT was seen in Part I that there are three distinct branches of physics, namely, acoustical, mechanical and electrical, involved in the study of microphones, and that each is analogous to the other two, in that the quantities involved, and the equations of motion by which these quantities are related, are very similar. This article begins with considerations of some physical aspects of the sound wave, with particular regard to the way in which it is affected on meeting an obstacle such as a microphone.

We need only deal with air as the sound-conducting medium, and we can define sound waves as the periodic compressions and rarefactions that occur in air when this medium is disturbed by some form of vibrating object. The waves are known as longitudinal waves, since the particles oscillate backwards and forwards on the axis along which the wave is propagated. This is depicted both pictorially and graphically in Figs. 1a and 1b, where four successive waves of a sinusoidal tone are shown.

It is seen that the air pressure is varying both above and below its normal value, and may therefore be regarded as an alternating component superimposed upon a steady state of pressure. Normally, we are not concerned with the steady component and refer only to the amount of excess or deficit of pressure, known as the amplitude, P_0. The magnitude of the steady component is, of course, about 15 lb. per sq. in., which is roughly equivalent to 10^6 dynes per sq. cm. As in the electrical circuit, the pressure, p, at any instant of time, t, is given by the expression:

$$p = P_0 \sin \omega t$$

Even for comparatively loud sounds the value of the pressure amplitude is extremely small, being of the order of 1 dyne per sq. cm. R.M.S. for speech sounds at a distance of 6 in. from the mouth. This minute pressure is therefore roughly 10^{-6} of normal atmospheric pressure, while the weakest audible sound goes down to about 10^{-9} of normal pressure.

In the study of microphones we are not particularly interested in the

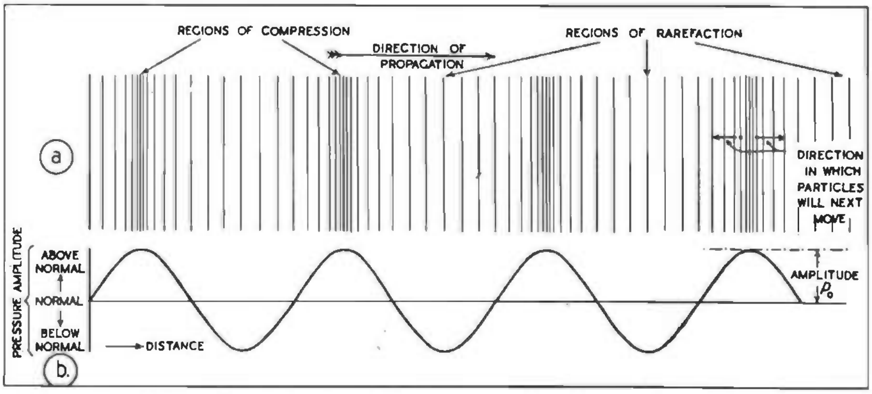


Fig. 1 (a) and (b). Pictorial and graphical representation of a sound wave of pure tone.

propagation velocity, c, except in so far as it gives us the wavelength, λ, by the usual relationship, $\lambda = c/f$, and it is often by a consideration of the wavelength rather than the frequency that acoustical problems are solved. Taking the velocity of sound in air to be 1,100 ft. per second, we deal with wavelengths varying from 40 ft. (equivalent to 27.5 c/s.) to under 1 in. (1 in. corresponds to 13,200 c/s.).

Another velocity of particular interest is the particle velocity. This is the speed of alternating movement of the air particles themselves along the direction of propagation of the sound wave. The phase relationship between particle velocity and instantaneous pressure depends on the nature of the sound wave. In a plane progressive wave they are in phase and may be compared with current and voltage respectively in a correctly terminated transmission line, with a power factor of unity. In the same way that it is possible, under certain conditions, to get "standing waves" on a transmission line, so it is possible—due to reflexions—to produce standing waves of sound. Such a wave might rightly be termed a "wattless" sound wave, since there is no energy transfer and the phase difference is 90°. Unfortunately it is not easy to illustrate the progress of the wave, for any graph (such as Fig. 1) showing the instantaneous distribution of pressure in space for a progressive wave is exactly the same shape as that for a standing wave, and it is not possible to show on one graph of instantaneous pressures the phase relationship between velocity and pressure. It can be shown that particle velocity is proportional to the amplitude, and—by simple differentiation—proportional to the frequency also (for a given amplitude)

i.e., particle velocity, $v = p.\rho c$

where p = excess pressure

ρ = density of the medium

and c = velocity of propagation of sound in the medium.

This relationship holds good only for a plane wave, but if we have to consider diverging waves emitted from a source with dimensions small compared with the wavelength, then the formula can be modified to:

$$v = p.\rho c \sqrt{1 + \frac{1}{4\pi^2}\left(\frac{\lambda}{r}\right)^2}$$

where r = radius of curvature of the spherical wave, *i.e.*, the distance from the source. It will be seen from this latter expression that the velocity component of a wave of given amplitude becomes greater as $\frac{\lambda}{r}$ increases. At a given distance from the source, r, the velocity component increases as the wavelength increases, or as the frequency decreases. Any anomalies caused by increase of particle velocity, then, will be more in evidence at low frequencies than at high ones. This is important in the design of microphones which rely on the magnitude of the particle velocity of a sound wave for their opera-

* Engineering Training Dept., B.B.C.

tion, and will be treated in greater detail in Part IV.

It has been pointed out already that the acoustical-mechanical conversion is generally accomplished by means of a form of diaphragm which may be exposed to the sound on one side only, or on both sides. In the former case the movement of the diaphragm depends on the value of pressure exerted on the front of it; in the latter case the movement will depend on the difference in pressure between front and back of the diaphragm, and this difference in pressure can be shown to be proportional to the particle velocity. The term " pressure gradient " is often used in place of pressure difference, but as " gradient " has a mathematical significance which is difficult to visualise, it will not be discussed here. These two modes of operation are distinguished by the terms " pressure " and " velocity " respectively. As pointed out in the electro-acoustic analogies, pressure may be compared with e.m.f. and velocity with current. Hence a pressure microphone may be likened to a voltmeter and a velocity microphone to an ammeter.

Once again it is wise to keep in mind the magnitude of the forces with which we are dealing, so as to appreciate better the delicacy of construction of a sensitive microphone. At a frequency of about 200 c/s. and for speech at about 6 inches from the mouth, the maximum particle velocity is about 0.1 cm. per second, while the maximum displacement of the air particles from their mean position is only 10^{-4} cm.

Pressure Operation of Microphones

Any microphone that has its diaphragm exposed to sound waves on only one side is a pressure-operated type, *i.e.*, the displacement of the diaphragm is proportional to the instantaneous pressure developed in the sound waves. Its action can be compared with that of a quick-acting aneroid barometer. If the microphone is imagined as extremely small, so that it does not in any way disturb the air particles in their motion, then the pressure exerted on the diaphragm would equal exactly the excess pressure that would be developed in the sound wave at that same point in space if the microphone were not there. This, however, can never be achieved in practice as the microphone must have a finite size and will therefore present an obstruction to the progress of the wave. We can now consider the effect of introducing such an obstacle in the path of a wave train, and the general behaviour of sound waves under these conditions. Figs. 2a and 2b (drawn in cross-section for clarity) illustrate two cases were sound waves of long and short wavelengths respectively are impinging upon a microphone AB, of width *d*.

If we consider a point O in the centre of the diaphragm at a time when the pressure has built up to a maximum, then it is clear that very shortly after this maximum pressure has occurred the wave must sweep on around the sides of the obstruction and reunite later at the back. This process is known as " diffraction." The time taken for the wave to get round the obstacle may be either a small fraction of the time of one cycle (or the distance from front to back is a small fraction of the wavelength, as in Fig. 2a), or a large fraction, as in Fig. 2b. In the former case, little disturbance of the wave front takes place, but in the latter, considerable disturbance is shown. Another way of looking at this is to imagine a reflected wave being set up and moving in the opposite direction to the incident sound. Such reflexions, which do occur, and can be shown by experiments with ripples produced in water tanks, give rise to interference patterns; but these have been omitted in order to simplify the diagram. The important point is that the incident wave "builds up" in front of the obstacle and as a consequence the effective pressure acting on the diaphragm can be as much as twice the pressure due to the incident sound alone. The figure of twice the pressure has given the name " pressure doubling " to this effect, although an exact doubling can only take place when the obstacle is infinitely large and complete reflexion (without absorption) takes place. The effect, however, becomes appreciable when the width of the obstacle is comparable with the incident wavelength. The exact mathematical analysis for various shapes of obstacle (both flat and solid) has been investigated by Rayleigh, Ballantine, and others and is too complex to be discussed here.

The construction of many pressure microphones, particularly those employing stretched diaphragms secured by a damping ring, results in a " cavity " being formed at the face of the microphone. The photograph (Fig. 3), which is of a modern moving-coil microphone, shows this cavity very clearly. As explained in the first article, a cavity containing air (which possess both mass and elasticity) behaves as a short stubby " pipe," closed at one end, and having a resonant frequency. The pressure at the closed end of such a pipe may, at resonance, be two or three times that at the open end. In actual fact the microphone illustrated in Fig. 3 has a substantially level response, for the cavity effect has been offset by the inclusion of acoustic

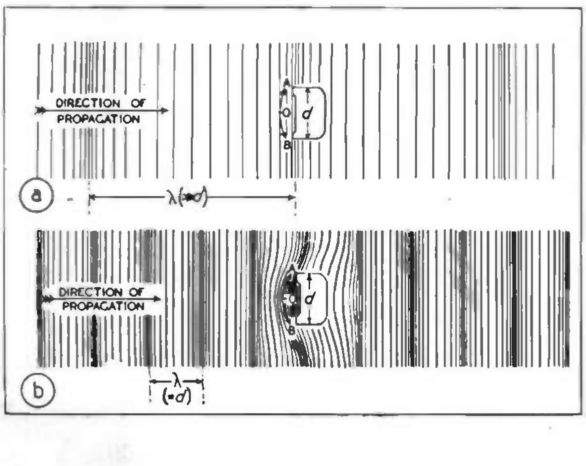
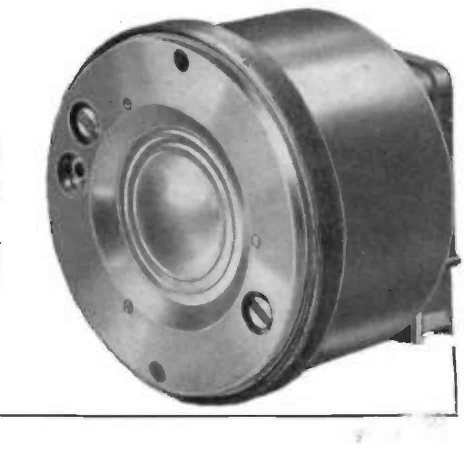


Fig. 2 (a) and (b) (left). Diffraction of long and short waves around a microphone, showing "pressure - doubling."

Fig. 3 (right). View of a modern moving-coil microphone with the cover removed.



elements behind the diaphragm. These will be considered in Part III.

From the above considerations it will be seen that frequency distortion, particularly at the higher frequencies, is likely to occur due to these increases in pressure at the diaphragm of the microphone as compared with the pressure in free space. Fig. 4 gives some idea of the resultant of these two effects for an obstacle, the dimensions of which are typical of some of the earlier condenser microphones. It will be seen that a total "lift" of 12 db. occurs at the resonant frequency of the cavity. In modern types of microphone, small size and special construction have reduced these effects.

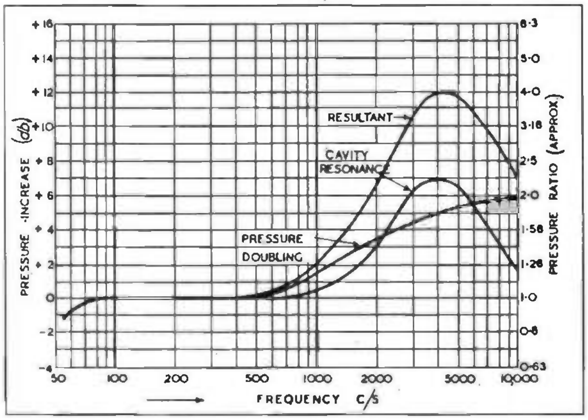


Fig. 4. The combined effects of cavity resonance and "pressure - doubling" on the frequency response.

In the last three paragraphs we were only concerned with waves at "normal" incidence (*i.e.*, direction of propagation at right angles to the diaphragm). If the wave approaches the microphone at any angle other than the normal then other effects—sometimes undesirable—take place. An overall curve shows progressively less response to high frequencies as the angle becomes greater, so giving the microphone a marked degree of "directivity." A qualitative explanation of this can be given in the following way. Fig. 5a shows a train of relatively long waves arriving at an angle θ to the normal, while Fig. 5b shows the same diaphragm being similarly subjected to a train of waves where the wavelength is comparable to the diaphragm width. Consider three points on the diaphragm, P_0, P_1, and P_2, at the centre and to the sides respectively. In the case of the long wave there will be very little difference in the excess pressure whether taken at P_0, P_1 or P_2. This is shown in the projection on to the sinusoidal graph drawn at the side of the pictorial representation. When we examine the short wave of Fig. 5b by the same method it can be seen that it is possible for the diaphragm to be subjected to regions of compression and rarefaction at the same instant. The result of the compression part of the wave is such as to oppose that due to the region of rarefaction and so, for that particular wavelength and angle of incidence, the output of the microphone is very much reduced. The effect of reduced "top" at wide angles of incidence is offset by the increases due to pressure-doubling and cavity-resonance already referred to. Consequently, when all factors are considered together, one can see how the final frequency response for any particular angle may be similar to those shown in Fig. 6, which is for a typical large-sized pressure microphone.

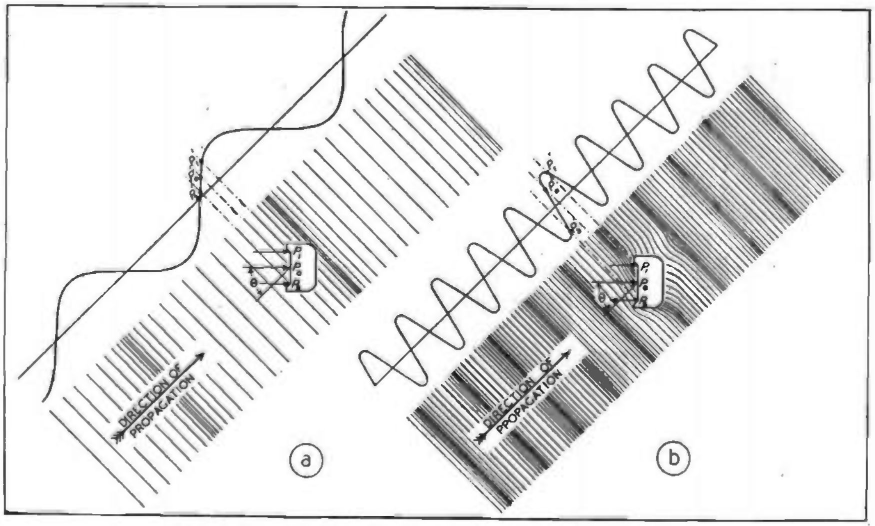


Fig. 5 (a) and (b). Effect of oblique incidence of waves.

Early microphones of the carbon-granule and condenser types suffered from frequency distortion to a marked degree, due to the various causes enumerated above; and it is doubtful whether this was appreciated at the time. If any calibrations were carried out at all in these early days they were "pressure calibrations." Pressure calibration consists of applying a known acoustical pressure to the diaphragm (the method of doing this will be described at the end of this article) and so only the mechanical-electrical conversion characteristic is obtained . . . a characteristic which is more flattering to the microphone than that obtained from "free air" calibration. The principle of the latter method is as follows: The microphone is placed in an acoustically "dead" room and is subjected to a train of sound waves; the microphone is then removed and the pressure measured at the place which the microphone had just occupied.

Examples of purely pressure-operated microphones include the carbon-granule (response similar to Fig. 6), the single-sided condenser, the moving coil, and the piezo-electric types. The carbon granule microphone has major defects other than those of a mechanical or acoustical nature and is no longer considered to have a place in high-quality broadcasting or sound recording. The others have been improved by various artifices and of these the moving-coil type is a notable example. In Part III it will be shown how, by making the microphone of small dimensions and by adjustment of several acoustic elements (cavities, slits, tubes, etc.) behind the diaphragm, the response has been made relatively level over a wide frequency band.

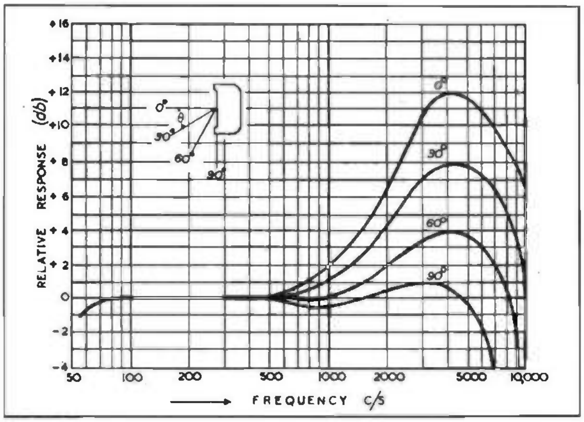


Fig. 6. Response curves for different angles of incidence.

Piezo-electric microphones may be constructed with single crystal elements or with a number of elements grouped together. The single-element type, by reason of its inherent smallness and the absence of a cavity, is relatively free from the defects mentioned above; but some of these advantages are thrown away when several elements are used to gain sensitivity. Single-element crystal microphones and some other modern types which are of particularly small pnysical dimensions are therefore practically omnidirectional, *i.e.*, whose frequency response is the same no matter what the angle of incidence. Other, large microphones, due to the variation in shape of the polar diagram with frequency, require the performers to be grouped within a small angle in front of the diaphragm. This directional nature of the larger type of microphone also has an effect on their response to reverberant, or indirect, sound which we shall discuss later.

Velocity Operation

At the beginning of this article it was stated that if a diaphragm were exposed on both sides to a sound wave, then a difference in pressure would result due to the sound wave arriving at the back in a different phase from that at the front. The diaphragm would then move according to the difference in pressure between front and back. This pressure difference can be shown to be directly proportional to the particle velocity.

First consider a small diaphragm, AB, situated in a set of waves travelling from left to right (as in Fig. 7a) and a wavelength which is long compared with the diaphragm width. Diffraction occurs and the wave "re-forms" at the back of the diaphragm, having moved a distance d around the edges of the diaphragm in so doing. It is the time taken to move this distance d that gives us the required phase difference; and d has been transferred to the graph to show how the two different pressures, p_0 and p_1, are set up under these conditions. Fig. 7b shows a similar set-up but with the wavelength made much smaller (in fact, $\lambda = d$), and it is seen from the accompanying graph that no matter where the wave is with respect to the diaphragm the pressures at the front and the back are equal, *i.e.*, $p_0 = p_1$, or $p'_0 = p'_1$. Consequently no output results at this particular frequency. This is sometimes described as an example of the "breakdown" of the velocity principle, the "velocity principle" presumably being that there is a pressure difference between the front and the back of an obstruction. The authors are not in favour of this statement as it is not really a principle that has broken down, but merely that the principle shows that no pressure difference exists at a certain frequency. In the design of velocity microphones care is taken to keep this frequency as high as possible. In actual fact, exact cancellation does not occur at this "extinction" frequency, due to the inequality of pressures at back and front brought about by diffraction effects.

The main difficulty in understanding the operation of this microphone is in determining exactly the length of d, because the exact path that a wave takes when it is diffracted round an obstacle is not obvious. A flat diaphragm has been taken in the example, but a practical microphone must have something besides this and in most cases it takes the form of the pole pieces of a magnet between which the diaphragm (a ribbon) moves. These pole pieces naturally add to the area of the obstacle and so the distance d is made larger, with a consequent lowering of the frequency at which the cancellation effect (referred to in the last paragraph) takes place. One of the earlier R.C.A. microphones was so designed that the pole pieces were very thin, thus keeping d as small as possible, but as the cross-section of these pole pieces was then insufficient to carry the magnetic flux, side pieces were added, leaving spaces through which the sound waves might pass without much hindrance (Fig. 8). This results in the "extinction" frequency being high enough to maintain the frequency response over the major part of the A.F. band. In the design of the B.B.C./Marconi ribbon microphone, this extinction frequency is allowed to occur in the middle of the audio-

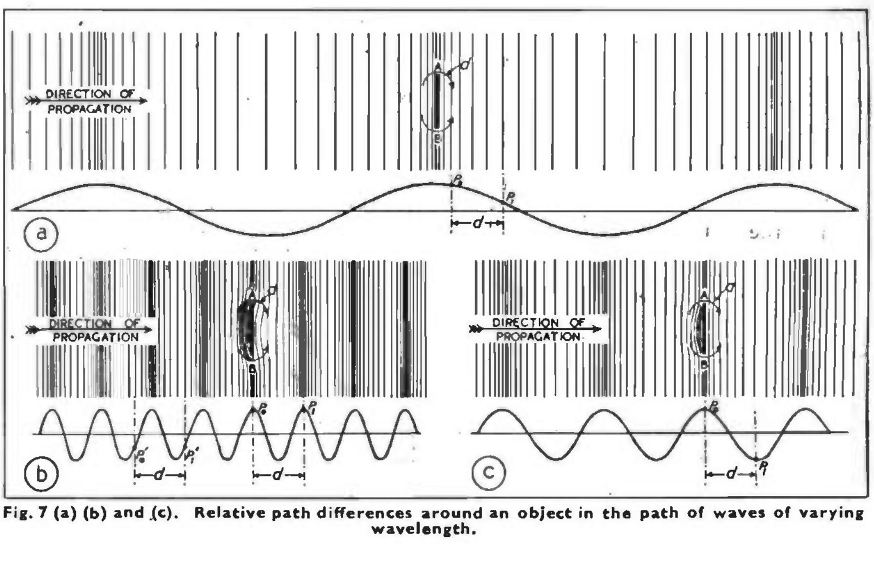


Fig. 7 (a) (b) and (c). Relative path differences around an object in the path of waves of varying wavelength.

frequency band, at 4,500 c/s. The falling-off of output is then compensated for by a resonance of the cavity formed in front of the ribbon by the chamfered faces of the pole pieces. Fig. 9, a view taken looking down on the microphone, with its covers removed, shows the cavity which is formed by the chamfered pole pieces and the ribbon.

Apart from the high-frequency cut-off referred to above, the ribbon-type velocity microphone gives a sensibly level response curve for plane waves and it is instructive to know why this is so. It is due to two frequency characteristics which are complementary to each other, but which can be considered separately: The ribbon itself is very lightly tensioned and its stiffness reactance is extremely small, giving a resonant frequency which is below the audible range (20 c/s. or less). This gives a mechanical system which is "mass-controlled" over the audible frequency range and hence, as explained in Part I, the velocity of movement of the ribbon (to which the output is directly proportional) is inversely proportional to frequency for a constant applied force or pressure. Returning to Figs. 7a and 7c it will be seen that the pressure difference is very small for long wavelengths as in Fig. 7a, but will increase with increase in frequency until it becomes a maximum when the path difference d is equal to half the wavelength (Fig. 7c). So, for the greater part of the frequency range the force, or pressure difference, increases for increase in frequency. The force is actually directly proportional to frequency up to the frequency at which the path difference is about equal to one-quarter of the wavelength, but it begins to fall short of the linear relationship above this frequency, and increasingly so until it eventually passes through zero where $d = \lambda$. These two characteristics, namely the falling velocity-frequency characteristic due to mass control, and the rising force-frequency characteristic due to the velocity principle, together give us a velocity of movement that is substantially independent of frequency up to the value for which $d = \frac{1}{2}\lambda$. By working on these lines the form of the total response can be calculated in the manner shown below. It should be noted, however, that in this simplified treatment of the problem the pressures on the two sides of the ribbon have been taken as being the same as

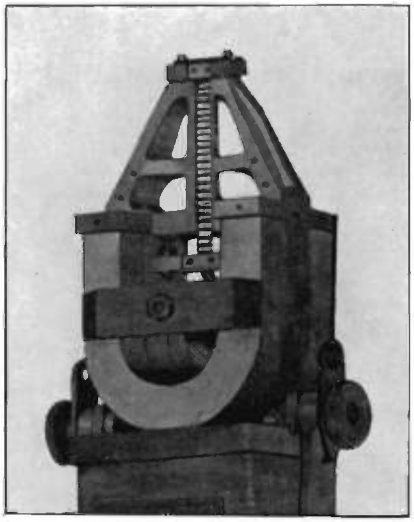


Fig. 8. An early R.C.A. microphone showing cut-away pole pieces.

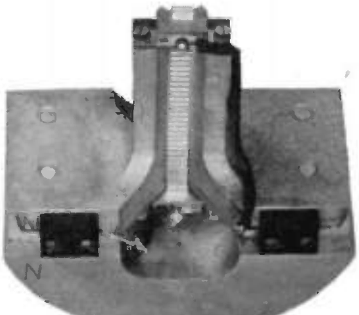


Fig. 9. View of B.B.C./Marconi (Type B) ribbon microphone showing cavity formed by pole pieces.

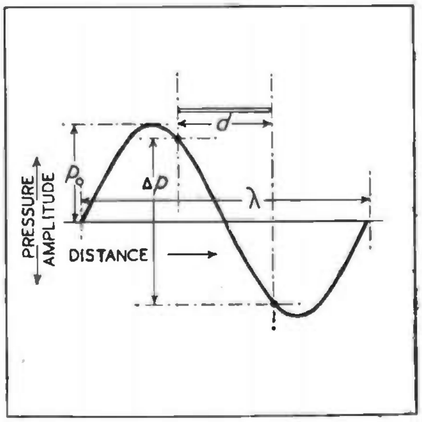


Fig. 10. Illustrating derivation of formula for pressure difference.

those existing at two points on the line of propagation of the sound wave in free space and separated by a distance d. The pressures at two such points are equal in magnitude and differ only in phase. A rigorous treatment would have to take account of the fact that the obstacle effect of the microphone modifies the magnitude of these pressures also. It is for this reason that the output of the microphone does not completely vanish when $d = \lambda$ since the front and back pressures though acting on the ribbon in opposing sense are not exactly equal.

Fig. 10 shows a single cycle of a sine wave of length λ and amplitude p_0 together with a path difference of length d alongside it. The pressure difference moving the ribbon is shown as Δp, which is calculated by:

$$\Delta p = 2p_0 \sin \frac{d \times 360^\circ}{2\lambda}$$

$$= 2p_0 \sin kf, \text{ where } k = \frac{180d}{c}$$

In this, f is the frequency of the sound wave and k is a constant for a given path difference which involves c, the velocity of sound in air. Hence the force operating the ribbon is proportional to $p \sin kf$. This force is a maximum when $\sin kf = 1$, *i.e.*, when $kf = 90^\circ$, giving $d = \frac{1}{2}\lambda$; and is zero when $\sin kf = 0$, *i.e.*, when $d = \lambda$. It was seen in Part I that the velocity of the ribbon, assuming it to be mass-controlled, is inversely proportional to frequency for a given applied force. Moreover, the output voltage from a velocity microphone is directly proportional to ribbon velocity. Thus

$$\text{Output voltage} \propto \text{ribbon velocity} \propto \frac{\text{Force}}{\text{Frequency}} \propto \frac{p_0 \sin kf}{f}$$

For a given applied pressure amplitude, then, the output voltage of the microphone is proportional to $\frac{\sin kf}{f}$ and the response curve is hence defined by the expression

$$20 \log_{10} \frac{\sin kf}{f}$$

in which $k = \frac{180d}{c}$. This function is plotted in Fig. 11 from which it is seen that the output voltage calculated from this simplified theory falls rapidly above the frequency for which $d/\lambda = \frac{1}{2}$. This diagram can be applied to any microphone of the ribbon velocity type in order to determine its theoretical response curve. It is only necessary to move the logarithmic frequency curve until the "extinction" frequency coincides with $d = \lambda$, and this has been done for a hypothetical case where this frequency is 10,000 c/s. ($d = 1.32$ in.) and for the B.B.C. model ($d = 2.93$ in.).

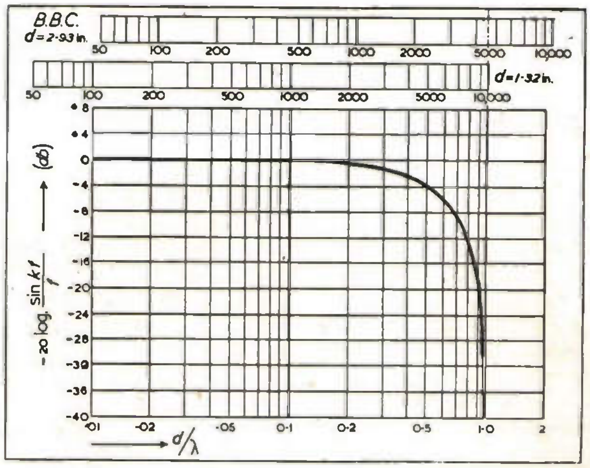
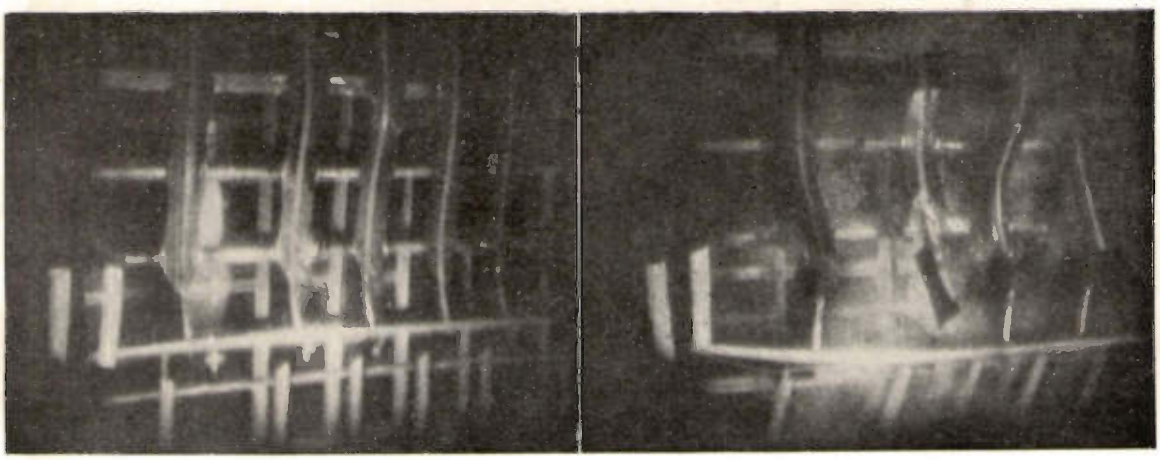


Fig. 11. Response of ribbon velocity microphone calculated from simplified theory (see text).

Microphone Calibration

As stated above, the early microphones were "pressure" calibrated by applying a known acoustical pressure to the diaphragm. One of the methods is to use a "thermophone," consisting of a pair of gold or platinum strips placed in a small container filled with hydrogen and clamped to the face of the microphone. (A hydrogen atmosphere is used in the enclosed space to increase the propagation velocity so that there is no possibility of producing wavelengths small enough to cause standing waves.) A mixture of A.C. and D.C. is then passed through the conducting strips, which alternatively heat and cool, causing the hydrogen atmosphere to expand and contract—this providing the alternating pressure on the diaphragm. Since all the parameters of the device are known it is possible to calculate the actual pressure exerted on the diaphragm. An alternative method of pressure calibration, known as the "electrostatic actuator," may be used with condenser microphones. In front of the diaphragm a rigid grille is fixed, and this acts as a third electrode. If an alternating voltage of suitable frequency is applied between this grille and the diaphragm, the latter will be subjected to an electrostatic force the magnitude of which can be calculated from the physical dimensions of the plates, their distance apart, the voltage applied, etc. In order to obtain the "free air" calibration, not given by the above two methods, the Rayleigh disk is used. This consists of a tiny flat disk, suspended on a torsion wire, in the path of the sound wave. The disk will tend to set itself across the line of propagation of the sound wave and from a knowledge of this deflection the absolute sound pressure can be calculated. The procedure adopted is to subject the microphone to sound waves in a lagged chamber, or in the open air, to note its output, and then to substitute the Rayleigh disk in the place of the microphone. Having calibrated any microphone in this way it may then be used as a sub-standard for free-air calibration of other microphones, by substitution. Microphone response is usually expressed with respect to a standard reference level. The acoustical input is measured and the output is quoted in db. with respect to 1 volt on open circuit, for an input pressure of 1 dyne per sq./cm.

Electronic Flash Tubes *(continued from p. 135)*



(a) (b)

Fig. 5. Effect of impact of shock wave on bulkhead : (a) before and (b) 17.5 milliseconds after impact.

milliseconds after the impact of the shock wave.

The quality of the photographs would be much improved if more light were available, for then not only could the ideal exposure be given but the lens aperture could be reduced resulting in greater depth of focus and finer detail.

In single-flash photography the increased light may be provided simply by increase in the energy of discharge (the energy is ultimately limited by that which the flash tube will stand without disintegrating). In multiple flash photography the problem is not so simple since it may involve the dissipation of several kilowatts in the flash tube.

This problem is being tackled in many ways and by a number of establishments. At Admiralty Undex Works, a unit has recently been completed which operates at a fixed frequency of 1,000 flashes per second and gives five times as much light per flash as was available when the photograph of Fig. 4 was taken. This unit is shown in the development stage in Fig. 6.

Nuclear Energy

PART III.—Experimental Methods

By W. D. OLIPHANT, B.Sc., F.Inst.P., F.R.S.E.

Atomic Projectiles

ARTIFICIALLY produced nuclear disintegration requires that the sub-atomic bombarding projectiles be accelerated to such a velocity that their energy is at least sufficient to penetrate the nuclear potential barrier; this was demonstrated in Part II. The positively charged particles which are most commonly used for this purpose are:

The proton (${}_1H^1$), which is the nucleus of the normal hydrogen atom having a mass of 1.67×10^{-24} gm.

The deuteron (${}_1H^2$ or ${}_1D^2$), which is the nucleus of heavy hydrogen or deuterium, comprising one proton and one neutron, and having a mass of 3.33×10^{-24} gm.

The α-particle (${}_2He^4$), which is the nucleus of the helium atom, comprising two protons and two neutrons and having a mass of the order of 6.66×10^{-24} gm.

The acceleration of all these particles is dependent on their electric charge and on their behaviour in an electric field alone or under the influence of simultaneously applied electric and magnetic fields. The neutron (uncharged) cannot be accelerated by such methods and its isolation and subsequent energy is dependent on, say, the bombardment of metallic beryllium with either α-particles or deuterons.

The Electrodynamics of Charged Particles

A particle of mass m, charge e and initially at rest, is accelerated by a potential difference V to a final velocity v in accordance with the energy relation

$$\frac{1}{2} mv^2 = Ve \quad \ldots\ldots\ldots\ldots (1)$$

and this is the fundamental equation governing pure electrostatic or electric acceleration.

Once the charged particle is in motion, it has associated with it a magnetic field which will interact with an externally applied magnetic field and the particle will be subjected to a reactionary force which will deflect it from its rectilinear path. If the external magnetic field (H in e.m.u.) is normal to the direction of motion, then the magnitude of the force is given by

$$F = \frac{Hev}{c} \quad \ldots\ldots\ldots\ldots (2)$$

If the charge e is already expressed in e.m.u., then this force is given by Hev, since c is the ratio of the e.m.u. of charge to the e.s.u. of charge and is numerically equal to 3×10^{10}.

For a positively charged particle, the direction of this force is shown in Fig. 1 which depicts three vectors (representing H, v and F) which are mutually normal to each other. (For a negatively charged particle, the direction of the force vector is reversed.)

If the velocity remains constant and the field (H) is uniform over the entire path of the particle, then the force will remain constant; F is thus a normal or centripetal force and the particle orbit will be circular.

If, then, r be the radius of curvature of this orbit and ω ($= v/r$) be the angular velocity,

$$F = m\omega^2 r = \frac{mv^2}{r} = \frac{Hev}{c} \quad \ldots (3)$$

from which

$$\omega = \frac{v}{r} = \frac{He}{mc} \quad \ldots\ldots\ldots\ldots (4)$$

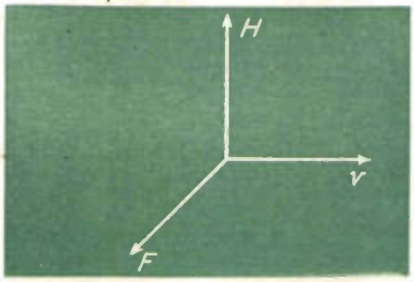
This relation is of fundamental importance in ionic acceleration in the cyclotron, in mass spectroscopy and in isotopic separation—three important experimental techniques which form the subject under the present heading.

A study of Equation (4) indicates the following:

(1) The angular velocity of an ion or charged particle moving in a uniform magnetic field is invariant with its linear velocity or the radius of curvature of the path; in other words, the time required to traverse a semicircular path, say, is not dependent on v. If the velocity is increased, so also is the radius.

(2) The angular velocity, and hence the time required to traverse a given arc, is directly proportional to the impressed magnetic field intensity and to the ratio of the charge to the mass of the particle or ion (e/m).

(*Continued on page 151.*)



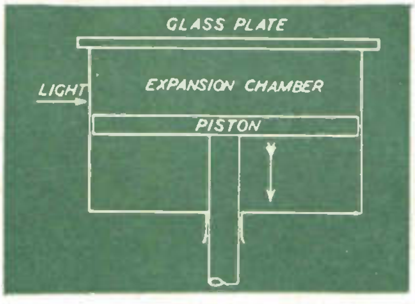
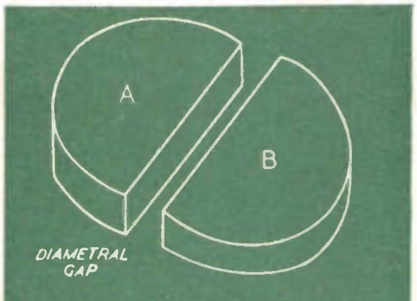


Fig. 1 (above). Direction of force F on a positively charged particle moving with velocity v in a magnetic field H which is normal to the path of the particle.
Fig. 7 (below). The Wilson cloud chamber. Simple design shown in section.



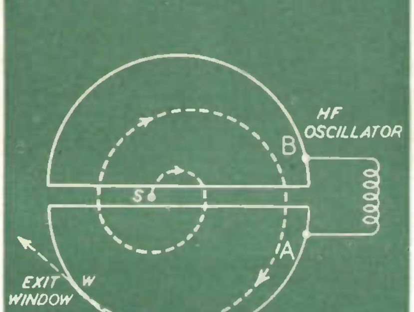


Fig. 3 (above). Arrangement of cyclotron accelerator electrodes or "dees."
Fig. 4 (below). Plan of cyclotron accelerator electrodes showing H.F. connexions and path of accelerated particle (exaggerated). Magnetic field normal to plane of diagram.

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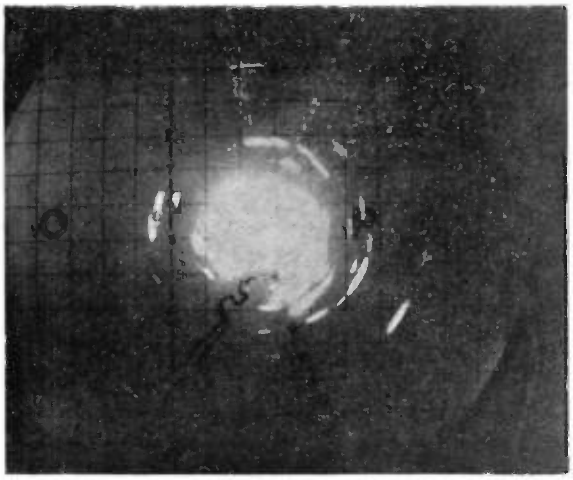

Fig. 4. P.P.I. (Plan Position Indicator) display.

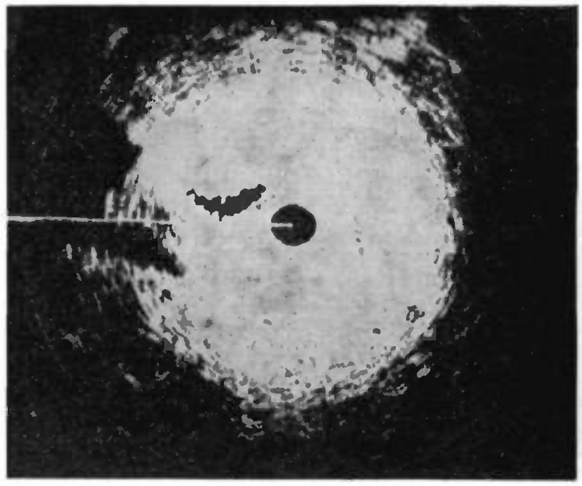

Fig. 8. H_2S display with electronic marker.

Cathode-Ray Tube Displays

This account of the use of the cathode-ray tube in radar is extracted from the paper *A Survey of C.R.-Tube Problems in Service Applications, with special reference to Radar,* read before the Radiolocation Convention at the Institution of Electrical Engineers by **J. G. Bartlett, D. S. Watson,** and **G. Bradfield,** the part dealing with radar displays in the R.A.F. being dealt with by Mr. Bradfield

Classification of Cathode-Ray Tube Displays

THE versatility of the cathode-ray tube gives rise to great variety in the form of the presentation. Some of this variety can be traced to historical causes, but the major part results from differences in the information being presented and in the use to which this information is to be put. It is therefore helpful to classify displays under the generic terms: conventional, pictorial, realistic and instructional. These can then be subdivided into two types, in the first of which the correlation of variables is more or less rough and in the second it is so accurate that the display does not constitute a restriction on the overall accuracy. These types are described as "general" and "precision."

A "conventional" display is one in which the observer has to learn what is meant. For instance, he has to learn that range is shown by a "blip" below the line and that range increases as the "blip" moves to the right. The conventional display is generally best suited for depicting especially important information needed for control purposes in a manner most readily grasped. Usually the equipment selects this information though an assistant may do the selection.

A "pictorial" display is one with which the observer is naturally familiar, such as a bird's eye view of terrain surrounding him. Very often, though not inevitably, the pictorial type of display presents all received information very completely and makes full use of the ability of the human eye to see numerous items of information in a short time, but, of course, this task of searching through a great variety of unselected material will necessarily be very tiring.

The term "realistic" is confined to those displays giving to the observer a picture which has a marked similarity to the normal visual picture he would see *when in his present location.* The idea behind the provision of this display is that such a picture should produce instinctively on the part of the observer the appropriate physical reaction.

The final main division under the term "instructional" has been reserved for displays where the picture tells the operator what his next action should be as regards its nature and extent; this is in contra-distinction to the preceding types of display, all of which merely supply information without telling the operator what to do.

Fundamentals of Display Circuit Technique

Consider first a radar system similar to that which will be described later under the name "C.H.L." (Chain Home Low). In this case a master oscillator produces a sine wave (Fig. 1(a)) of a frequency equal to the desired recurrence frequency of the transmitter pulse. This is amplified and squared by "bottoming" a valve anode (Fig. 1(b)) and then differentiated (Fig. 1(c)) to give a locking pulse for the transmitter (Fig. 1(d)). This latter pulse, or one suitably delayed or advanced, is also used to trigger the time-base circuit of the cathode-ray tube. This circuit is a multi-vibrator normally resting in one stable condition. The triggering pulse trips this over, in the well-known way, into a second condition during which the grid condenser which maintains one of the valves biased beyond cut-off gradually discharges until, after a certain time, the multi-vibrator reverts to its previous condition. The circuit thus generates a square wave (Fig. 1(e))

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which can be applied to the grid of the cathode-ray tube to brighten the spot during the period of operation of the time base (compare received signal plus noise in Fig. 1(g) and the deflection displayed in Fig. 1(h) illustrating blacking out of the unwanted part of the trace).

The pulse produced when the multi-vibrator reverts to its previous condition is used to energise a valve which short-circuits a condenser, normally being charged from a high voltage through a high resistance. Thus, this condenser starts to charge synchronously with the transmitter pulse, and the linearly rising wave (Fig. 1(f)) so produced is applied through an amplifier to the time-base deflection plates of the cathode-ray tube and produces a movement of the spot with uniform velocity starting with the transmitting pulse and lasting for the paralysis period of the multi-vibrator. It will be clear that, since this uniform velocity starts with the transmitter pulse, distances along the time base are proportional to the range of the target from the transmitter and repeated traces merely superimpose more noise and target traces one on top of the other.

It it is necessary to apply magnetic deflection to a cathode-ray tube this is done most simply as in Fig. 1(l) by injecting the voltage waveform into an amplifier which drives a current *I* of the same waveform through a coil around the neck of the cathode-ray tube, thus producing the required deflection.[1] To cut out non-linearity and other faults of the equipment, a voltage *IR* is fed back in series with the input. In general the earlier circuits for magnetic deflection were not so simple as that described, but this is a matter of circuit history which need not concern us here.

In the case of time bases for magnetic tubes it is often best to generate a balanced wave, such as is shown in Fig. 1(k) where a saw-tooth is succeeded by a wave sweeping through the axis in the opposite sense and shaped so that the mean value lies at the commencement of the rising wave.

When it is desired to rotate the time base, a saw-tooth wave is fed into the rotor of a generator with two stator phases at right angles, and the windings of the latter are connected to the deflection plates of a cathode-ray tube or to a stationary two-phase coil around the neck of the cathode-ray tube as shown in Fig. 1(l). If the rotor is turned, rotation of the time-base trace results and this rotation is synchronised with that of the aerial array. This scheme was widely used in aircraft installations but the majority of ground-station equipment with rotating time bases used a linearly rising current wave in coils which were rotated through gearing by a synchronous motor energised from a generator turned by the aerial array.

With H_2S equipment, a correction to the waveform has to be made to compensate for aircraft height.[2] In this case a network of condenser-resistance elements is charged with a voltage proportional to height and discharged at the time of the generation of the rising saw-tooth to accelerate the rise of a delayed wave as in Fig. 1(j).

One other circuit feature in connexion with displays needs to be mentioned. This is the use of strobes. It will be clear that the square waveform of Fig. 1(e) can be regarded as a delayed waveform at *S* and this wave can be used to switch on a valve and start a new train of waveform generation delayed by the paralysis time of the multi-vibrator. Such a process is termed a delayed start of sweep and, when the period *S* is short, *i.e.*, 1 to, say, 20 microseconds, that part of the square wave is called a strobe. Alternative methods of delaying the strobe, such as differentiating on the grid of an amplifier through a variable condenser and leak and thereafter squaring, are also possible.

Historical Survey of Cathode-Ray Tube Displays over the Period 1936-1945.

The first radar displays in Britain were of the C.H. (Chain Home) type (see Fig. 2), the system used being rather similar to that described above. The radiation from these stations had wide polar diagrams in azimuth and elevation, and when once an aircraft was detected it was necessary to balance two or more aerials through goniometer systems in order to determine azimuth and height. Balance was evidenced by decrease of the aircraft echoes of Fig. 2 to invisibility. The display comes in the "conventional" category and although accuracy was good, the term "precision" was not applicable.

Late in 1939, C.H.L. (Chain Home Low) equipment came into operational use, enabling low-flying aircraft and ships to be readily seen, and, using very directional rotatable arrays, a high degree of azimuthal accuracy could be obtained by a device known as "split." By altering the phasing of the radiating elements of the array the beam was moved slightly, so

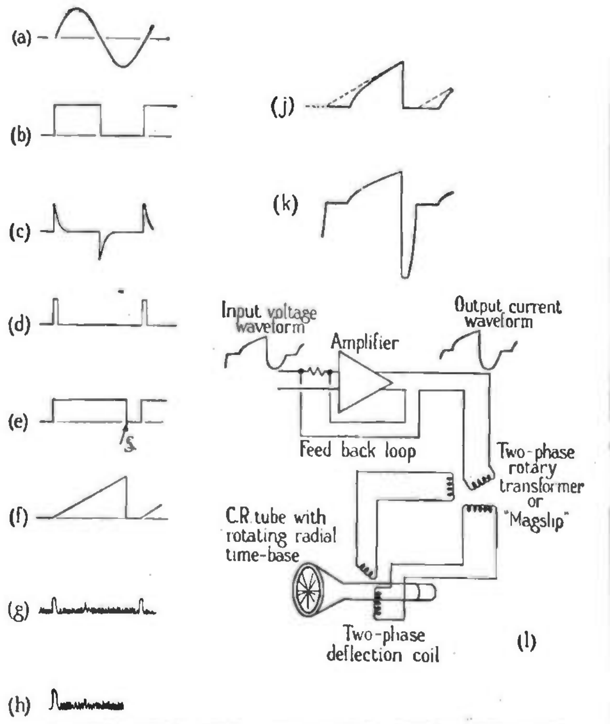

Fig. 1. Illustrating the stages in producing triggering pulse for time-base circuit, waveform for magnetic deflection, and method of producing radial trace.

changing the field strength at the target aircraft. The resulting change of receiver signal was displayed as a side-by-side comparison on a cathode-ray tube. The side-by-side positioning was affected by synchronously shifting the beam and slightly altering the zero of the range trace every other transmitter pulse. Again this display was of the "conventional" type. The cathode-ray tube used was the VCR151, a 12-in. tube with a willemite screen.

At the end of 1939 an A.I. (Air Interception) equipment was being tried, the display of which took the form shown in Fig. 3. This used a switching technique for azimuth and elevational aerials, interlocked with switching of the sense of the cathode-ray tube traces so as to place them back-to-back as shown. The A.S.V. (Air to Surface Vessel) equipment was similar but was simplified by the omission of the elevational aerials and was used operationally before A.I.

These displays in Fig. 3 must be classed as "conventional" with few "realistic" features, but a surprising facility was achieved by the R.A.F. in their use. The adoption of these types of display, together with the introduction of the high deflection sensitivity cathode-ray tube, enabled relatively simple equipments to be produced.

As far back as 1936 the possibility of an entirely new form of display, the P.P.I. or Plan Position Indicator, had been visualised. In the early part of 1940 work on this was intensified and it came into operational use in May, 1940. It was an immediate success, giving unexpectedly accurate indications of azimuth. It represented a great advance in realism and this conduced to rapid action. The equipment concerned constituted a rotating directional array like the C.H.L. with means for making the range trace, now intensity modulated, rotate on the cathode-ray tube.

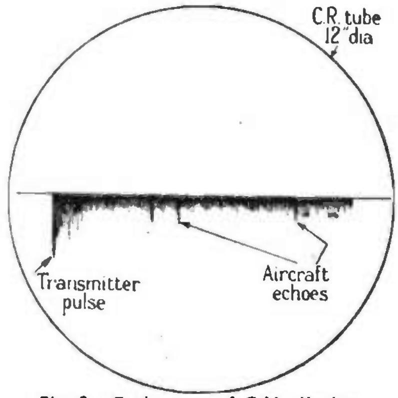

Fig. 2. Early type of C.H. display.

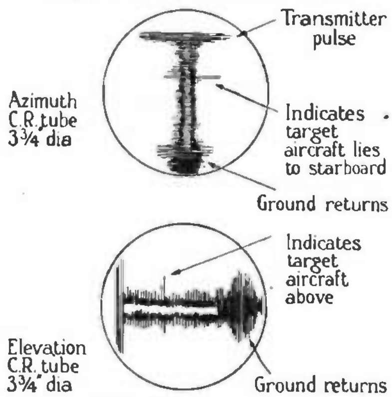

Fig. 3. (Above.) A.I. displays.

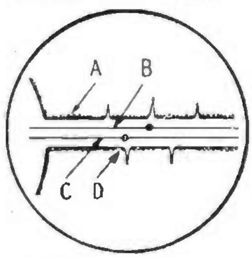

Fig. 5. (Left.) Gee display.

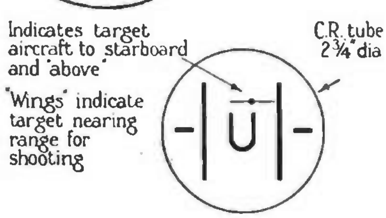

Fig. 6. (Below.) Later A.I. display.

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It will be seen from the photograph (*see* Fig. 4) that surrounding reflecting objects are shown in plan position; this justifies the placing of the display in the category "pictorial." The technique of intensity modulation was imported from television practice and it was found necessary to limit the signal electrically to avoid over-modulation of the cathode-ray tube. This gave clean-cut edges to the arcs generated and, by bisecting these, azimuth was accurately obtained.

In order to retain a trace on the cathode-ray tube after the aerial had swept to a new position (the rotational speed being low, about 6 r.p.m.), a screen of especially long afterglow type was introduced and this enabled echoes to be seen for many seconds and even a minute after the first recording.

The next display,* shown in Fig. 5, was in the very important "Gee" equipment for aircraft, the design of which was started early in 1940 and was used operationally in August 1941. This equipment used a display which was in the "conventional" category but was of the "precision" type. Use was made of a crystal oscillator which generated both time-base recurrence and calibration pips, the locking of the former to the master ground or "A" station transmission ensuring accuracy of calibration and being judged by the freedom from drift of the trace.

Besides ingenious circuit features, Gee equipment exhibited two important possibilities in cathode-ray tube displays, firstly the ease with which different pictures can be shown on the tube by a simple circuit changing switch, and secondly the ease of recognition of a signal originating from a

*See ELECTRONIC ENGINEERING, 1945.

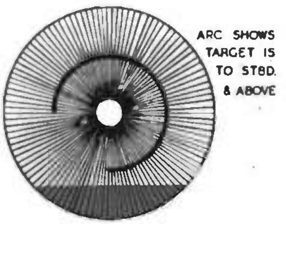

Fig. 7. Centimetric A.I. (air interception) with spiral scan.

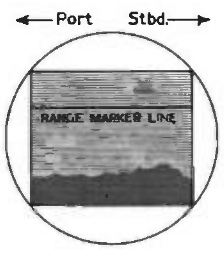

Fig. 9. B-scope display. Used on: A.S.V. Mk. XI., A.I. X, A.S.D. and A.I. Mk. X.

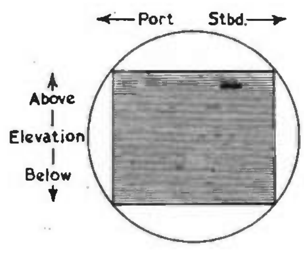

Fig. 10. C-scope display. Used on centimetric A.I. equipment.

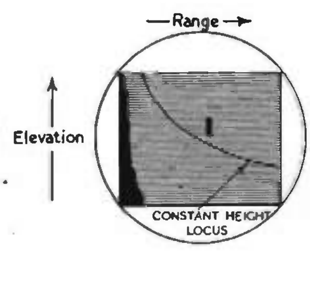

Fig. 12. VEB (vertically elevated beam) and AMES Type 16 display.

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C.R. Tubes used in Radiolocation

THE top photograph shows the gun assembly of the VCR84, a tube specially developed for radar with a long afterglow double-layer screen.

Gun Assemblies

Various gun assemblies are shown in the photograph on the right. These are (from left to right): Gun mounted in eyeletted mica disks assembled on stainless steel support rods. Alternative construction using ceramic rods and metal bands integral with the electrodes. Similar alternatives using glass are shown in the next two examples. The small gun structure shown is of the simplest type, as used for magnetically focused tubes. The last example shows a complete assembly built on an accurately fabricated cylindrical second anode, a method which avoids the need for jig mounting during assembly.

Tube Types

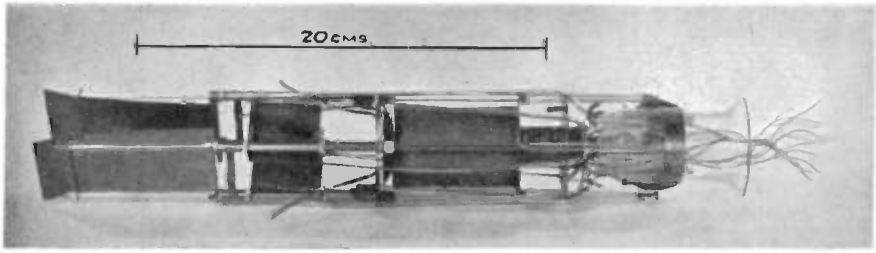
Tubes used for P.P.I. and range-bearing displays are shown in the next photograph. From left to right these are: VCR140, VCRS16, VCRS20, VCRS17, VCR.S30, VCRS24, ACR22. The first two were based on television tubes of prewar construction, the third being a magnetically focused and scanned tube for large screen projection. The VCRS17 is suited to a circular scan and operates at 3,SOO V VCRS24 is noteworthy in using post-deflection acceleration, and the ACR22 has a pressed glass screen end with long afterglow screen.

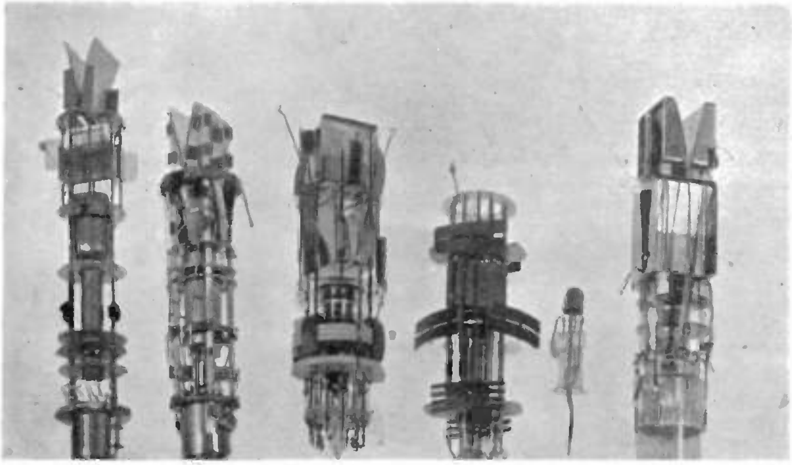
Types of Magnetic Scanning System

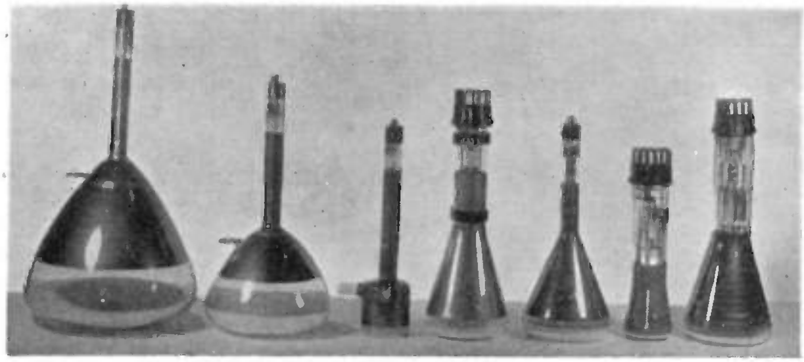
1. E.M.I. iron-clad coil.
2. T.R.E. version of No. 1.
3. Two-phase magslip stator.
4. Final VCRS30 two-phase coil.
5. Short version of No. 4.
6. Two-phase coil by G.E.C. (Leicester).
7. 8-tooth coil (T.R.E. design, made by G.E.C.).
8. Screen case for H.
9. E.M.I. toroidal coil in case.

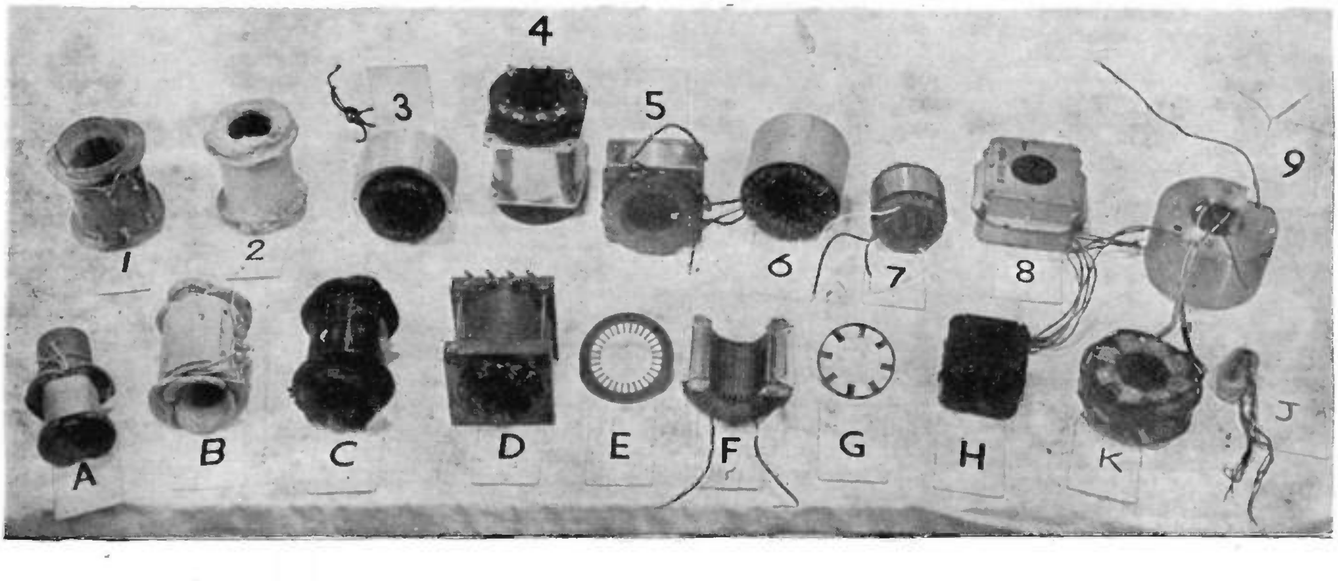
A. Single-field coil for turning mechanisms.
B. Early sample of No. 2.
C. Later sample of No. 2.
D. Early version of No. 4.
E. Stamping used in No. 4.
F. Section of No. 6.
G. Sample for No. 7.
H. U.S.A. square-yoke coil.
J. One of the 8 coils on K.
K. H out of case.

The tube photographs are reproduced from the paper, "War-Time Developments in C.R. Tubes for Radar," by L. C. Jesty, H. Moss and R. Puleston, and the photograph of scanning coils from the paper by G. Bradfield already referred to.









certain station by "ghosting," *i.e.*, duplication of equal or reduced amplitude with a fixed known delay. The VCR97 cathode-ray tube, already established, again proved its worth in Gee displays and was used at 1.8 to 2 kV.

The development of A.I. was proceeding along three lines: (*a*) improved metric systems, (*b*) spiral scan centimetric systems, and (*c*) helical scan centimetric systems, all of which involved different displays. The first system gave rise to the display shown in Fig. 6, the prototype design of which was produced late in 1941 and which became operational in 1942. This was, perhaps, a high-water mark in display design. It can legitimately be described as "realistic" as the target aircraft echo was roughly correctly positioned in azimuth and elevation as a spot of constant brightness on the screen which "grew wings" as it approached, until when the wings touched the uprights it was time to fire. Although initially the necessary control of the spot was by an observer strobing the range trace, later (the design starting in 1942 and becoming operational in 1943) A.I. Mark VI equipment was developed in which this was done automatically and the display then became suitable for single-seater aircraft.

Almost concurrently, spiral scan centimetric A.I. was developed in 1941 and became operational in the early summer of 1942. The helical scan system was recognised as a rather longer term development and accordingly Dr. Bowen went over to the U.S.A. to introduce these ideas. The display of the spiral scan centimetric A.I. is shown in Fig. 7. It should be noted that range increases from the centre outwards. It is in the "conventional" category but has some realistic features.

During 1942 the P.P.I. was incorporated in an aircraft display, the equipment being known as H_2S.[2] This used a 10-cm. pulse transmitter, with a paraboloid for transmitting and reception giving a 10° beam in azimuth. These equipments were also used for A.S.V. and played a great part in anti-submarine warfare before 1942 was ended. The early displays had a range gap due to the height of the aircraft. Although it was not troublesome for A.S.V. purposes for H_2S navigation and bombing a seriously distorted picture occurred. Certain adjustments could be and were made to reduce this distortion but it was not until 1944 that a really good system was introduced to overcome the trouble by the use of a hyperbolic waveform for the scan.

The resulting display can justifiably fall in both "pictorial" and "realistic" categories. It is noteworthy that early in 1943 H_2S displays had incorporated an advance of considerable importance, the use of electronic markers (*see* Fig. 8) for azimuth and range. This avoided parallax troubles and was of considerable assistance in increasing accuracy.

Dr. E. G. Bowen had aroused enthusiasm in U.S.A. for a helical scan system of centimetric A.I. and the SCR720, known in this country as A.I. Mark X, resulted. This was altogether more complex than the A.I. Mark VII or Mark VIII equipment and this complexity extended to the display. The latter no longer consisted of a simple tube but the functions of azimuth and elevation indication were separated. Fig. 9 shows a range azimuth display in a form which came to be known as the "B"-scope, while the observer in the aircraft "strobed" for the required target aircraft echo to be presented on another tube (*see* Fig. 10) known as the "C"-scope. It will be appreciated that both the B-scope and the C-scope displays fall into the "conventional" category although the latter has some claim to realism; this claim is shaken to some extent by the fact that the arc depicted on that tube only shows up for a very brief period and consequently there is a fairly bright flash followed for the rest of the time by a dim and decaying signal. It is of interest that the B-scope presentation, although only "conventional," was sufficiently easily interpreted to permit some sort of course setting for cut-off vectors in A.I. interception, thus to some extent eliminating the necessity for the stern chase inevitable with the A.I. Mark VII and Mark VIII types of equipment and display, a matter of considerable importance with the very fast aircraft which the Germans were then employing.

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Before leaving ground radar with its narrow beam, mention should be made of the display of Fig. 11 associated with centimetric radar for height measurement at any desired azimuth. The interesting feature about this display was that for the benefit of the operator it attempted to depict target height realistically. In the case of the VEB and AMES Type 16 types of display in Fig. 12, a line of constant height was part of a hyperbola and therefore an aircraft flying at fixed height resulted in the echo moving in an unnatural way on the face of the cathode-ray tube. This was overcome, as will be seen in Fig. 11, by an ingenious arrangement of deflection signals. The range trace was applied to the X-plates in the normal way and at the same time was injected into the rotor of a generator fixed to the array, the output from a stator winding of the generator feeding the Y-plates.

An off-shoot of the A.I. type of display was known as "Windscreen Projection." This presented an "image" of the target aircraft to the pilot's eye appearing as though it were a great way off and in the direction he would actually have to look to see the target he was approaching. In addition, an artificial horizon was visible, and, at will, a gun sight, so that the pilot, when he saw a real dim shape through his windscreen-reflected image, would manœuvre the aircraft to make it match the gun sight and, at the cor-

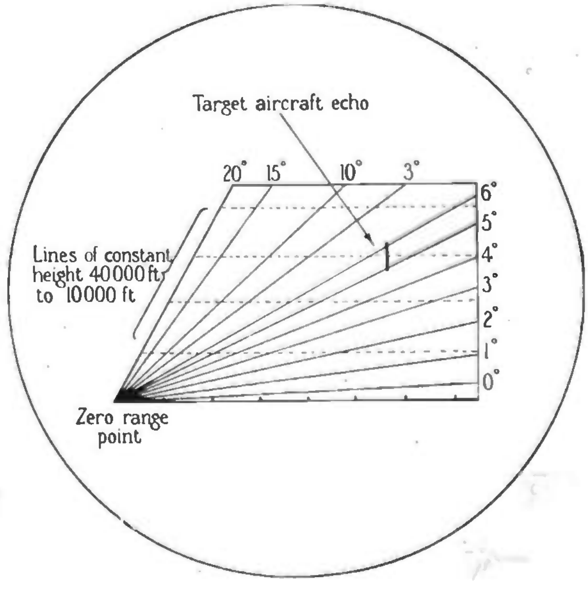

Fig. 11. Centimetric display for height at any azimuth.

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rect range, would fire. The display carries realism one step further and the scheme is thought to have great possibilities.

Visibility of Cathode-Ray Tube Traces and Patterns

A display is no use unless it is visible and in general the more easily visible it is, the more use it is. In this section the importance of visibility and ways to improve it are discussed briefly. The matter falls into two broad divisions: (*a*) making weak signals readily visible in noise, extraneous lighting being negligible, and (*b*) providing displays which are readily visible under conditions of bright extraneous lighting.

Before considering details, some general remarks on visibility should be noted. Early in the war, effort was directed on a simplified visibility problem to provide design data for the above, and a most useful preliminary study was carried out.[3] We have replotted some of these results in Fig. 12 in a form useful for our visibility investigations. The investigations show that the contrast ratio for "just visible" line traces varies inversely as approximately the $\frac{3}{8}$ power of the area of trace and as approximately the $\frac{1}{2}$ power of the background brightness. For higher brightnesses the latter factor becomes of less and less importance.[4]

In practice it was found that a trace brightness of around 100 e.f.c. was comfortably visible and about 20 e.f.c. was just usable. As the cathode-ray tube screen voltage was limited to 2.5 kV and the duty ratio was down to 0.002 (ratio of active to inactive time of cathode-ray tube presentation) a beam current of around 250 μA was necessary and, as the installation demanded a very compact tube, the VCR526 incorporating these properties was developed.

The following figures in Table 1, taken by the R.A.F. Physiological Laboratory, should be noted.

TABLE 1
Visibility of Green Trace 1 mm. Wide, $1\frac{3}{4}$ in. Long with $\frac{1}{4}$ in. Blip

Screen brightness	Threshold		Legible but faint		Comfortably bright	
e.f.c.	e.f.c.	% Contrast	e.f.c.	% Contrast	e.f.c.	% Contrast
40	3	7	8	16.5	50	55.6
160	17	9.5	27	14.5	180	52.8
500	37	7	200	23	400	45.5
2,250	85	3.75	350	13.4	—	—

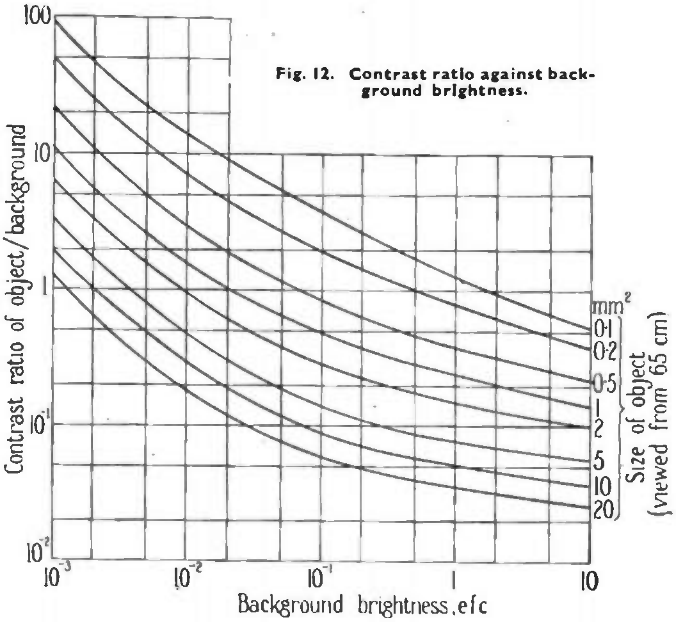

Fig. 12. Contrast ratio against background brightness.

It must be realised that a very bright cloud near the sun can have a brightness of as high as 10,000 e.f.c. which can illuminate the screen of the cathode-ray tube by shining through the hatch of the aircraft. The resulting brightness on the face of an unprotected cathode-ray tube can reach 1,000 e.f.c. or even higher, especially in direct sunlight, but it was soon found that quite a small visor would ease the situation considerably, a type a few inches long and with an aperture 4 in. × 1 in. cutting down the light by some 50 times. This limits eye freedom, but fortunately this has not been found to constitute a serious restriction on the use of either visors or magnifying lenses. In addition, neutral filters and colour filters of the same colour as the cathode-ray tube trace were helpful.

The problem of making weak signals visible in strong noise on B-scope or P.P.I. displays has taken up a considerable amount of effort and we now have a firm grasp of it. It will be appreciated, by looking at Figs. 5 and 9, that the noise background is speckled and detracts from the visibility of a single signal, the effect being worse when the size of the latter is comparable with the noise spots and when its brightness is low in comparison with the latter.

From tests it can be shown that, in a general way, increasing brightness of the background makes the display more sensitive but that the improvement is not as great as would be predicted from the simple plain background case and this is probably due to the noise peaks also being brighter and hence more distracting when general brightness is higher.

A further improvement occurs when an increased number of traces are superimposed due to smoothing of the noise background through superposition.

From these considerations and from practical tests, it has been found that the sensitivity of cathode-ray tubes on B-scope displays can be improved by increasing the recurrence frequency, broadening the aerial beam, increasing the pulse length, decreasing the speed of rotation of the aerial and by increasing the brightness of the cathode-ray tube itself by using higher voltages and by using high beam currents and efficient screen materials.

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[2] Carter, C. F.: "An Airborne Radar Navigation and Bombing Aid," I.E.E. Paper.
[3] Hopkinson, R. G.: "Visibility of Cathode-Ray Tube Traces in Radar Displays," I.E.E. Paper.
[4] Steinhardt, J.: *Journal of General Physiology*, 1936, *20*, 104.

[2] and [3] are yet to be published—ED.

The assistance of the staff of the Institution in providing material and illustrations for this and other extracts is gratefully acknowledged—ED.

The C.R. Tube in Naval Radar

Extracted from the paper previously referred to, the Naval section being contributed by D. Stewart Watson, B.Sc., A.M.I.E.E., of the Admiralty Signal Establishment

THE c.r.t. is an essential part of radar equipment, and the rapid development of radar resulted in c.r.t.s being used in large quantities in H.M. ships. A modern ship may have over 40 in use at one time, and, as adequate spares have to be carried, the total number of tubes in the ship is several hundred.

In naval equipment it has been the rule to run the tube with the final anode at earth potential. This complicates the design but allows the operator to touch the face of the tube with impunity, a feature that is of importance when the operator has to write on the screen.

Precision Ranging System

A considerable amount of thought was given in 1941 to the development of a system that would give very accurate ranges, and would at the same time be simple and easy to manufacture. For this reason it was important that a conventional type of tube should be employed. Such a system was developed, the basic ideas of which have been embodied in all subsequent British naval precision ranging equipment.

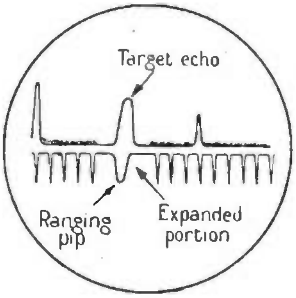


Fig. 1. Display of precision ranging system with expansion of trace.

The picture presented to the range-taker is shown in Fig. 1. The top trace shows ground wave and echoes presented in the conventional range-amplitude manner, except that a small portion has been considerably speeded up. The bottom trace is identical with the top trace, but in place of signals it shows calibration pips. The two traces are separated by a few millimetres.

A special phase shifter allows the calibration pips to be moved, and if the phase shifter is rotated continuously in one direction, the pips will appear to move steadily to the right or to the left. If a pip is first set against the ground wave, and then moved to the right until it is exactly against an echo, the range of the echo can be ascertained from the total rotation of the phase shifter. The calibration pips are derived from a 163.9-kc/s. crystal oscillator, so that a phase shift of 360° represents 1,000 yd.; the calibration pips are thus at 1,000-yd. intervals.

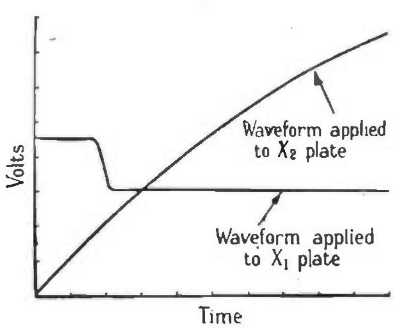
The essence of the scheme lies in the fact that the expanded portion of the trace is selected by a potentiometer, which is so coupled to the phase shifter that the same calibration pip remains in the centre of the expanded portion at all times. This identifies a particular pip and also allows precision setting. The phase shifter can be coupled to a dial which reads the range, the setting of the selected pip against the echo will result in the correct range of that echo being given. It will be appreciated that the range taker sees the whole picture from zero to maximum range, a feature that is of considerable operational value.

The c.r.t. required is a simple electrostatic model. Adequate brightness is called for in the expanded portion, and a really fine focus is useful. The voltages applied to the deflector plates are unusual, as one plate is supplied from a conventional type of exponential time-base generator, while the other is supplied with a step-shaped waveform (Fig. 2).

The technique of setting the calibration pip against the radar echo is one which gives surprisingly accurate results. The scatter of a series of readings on a fixed target at a range of 20,000 yd. is only a few yards.

As radar fire-control equipment grew more complicated it became necessary to adapt the ranging system to meet new requirements. A modified form was invented, and the picture presented to the range taker was as shown in Fig. 3.

Fig. 2.



Comparison will show that the lower trace of the former display has disappeared and that the calibration pip has been replaced by a bright spot. When used for ranging, this bright spot is set on the leading edge of the echo, as shown in the diagram. The spot is obtained in a similar manner to the calibration pips in the former system, except that the pulsed *LC* oscillator is used, *i.e.*, one that starts oscillation when the transmitter fires. All the pips except one are suppressed, and the one that remains is applied as intensity modulation.

Plan Position Indicators

The year 1942 saw the introduction to the Navy of P.P.I.s In a P.P.I. a radial time base is employed, range being measured from the centre outwards, the time base being so arranged that it rotates in synchronism with the aerials.

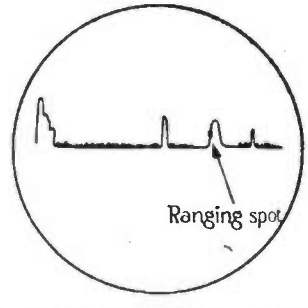


Fig. 3. Modified ranging system with spot for calibrating.

In the absence of signals the trace is invisible, echoes being made to brighten the trace. The P.P.I. thus builds up a radar map of the neighbourhood, the process being facilitated by the use of a c.r.t. with an afterglow screen.

The operational demand is for a tube on which weak signals fade out between one " paint " and the next and stronger signals persist for several " paints." It would be thought that, since the speed of rotation of the aerials may be anywhere between 2 and 15 r.p.m., a series of tubes with different screen materials would be

I.E.E. Radiolocation Convention

required. Fortunately this has not proved necessary, and only one type of screen is used for naval P.P.I.s.

If the time base rotates in step with the motion of the aerial relative to the ship, then, if the ship is turning fast, say, 3 deg./sec., a fixed echo will be at a different point on the tube each time it appears, the angular separation of the points being 18° for an aerial rotating at 10 r.p.m. It will thus be clear that the picture obtained will be difficult to interpret, and that for naval purposes the display for this type of radar set must be arranged so that True North always appears at a definite position on the tube. This can be done (using suitable differential gearing) by combining the ship's course relative to True North (obtained from the ship's gyro-compass system) with the position of the aerials relative to the ship.

Relative Plan Position Indicators

Sometimes for operational reasons a display is required in which ship's head is always at 12 o'clock. This is known as a relative display. As has been explained, to obtain a satisfactory picture it is necessary to arrange that a fixed target " paints " at approximately the same point on the screen for consecutive rotations of the aerial system.

This can be arranged, at the expense of some mechanical complexity, by arranging that a target, say, North of the ship, always " paints " on the same spot on the c.r.t., and that the tube is rotated in step with the ship's alterations in course. The system adopted is shown in Fig. 4. It will be appreciated that this scheme is necessary only at low aerial rotational speeds and with long afterglow screens.

Magnetic Screening

The extensive use of P.P.I.s on board ship brought to light the need for careful magnetic screening of the tube. The amount of screening required varies greatly, depending on the position of the instrument.

It is necessary to guard against deflection of the spot caused by the degaussing coils in the ship, and against changes in the local magnetic field when the ship alters its position in the earth's magnetic field.

In a horizontally mounted tube (*i.e.*, screen vertical) the horizontal component of the earth's field will cause the spot to move vertically as the ship turns through 360°. This trouble becomes more pronounced in the Indian Ocean, since the value of the horizontal field increases compared to home waters by a factor of about 2.

A typical figure for home waters, for a unit without special shielding and in an exposed position, is ± 3 mm. for a VCR516 tube (CV1516) run at 5 kV. In order to ensure trouble-free operation in a local field of any intensity, it is now the practice to shield the tube with a Mu-metal screen, itself surrounded by a soft-iron screen.

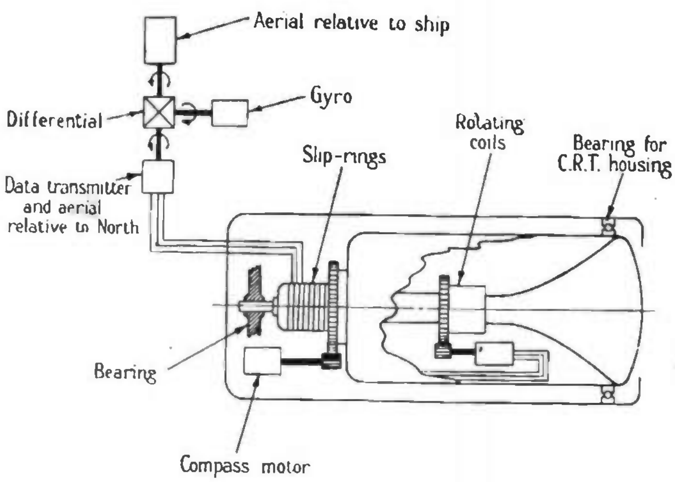


Fig. 4. Arrangement of C.R. tube and mounting to give display relative to position of ship's head, which is at 12 o'clock on the screen.

Use of Film in Radar Training

One application of a c.r.t with photography was in an equipment used for training purposes. A trainer cannot rely on normal air flights, and the problem was to build a simulated P.P.I. display. This was accomplished by recording echo signals photographically and later reproducing them on a P.P.I. tube in the following sequence:

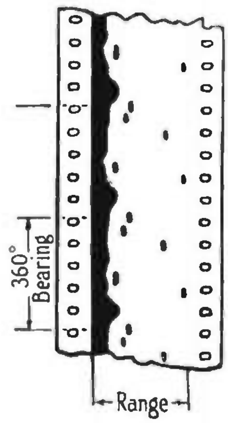
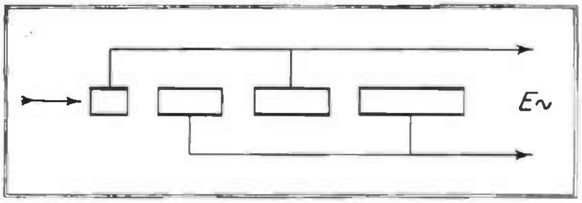


Fig. 1. Film for training in P.P.I. display.

(*a*) *Recording*.—A radar set with a rotating aerial scan puts intensity modulated signals on a blue-screen c.r.t. having a horizontal-line range trace. This trace, repeating at about 1,000 times per sec., is photographed across the width of a continuously moving film (Fig. 1). Now if the aerial scan speed is 1 rev. per 20 sec., the recorded picture will repeat every 20,000 lines, except for the slight changes due to the movement of aircraft.

(*b*) *Reproduction*.—The processed film is made to move past a similar blue tube with the same line trace, but this time at constant brightness. A photocell receives light from the c.r.t. that has passed through the film and been modulated in sympathy with the original signals. The radius-vector time base of the trainer P.P.I. display is synchronised with the time-base line on the blue c.r.t. The scanning coil around the P.P.I. tube which generates this vector is made to rotate at 1 rev. per 20 sec., and the moving film is synchronised to it. The signals from the photocell are amplified and used to intensity modulate the P.P.I. tube, thus giving a reproduced P.P.I. picture.

Nuclear Energy (continued from page 142)



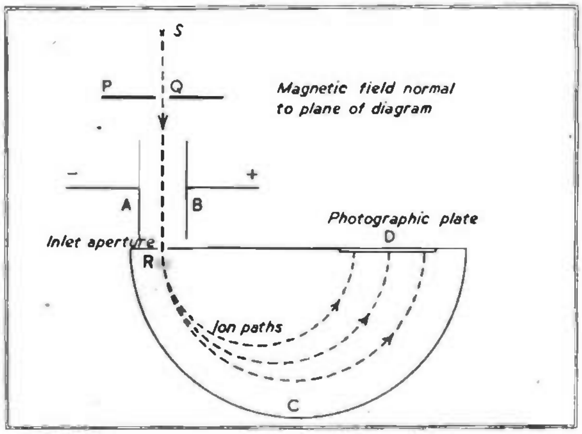


Fig. 5 (right). The Bainbridge mass spectrograph.

Fig. 2 (left). The linear electrostatic resonance ion accelerator. (The electrodes are assembled within an evacuated envelope.)

(3) The orbital radius is directly proportional to the momentum and inversely proportional to the magnetic field intensity. It is also inversely proportional to the ratio e/m.

Production of High Energy Particles

The simplest method is to make use of the direct acceleration produced by a high electric field in accordance with Equation (1). The required high voltage may be obtained in one of many familiar ways, either by the use of cascade transformers and rectifiers or by voltage multiplier circuits; it may also be produced by an electrostatic band or belt generator of the van de Graaff type. The evacuated accelerator tube must be of linear form and suitable insulation must be provided; these two requirements set a practical limit to the maximum energy possible from such a system. Particles having an energy of the order of 1 MEV. have been obtained by these direct methods.

(The energy of 1 MEV. (one million electron volts) is equal to 1.6×10^{-6} ergs and in accordance with the Einstein mass-energy relation is equivalent to a mass of 1.77×10^{-27} gm., or to an atomic weight of 0.00107. In accordance with the quantum theory, it is the energy of a radiation quantum of wavelength equal to 0.0123×10^{-8} cm.)

In order to overcome the insulation difficulties, methods have been developed whereby successive acceleration has been brought about by a relatively low electric field intensity; this has been made possible by introducing high-frequency technique and requiring that the fast-moving ions be in resonance or synchronism with a periodic electric field.

The fundamental principle of all such resonance accelerators was first described by Wideröe and the essential electrode arrangement within an evacuated accelerator tube is shown in Fig. 2.

A series of metal tubular electrodes, separated by gaps and of progressively increasing length, are arranged on a common axis. A high-frequency source ($E\sim$) is connected, as shown, to alternate tube sections so that an electric field is established across each gap, while the inside of each tube is effectively screened from the electric field. A charged particle, entering the system from the left, will thus be accelerated each time it crosses a gap, but its velocity will remain constant each time it is passing through a tube section. If there are n such sections, then in terms of the notation used in Equation (1), the final particle energy will be nVe electron-volts corresponding to a velocity in cm.sec.$^{-1}$ given by:

$$v_n = \sqrt{\frac{2nVe \times 1.6 \times 10^{-12}}{m}} \quad \dots\dots (5)$$

If l_x is the length of the xth tube section, then this length must be such that the time (t) necessary for the particle to pass through must be equal to the half-period of the applied H.F. potential difference; that is to say, $t = 1/2f$ where f is the frequency.

Hence the frequency of the applied p.d. must be such that

$$f = \frac{v_x}{2l_x} \quad \dots\dots (6)$$

The linear nature of this type of tube sets a practical limit and it has been found best suited to the acceleration of heavy particles such as mercury and sodium ions. One inherent advantage of the method is the fact that the ions are concentrated into a narrow axial beam due to the focusing action of the electric field at each gap. In one reported experiment, 36 cylinders and an accelerating potential of about 80 kV imparted an energy of the order of 3 MEV. to singly charged mercury ions; the overall length of the electrode assembly was 185 cm. with a spacing between cylinders of about 20 per cent. of their individual length.

The Cyclotron

The most important practical application of the above principle is the cyclotron or magnetic resonance accelerator which was suggested and developed by E. O. Lawrence in the University of California. As in the Wideröe arrangement, the particle is made to pass repeatedly through the same accelerating potential difference, only use is now made of the influence of a uniform magnetic field set normal to the path of the particle; in other words Equation (4) and its consequences also enter into the theory of the method.

The accelerator electrodes now take the form of two semicircular hollow metal boxes known as "dees" which are placed within an evacuated chamber and set relative to each other with a diametral gap as shown in Fig. 3.

These electrodes are placed between the poles of a large electromagnet so that there is an intense and uniform magnetic field normal to the flat faces of the electrode. An alternating potential difference of the order of 10 kV and of frequency 10^7 c/s is applied across the electrodes as shown in plan in Fig. 4.

Near the centre (S) of the electrode system and slightly below a hot cathode is mounted and the emitted electrons, which are collimated by the magnetic field and accelerated by a subsidiary electric field, produce ionisation in the gas at low pressure which has been introduced through a small leak into the evacuated chamber. (A residual air pressure less than 10^{-6} mm.Hg. is established by pump and a suitable gas, from which ions are to be produced, is admitted until the resulting pressure is of the order of 10^{-4} mm.Hg. Protons require hydrogen gas and α-particles require helium gas. Deuterons are obtained from deuterium gas which has been generated by the action of heavy water vapour on zinc filings heated to 350° C.) The ions so formed pass into the gap between the electrodes and receive their first acceleration; they move into the electrode which happens to be negative at the time and, in virtue of the magnetic field alone, pursue a semicircular path of small radius. On emerging at the next gap they are further accelerated to perform their second semicircular orbit of slightly larger radius. The ions thus spiral out as shown in Fig. 4, crossing and recrossing the gap many times till eventually they reach the periphery and are finally guided away by a deflector plate to a metal-foil window, to emerge finally as high velocity particles ready for use in a disintegration experiment.

The success of the method depends on the exact synchronisation of the ions with the periodic field. The frequency is defined by the relation

$$f = \frac{\omega}{2\pi} = \frac{He}{2\pi cm} \quad \ldots\ldots\ldots\ldots (7)$$

in extension of Equation (4).

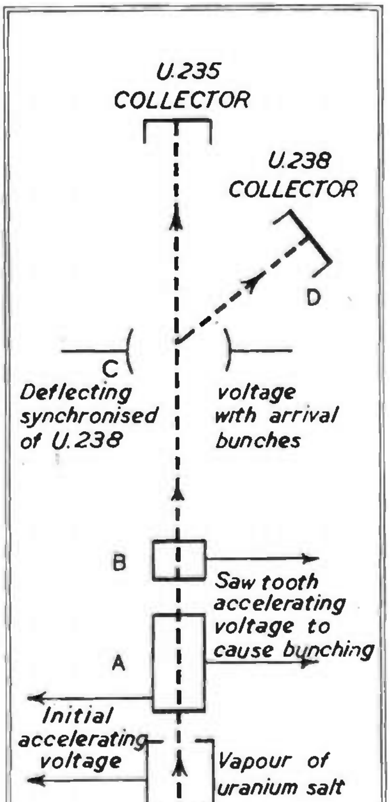
Once the resonant or synchronous condition has been established, the ions move in semicircular orbits of ever-increasing radius and they receive an increment of energy each time they traverse a gap which is proportional to the p.d. between the electrodes. One important feature of the resonant principle is the fact that the ions are subjected to velocity analysis by the action of the magnetic field; at any particular radius all the ions have the same energy. The ions which do not cross a gap at a potential maximum will not receive the maximum degree of acceleration, they will travel through the electrode system more slowly and will thus have to traverse the gaps oftener till they attain the energy appropriate to the point of exit. Furthermore, the ion beam is constantly being subjected to a focusing action by the combined electric and magnetic fields, so that a continuous well-defined beam of homogeneous high-energy particles is emitted from the terminal window.

Some idea of the size of a modern cyclotron can be obtained from the following data, which relate to the 37-in. machine built by Lawrence at Berkeley:

Weight of electromagnet = 85 tons. Weight of copper in magnet winding = 9 tons. Magnetic field intensity for a gap between poles of 3½ in. = 15,000 oersted. A radio-frequency oscillator of 20 kW supplies a potential difference of the order of 15 kV to the electrodes. With such a machine (so-called, because its size warrants the use of engineering terminology) it has been possible to produce α-particles of energy equal to 16 MEV. This machine has been superseded by a still larger one possessing pole faces 60 in. in diameter. Here, to quote just one figure, the weight of the entire unit is of the order of 200 tons. With this monster, Lawrence has produced 8 MEV. protons, 16 MEV. deutrons and 38 MEV. α-particles. Even this is not the limit, for a 184-in. cyclotron is now planned which will deliver deutrons of 100 MEV. energy.

Apart from any consideration of financial and material resources (to say nothing of laboratory space and strength), one is justified in wondering what the upper energy limit is going to be. When it is realised that the splitting of one uranium atom involves an energy release of about 175 MEV., it is at once evident that cyclotron technique has just reached the half-way mark and the road of advance is beset by ever-increasing difficulties of which probably the most serious is the relativistic increase in mass with increase in energy. In this discussion it has been assumed that the particle mass remains constant so that it has been possible to adjust the drive frequency (in accordance with Equation (7)) to accommodate resonance. With a variable mass, it would appear necessary to provide for a variable frequency as any one ion passes from the centre to the outside. This would seem to be overcome by the possibility of designing the magnetic pole system in such a manner that azimuthal variation in the magnetic field exactly compensates for the increase in effective mass. This, however, is by no means the last word, since the focusing of the beam is also dependent on the field configuration.

Fig. 6. The isotron method of isotope separation.



Quite apart from any question associated with the utilisation of nuclear energy in industry, the continued development of the cyclotron technique will provide a means for gaining further fundamental knowledge and it will facilitate the manufacture of artificially produced radioactive substances which are proving of such value as tracers in biological investigations and in the treatment of malignant pathological conditions.

The accompanying illustrations, together with their captions, afford some idea of the external appearance of typical cyclotrons in current use.

Mass Spectroscopy and Isotopes

Prior to the discovery of radioactivity, it was tacitly assumed that all atoms of any one element were identical in all respects, including also mass. However, a study of the elements produced in the process of spontaneous disintegration provided sufficient evidence to show that all atoms of an element need not possess identical mass. Several groups of elements having identical chemical properties but different atomic weights are formed during radioactive disintegration; these elements occupy the same place in the Periodic Table and are known as isotopes.

Since practically all the atomic mass is concentrated in the nucleus, isotopic mass is essentially nuclear mass and the classical researches of Aston and others have gone far towards a complete understanding of nuclear structure. The search for isotopes among non-radioactive substances was initiated by J. J. Thomson in 1910, who succeeded in establishing the fact that neon possessed two isotopes of mass 20 and 22. This discovery accounted for the large discrepancy between the actual atomic mass of neon (20.2) and the generally accepted view that such masses should be whole numbers, a condition required by the unit structure of all atomic nuclei.

The method employed by Thomson was to determine the ratio of the charge to mass of positive ions formed in an electrical discharge tube containing neon gas. The focused ionic beam was analysed by parallel electric and magnetic fields and the resulting deflection was observed on a fluorescent screen; all ions with the same value of e/m, but with different velocities, forming a single parabola. This method, essentially qualitative in nature, was soon displaced by the more precise instruments of Aston and Bainbridge, to which latter attention will now be directed.

Any modern instrument for determining isotopic mass is known as a mass spectograph, since all positive ions of the same mass are made to fall on a single line on a photographic plate in exactly the same way that all light of the same wavelength falls on a single line in the optical spectrograph. The Bainbridge mass spectrograph is shown in diagrammatic form in Fig. 5.

Positive ions, emitted by a source at S, are accelerated in the usual manner by a potential difference applied between S and a plate P which has a small aperture at Q. The particles thus acquire a velocity in accordance with Equation (1) and some get through the aperture to the other side to be velocity-selected by an electric field applied between the parallel plates A and B and by a simultaneously applied normal magnetic field. Only those ions which possess one very definite velocity are allowed to pursue a linear course and enter the semicircular chamber C. They come under the influence of a uniform magnetic field applied normal to the plane of the diagram. In accordance with the theory already given (*see* Equations (3) and (4)) these ions will pursue semicircular orbits as shown, the radius on this occasion

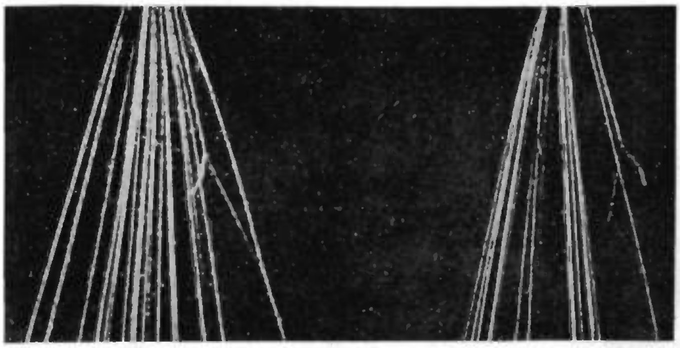


Fig. 8. Stereoscopic photographs showing α-particle tracks in nitrogen. The forked track indicates an inelastic collision with a nitrogen nucleus resulting in the ejection of a proton. —"*Radiations from Radioactive Substances*" *by Rutherford, Chadwick & Ellis, (Cambridge Press.)*

depending on the mass of the particles, since the velocity of all on entry is the same.

If the potential difference between selector plates A and B is V, and if the separation is d, then the force (towards A) on a positively charged particle (e) is given by Ve/d. Counteracting this force is that due to the magnetic field H and so only those ions which possess one velocity v will pass through undeflected; in other words, since $Ve/d = Hev$,

$$v = \frac{V}{Hd} \quad \text{.......................} \quad (8)$$

If the same magnetic field intensity is operative within the chamber C, then on combining with Equation (3) we obtain for the mass of an ion:

$$m = \frac{redH}{V} \quad \text{.......................} \quad (9)$$

Provided the ionic charge is the same, the orbit radius is a measure of the isotopic mass, and if a photographic plate is inserted at D a series of lines will appear constituting the mass spectrum of the particular element under observation. The relative intensity of the lines is also a measure of the relative abundance of the isotopic content in a given element. The apparatus may be calibration-checked by introducing ions of known mass during the course of an exposure.

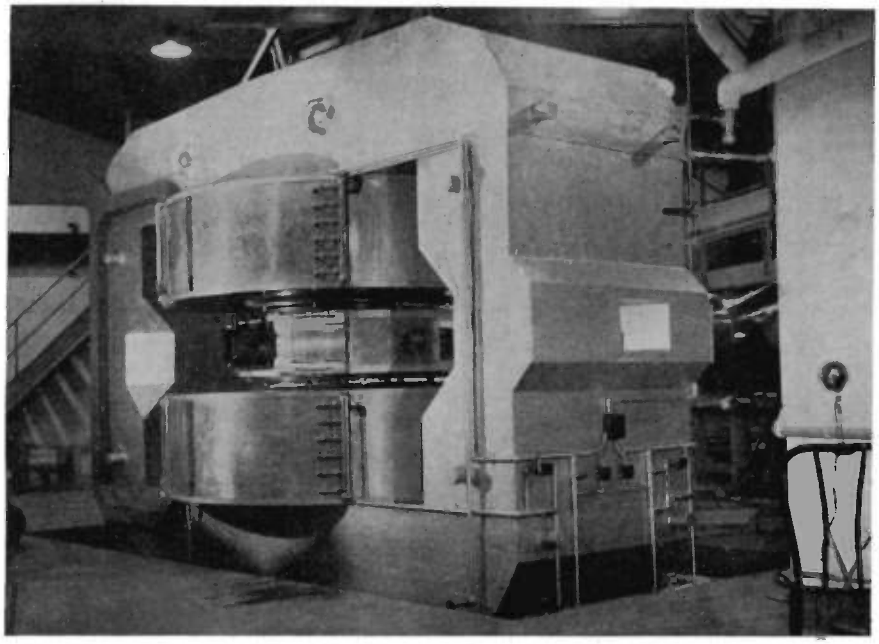
Isotopic Separation

The separation of the uranium isotope of mass number 235 (U_{235}) from that of mass number 238 (U_{238}) constituted one of the major investigations in the development of the atomic bomb, and in this connexion two methods were explored based on electromagnetic and on diffusion principles.

In the electromagnetic method, the principle of the Bainbridge mass spectrograph was employed, and, since one of the Berkeley cyclotron electromagnets was incorporated, the device came to be known as the calutron. Positive uranium ions were produced by firing a beam of high-speed electrons from an electron gun through the vapour of a uranium salt. These ions, which may be regarded as originating at S in Fig. 5, are then treated in the manner already described, only instead of a photographic plate there are now mounted two collectors for U_{235} and U_{238}, the former collector being placed nearer to the inlet aperture R. The whole of this operation, like that in the mass spectrograph, is performed in an evacuated chamber.

Another method, dispensing altogether with a magnetic field, makes use of the klystron bunching principle and the device has been called the isotron. A diagram of the electrode arrangement is shown in Fig. 6, and it is to be understood that the whole of the assembly is contained in an evacuated vessel.

As before, uranium ions are produced by allowing a beam of high-speed electrons to pass through the vapour of a uranium salt. The emergent ion stream, containing U_{235} and U_{238}, is then accelerated into a cylindrical tube A where the faster moving U_{235} ions will begin to separate from the U_{238} ions. On emerging from A, the ions are subjected to a bunching electric field of saw-tooth waveform applied between electrodes A and B, the latter being also of cylindrical form. The final bunching is allowed to take place as the ion stream passes up the evacuated tube so that at C there are passing well-defined bunches of U_{235} and U_{238} ions. The beam is here subjected to a transverse deflector electric field (of square-topped waveform) which is so synchronised with the arrival of the bunches that the U_{235} ion bunch is allowed to pass straight up the tube while the following U_{238} ion bunch is deflected and made to pass along the side-tube D. Both the main and side tubes are terminated by suitable collector electrodes as shown. It is understood from publications on the subject that the isotron method has



General view of a cyclotron in which the cast steel pole structure, field coils and magnetic gap may be seen.

—By courtesy of Electronic Industries.

not yet been fully developed. If, however, it shows some promise in the separation of the uranium isotopes which only possess slightly over 1 per cent. mass difference, then it may well furnish a useful method for isotopic separation in cases where a higher percentage mass difference is present. As far as immediate war needs were concerned, attention was directed to the calutron method.

While the electromagnetic methods are of particular interest to readers of this journal, there are other methods of equal importance in the realms of physical chemistry. Certain of these methods may, with advantage, be employed to enrich the raw materials before they are subjected to the electromagnetic methods. In the atomic bomb development, considerable attention was given to the thermal diffusion method. If a gaseous mixture is exposed to a temperature gradient, a diffusion process takes place in which the lighter components tend to concentrate in the hotter regions and the heavier components in the colder regions. The efficiency of this process is, however, offset by normal diffusion unless the temperature gradient is also utilised to create a differential convection effect whereby the hotter gas is carried off in one direction while the colder gas is carried off in another. A normal diffusion process may be carried out in accordance with Graham's law wherein the diffusion velocity of a gas through a porous medium is proportional to the square root of the molecular mass, provided the pores are small compared with the molecular mean free path.

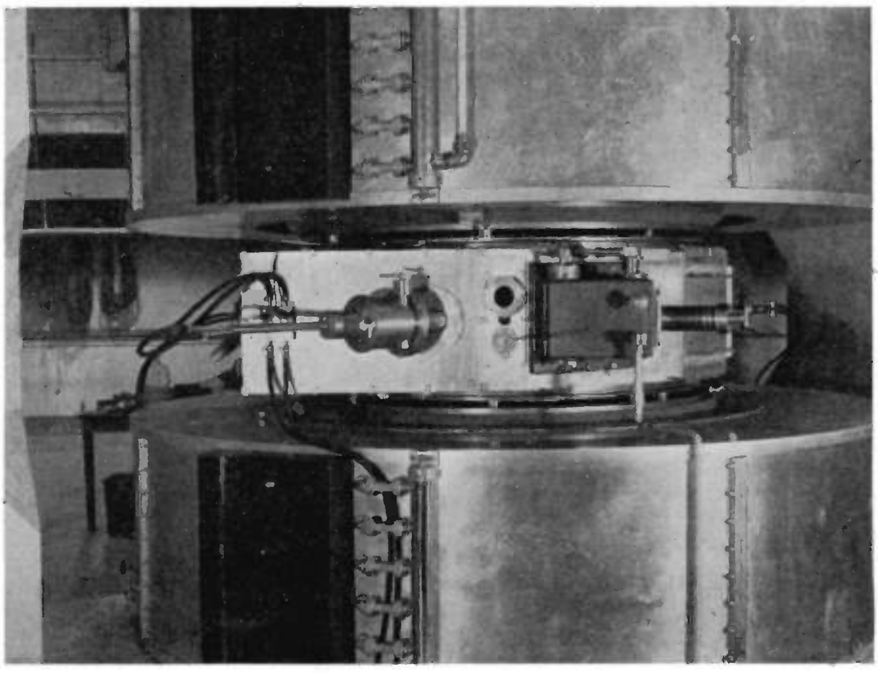
Other methods of isotopic separation, which here need only be named, involve gravitational or centrifugal diffusion, electrolysis, fractional distillation and chemical exchange.

The Wilson Cloud Chamber

The experimental study of nuclear reactions has been made possible in an extremely simple manner by a method developed by C. T. R. Wilson in 1911. If a gas is *suddenly* allowed to expand, it will do so adiabatically and will thereby become cooled down; the work which the gas must do in expanding is derived at the expense of thermal energy. If, then, the gas is saturated with aqueous vapour, a fog will establish itself within the volume due to the formation of droplets of water by condensation on dust and other particles present. If the gas, initially made dust free by a series of preliminary expansions and fog precipitations, is now traversed by a stream of, say, α-particles, a subsequent expansion will reveal the tracks of the particles in the form of vapour trails. These trails are formed by the condensation of water vapour on the ions which have been produced in the paths of the α-particles and they are known as cloud tracks. A diagrammatic

Close up of target and accelerating chamber of the Carnegie cyclotron. In using these for uranium isotope separation, a number of modifications were made.

—By courtesy of Electronic Industries.



sketch of the cloud chamber is shown in Fig. 7. It consists, in its simplest form, of a cylindrical chamber closed at the top by a plate of glass. The bottom of the chamber is closed by a blackened piston which is spring loaded and triggered to bring about a sudden expansion of the gas in the chamber at any required instant of time. The gas is maintained in a saturated condition by covering the walls of the chamber with a thin layer of wet gelatin. Near the end of an expansion, the α-particles are admitted and the resulting ionic tracks are rendered visible by means of reflected light. In practice, the tracks are photographed by two cameras set at right angles to each other so that a three-dimensional or space picture may be obtained.

Analysis of Wilson Cloud Tracks

In Part I an account was given of the bombardment of nitrogen by α-particles emitted from Ra.C and this was studied by Blackett with the help of the cloud chamber. Most of the observed tracks, involving some 500,000 in number, were straight and indicated the normal passage of an uninterrupted α-particle. Some α-tracks were found to terminate in a fork, which, in the majority of cases, was due to an elastic collision between an α-particle and a nitrogen nucleus. In an elastic collision (akin to that which occurs between two billiard balls) the total kinetic energy is conserved and the deflected α-particle and recoiling nitrogen nucleus give rise to the fork, the thicker and much shorter limb indicating the path of the nitrogen nucleus. In about eight cases, however, forked tracks of an unusual kind were observed; they were found to comprise one very thin track typical of a proton and another much thicker and shorter track typical of a heavy particle—in this case an oxygen nucleus. This is typical of an inelastic collision involving a nuclear transmutation in accordance with the nuclear reaction equation

$${}_7N^{14} + {}_2He^4 \rightarrow {}_8O^{17} + {}_1H^1$$

A study of the lengths and directions of the tracks showed that the total kinetic energy of the particles after collision was less than that of the incident α-particle by about 0.5 MEV. Some of the initial energy had thus been absorbed; the nitrogen nucleus had captured the α-particle and had finally split into an isotope of oxygen and a hydrogen nucleus.

A typical stereoscopic photograph involving one example of this reaction is shown in Fig. 8.

ABSTRACTS OF ELECTRONIC LITERATURE

INDUSTRY

The Theory of the Mercury-Vapour Pump and a New High-Speed Pump

(P. Alexander)

Theoretical considerations and experimental results show that the pumping effect of a mercury-vapour pump, usually called a diffusion pump, is not explained by Gaede's theory of the diffusion principle. Starting from Langmuir's condensation principle the same considerations lead to a different theory; a new pump has been designed on the basis of this theory. This pump has a volumetric pumping speed of the order of 1,000 litres/sec., and its effective working range extends from the lowest pressures up to 10^{-1} mm. of mercury.

—*Jour. Sci. Inst.*, Jan., 1946, p. 11.

Role of Automatic Rematching in H.F. Heating

(E. Mittelman)

The continuous rematching of the high-frequency generator to the varying impedance of the load during induction or dielectric heating is discussed. Variations in permeability and dielectric constant are discussed in relation to the problem of rematching. A schematic diagram of a rematching system in a high-frequency induction generator is given and graphs are used to compare the time required by two similar generators, one with and one without rematching, to reach a given temperature. The merits of automatic rematching are also pointed out.

—*El. World*, 4/8/1945, p. 98.*

Curve Tracer for Acoustic Devices

(R. K. Hellmann)

Acoustical devices are now manufactured in accordance with a performance specification which calls for a predetermined output-versus-frequency curve. Quality control over full-scale production output of handset receivers is obtained by the use of a heat-frequency oscillator whose frequency is varied by a mechanical drive, a long persistence cathode-ray tube, and suitable test fixtures. Production testing by the curve tracer can be applied advantageously for loudspeakers and receivers.

—*Electronics*, December, 1945, p. 130.

Supersonic Flaw Detector

(R. B. DeLano)

The supersonic flaw detector described in this article will locate defects in castings at distances of 10 ft. from the testing surface. The synchroniser gives three different output pulses sixty times a second and the sweep amplifier provides push-pull horizontal deflection for the cathode-ray tube. The pulse generator generates a 1,000-volt pulse and is continuously variable in overlapping ranges of frequency from 0.5 Mc/s. to 12 Mc/s. For longitudinal waves, an X-cut piezo-electric quartz crystal is used as an electro-mechanical transducer. It is energised with supersonic pulses and held against the object, the time for pulses to travel to flaw and back being measured with an oscilloscope.

—*Electronics*, Jan., 1946, p. 132.

MEASUREMENT

Light-Beam Wattmeter

(S. O. Richardson)

The need for a portable wattmeter capable of giving accurate readings in the frequency range of 400 to more than 3,000 cycles per second has led to the development of an instrument incorporating the light-beam principle. The design is similar to that of the Drysdale type of astatic reflecting dynamometer except that the moving system assembly is electrically and mechanically suspended by two taut suspensions instead of being freely suspended. The article deals with instrument losses, errors due to frequency and the calibration of the meter, and discusses applications of the basic instrument.

—*G.E. Rev.*, October, 1945, p. 59.*

A New Type of Differential Analyser

(V. Bush and S. H. Caldwell)

This paper describes a new type of differential analyser, of greater precision, scope and flexibility than earlier machines, but which retains and emphasises the useful features of the original design. The machine is intended to serve investigators working either locally or at a distance with equal ease. The history of differential analysers is briefly reviewed.

—*Jour. Frank. Inst.*, October, 1945, p. 255.

* Abstracts supplied by the courtesy of Metropolitan Vickers Electrical Co. Ltd., Trafford Park, Manchester

Exhibition of German Electronic Equipment

FROM March 4 until March 16 an exhibition was organised at Earls Court, London, by the Ministries of Supply and Aircraft Production (S.I.G.E.S.O.). It gave an opportunity to the manufacturers and research workers in electronics to see the more important techniques developed by their counterparts in Germany during the war years. Further, it provided them with a chance to ask for further information on specific items of equipment or on subjects of interest to them.

Spectacular amongst the exhibits were a Junkers JU88 night fighter with its radio equipment clearly labelled, a three-ton transmitter lorry, a Post Office mobile repeater station and numerous radar units and aerial arrays. There was an electron microscope by Siemens and Halske, rather more bulky than those we have seen in this country.

In general, however, it may be said that in each branch of the science normal practices were followed; deviations were, therefore, all the more interesting.

Components

Amongst the components on view one of the most outstanding features was the ubiquitous employment of ceramics. Metal welding to ceramic and wiring on ceramic are widely used, notably in the banks of composite capacitors.

A selection of plugs and sockets represents the best and most interesting German designs. Their strong points are the wide use of light alloy die-castings and their versatility due to the general interchangeability in the housings of the plug and socket inserts. In addition the provision of multiple cable entries makes it possible to use the housings as junction boxes. On the other hand many of the plugs and sockets are not waterproof so would be unsuitable for tropical use while the lack of sound contact between the housings when mated leaves them insufficiently screened.

An interesting component is a 2,000 volt electrostatic voltmeter with magnetic damping and a small brush intended to clamp the moving vane when the instrument is not in use.

Valves

The excellence of finish in the widely-used pressed glass bases for valves was particularly noticeable while the technique of metal to glass welding was epitomised in an X-ray mercury vapour rectifier. The gun, eight accelerating electrodes and anode, all mounted axially, are each sealed to their adjacent sections of the glass tube, the resulting alignment being exemplary. This tube has a final anode potential of 200,000 volts and passes a direct current of 1.2 amps.

Until the Germans captured an H2S equipment they were unable to use the centimetre wavelengths. This is clearly indicated in their LMS.10 pulse magnetron, copied from the British CV.64, with a peak power of 15,000 watts and wavelength range of 9.1 cms.

An interesting divergence from normal practice is the method of mounting some of the miniature valves. Briefly, the chassis is recessed to take the whole valve which—by usual standards—is inserted in reverse, contacts being made by radial pins. The insulating pin by which the valve was held is then removed, leaving the valve " base " flush with the outside of the chassis.

Relays

Several relays of miniature construction were on show. The rather more interesting features, however, were embodied in the more usual sizes.

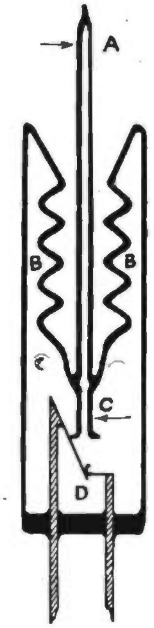


Fig. 1.

One high-voltage aerial changeover relay was noteworthy. The changeover contact assembly consists essentially of a piece of soft iron pivoted so as to operate the switch contacts. It is mounted within an evacuated glass envelope and actuated by two external solenoid electromagnets fitted to the assembly, one solenoid being used to actuate the contacts in each direction. At 24 volts nominal, the operating time is 5-7 milliseconds. The aerial and transmitter connexions are brought out of a ceramic shroud which provides insulation for high voltage working of 7,000 volts; the low voltage receiver connexion being brought out at the opposite end of the envelope.

Perhaps rather more novel was the switch, the contacts of which are operated by a flexible glass rod. The basic design of the magnetic circuit is similar to the G.P.O. pattern type 3,000 relay, but the orthodox contacts are replaced by a heavy duty "make" contact assembly mounted in an evacuated glass envelope. The sectional diagram shows the operation of the assembly (*see* Fig. 1). Movement of the central glass rod is brought about at A by the operation of the relay itself. Due to the " concertina " formation of the tube B, to which it is attached, tube B is slightly flexible and acts as a pivot, hence C moves as indicated, so breaking contact at D.

Communications

The outstanding feature in all the communications equipment was perhaps the very high degree to which intricate die-castings are used in addition, as already mentioned, to the large number of uses of ceramics. Towards the end of the war, however, presumably as a result of the machinations of our own Ministry of Economic Warfare, die-castings were outmoded in favour of what appears to be most inferior stampings.

In some models of civilian wartime receivers a paxolin chassis is used instead of one of pressed steel. Apparently adequate screening is obtained by the use of metallised valves, coil cans and metal foil on the floor of the cabinet. In one case the metal foil is mounted on a sheet of cardboard which, being larger in area than the floor of the cabinet, is folded upwards and clamped to the chassis itself when in its cabinet.

One ingenious device was a thermocouple check meter for clipping on the input terminals of a high-frequency transmitting aerial.

Acoustics

There were on view three types of recorder using plastic tape impregnated with red iron oxide. These recorders, some of which were used at the front by German war reporters, have a frequency response of from 100 to 6,000 c/s. When recording music the tape speed is 77 cm/sec. giving a half-hour recording, but on speech it can be run as slowly as 39 cm/sec, resulting in a record of one hours' duration.

The mine detectors, seven different types of them, are in general, regarded as inferior to those of British manufacture. One novel feature, however, is the provision of a visual indicator on the arm of one of the detectors, in addition to the usual aural devices. This, however, is not thought to be of much practical use.

Infra Red Equipment

The principle of the infra-red image convertor is fairly well known. Infra-red radiation passing through a lens is brought to a focus on a screen responsive to it. This screen then emits electrons which, by use of accelerating electrodes, are guided to a second screen, but of a zinc sulphide type. On this second screen the electrons produce a visible image of the original source of infra-red radiation.

Considerable work in this field was done by the German electronic engineers, but the war ended before any operational benefits could be gained. On show were the image convertors themselves, telescopes for the detection of aircraft by the infra-red radiation from their exhausts and equipment for assisting tank drivers. The area in front of the tank is illuminated by infra-red radiation and the infra-red telescope permits a clear vision for driving. A convincing demonstration was given in a darkened room. Figures, invisible to the naked eye, were illuminated by an under-run electric radiator and were seen clearly through a tank driver's infra-red equipment.

Other portable equipment included combined telescopes and projectors used as machine gun and rifle sights.

In this same section was the Donau or Wärme Peil Gerät thermal ship defector, having a range of 15-30 KM. Thermal radiation from the funnel of a ship is focused by a concave reflector on to a bolometer consisting of two very thin strips of antimony. These strips form two arms of a Wheatstone bridge and the heating of one strip throws the bridge out of balance. The out-of-balance current is amplified and fed to a galvanometer.

Navigational Aids

A comprehensive collection of photographs, diagrams, layout models, aerial arrays and actual equipment give an indication of the vast amount of work expended in this field. Operation of " ' Y ' Gerät " (similar to the British " Benito ") range-measuring system, " Bernhard," " Erika " and " Komet " (these last two were non-operational) systems were dealt with and the more recent " Egon," " Goldwever," " Mond," " Goldsonne " and " Hermine " systems described.

More important, perhaps, is the " Sonne " navigational system which was developed in order to provide a method of determination of bearings and fixers (using two such stations) of a receiving point relative to the ground station (or stations). Typical working ranges are about 1,500 miles over sea and 750 miles over land. One of the main advantages of this system is that since operation takes place in the band 250-450 Kc/s the standard medium frequency airborne receiver is used, thereby necessitating no additional airborne equipment. A station for the British version " Consol," is at present in course of erection at Bushmills in Northern Ireland.

Telemechanics

Radio control units of V1, V2, the Hs 293 glider bomb and rockets, acoustic and electrostatic proximity fuses were all covered in the telemechanics section. In addition to the apparatus itself, highly instructive diagrams and sketches helped to complete the picture.

The very helpful attitude of all the demonstrators bore out the sincerity of the invitation to ask questions. Any queries they could not answer were referred to the technical information stand or were noted so that a written reply could be given by an expert in the appropriate field and the answer given general circulation. Any enquiries subsequent to the exhibition may be addressed to:

S.I.G.E.S.O.,
Enquiry Office, M.S.A.P.,
40 Stratton Street,
London, W.1.

P. I. NICHOLSON.

H.F. Band-Pass Filters

Part 4 (conclusion) Practical Example in Band-Pass Design

By H. PAUL WILLIAMS, Ph.D., A.M.I.E.E.*

3.1 General

THE purpose of this section is to give those who have had little or no experience in band-pass design an idea of the problems involved in an actual practical case.

The problems are considered in some detail. In practice one is not likely to go into the "pros and cons" so carefully. But it should be remembered that no short cuts ought to be taken in radio design until one is fully aware of the degree of approximation to which one is working.

As an example, the 100 kc/s. I.F. stages of a double superheterodyne receiver have been chosen. The figures quoted are usually rounded off for easier reading but otherwise are essentially correct.

In Fig. 18 we have a simplified circuit diagram of the stages involved.

V_1 is a frequency changer which converts the first I.F. frequency of 1,700 kc/s. into an I.F. of 100 kc/s. The first I.F. frequency provides good second channel suppression while the second provides good selectivity. The overall selectivity curve is, in fact, almost identical with the response curve of the 100 kc/s. I.F. stages.

V_2 gives further amplification.

V_3 contains a diode rectifier and first L.F. amplifier.

V_4 is a heterodyne oscillator for C.W. working and a voltage from it is injected via a small condenser C_0 on to the diode rectifier.

* Standard Telephones & Cables, Ltd.

3.2 Statement of the Problem

The specification is as follows:

(a) The response over $\pm 2\frac{1}{2}$ kc/s. to be flat to within ± 2 db.

(b) The attenuation at ± 10 kc/s. to be as great as possible.

(c) The change of response with bias not to take us outside the limits set in (a).

The I.F. assemblies available have:

(a) Inductances which use two "E" type radio dust cores. With these a Q of 125 is obtained when $L = 9{,}000$ μH. When two of these inductances are as close as possible, the mutual coupling is 5 per cent.

(b) Trimmers with a range of 5 to 100 $\mu\mu$F.

(c) Adequate room for a fixed condenser and a small resistance across each circuit.

We shall assume that no "wobbulator" (by the use of which the response curve could be shown directly on a C.R. tube) is available.

3.3 Theoretical Considerations

Dynamic Impedance of Circuits

These cannot be considered satisfactorily until we know the damping effect produced by the associated circuits. The experimental procedure for these determinations is given in the next subsection. The results will be quoted here.

By itself on a Q meter, a typical coil shows Q = 120 at 100 kc/s. and tunes with 270 $\mu\mu$F.

$\therefore$ Dynamic impedance,

$$Q\omega L = 700{,}000 \text{ ohms.}$$

In circuit A (*see* Fig. 18).

Q = 45 (full volume, 1,600 kc/s. oscillator working).

$\therefore Q\omega L = 265{,}000\Omega$.

Dynamic impedance of tuned circuit only $= 700{,}000\Omega$.

$\therefore$ Impedance of associated circuit $= 425{,}000\Omega$.

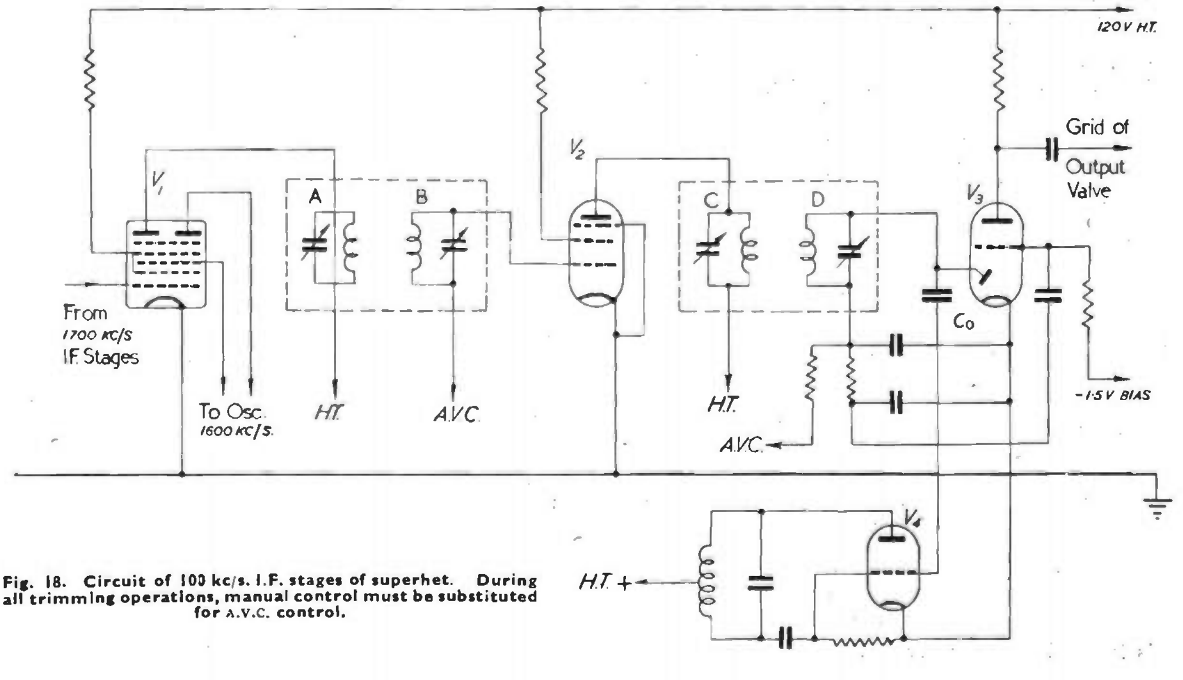


Fig. 18. Circuit of 100 kc/s. I.F. stages of superhet. During all trimming operations, manual control must be substituted for A.V.C. control.

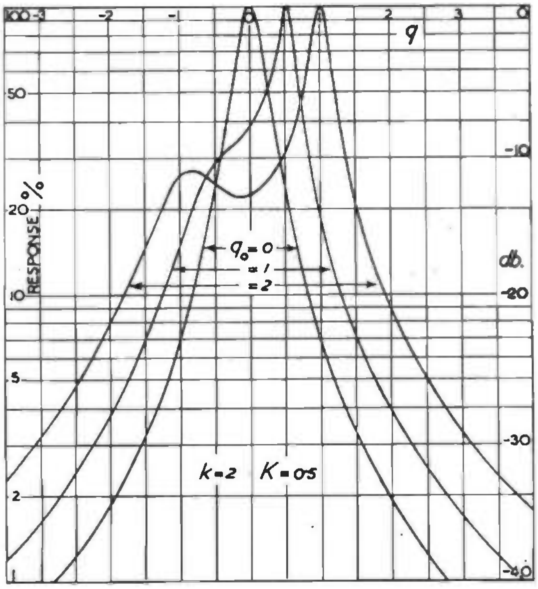


Fig. 22 (left).

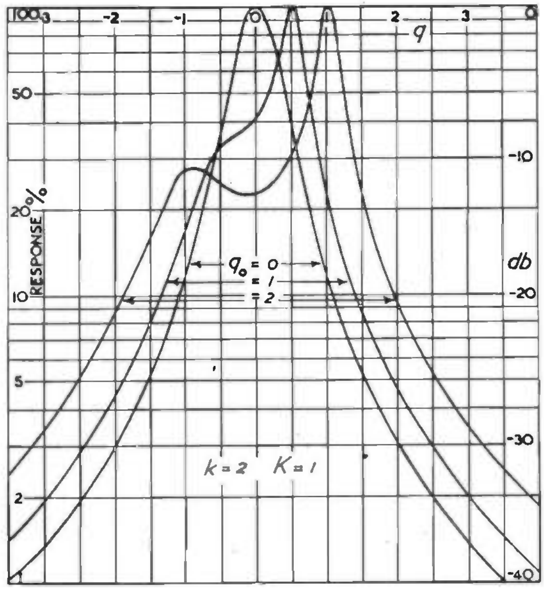
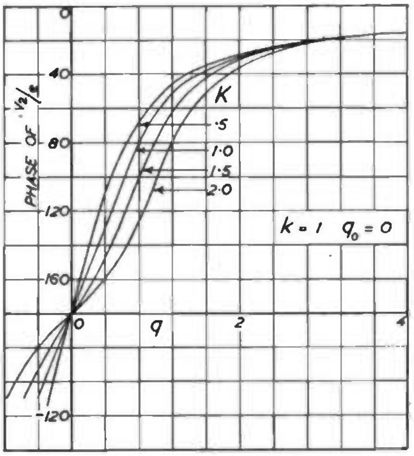


Fig. 23 (right).

Fig. 25 (below)



Similarly, it was found that the total damping impedances across the tuned circuits were:

Circuit A—400,000—1,500,000Ω (full to minimum volume)
B—700,000Ω
C—300,000—1,000,000Ω (full to minimum volume)
D—150,000Ω

It will be noticed that the damping in the anode circuits varies with the volume (*i.e.*, with grid bias). The variations are less in the case of V_1 due to the permanent bias produced by the oscillator section. Strictly speaking, of course, the damping varies over each cycle of the injected oscillator voltage, but since the frequency of the oscillator is several times that of the I.F. frequency the result is similar to a steady bias.

These impedance values immediately limit the effective Q of any circuits we may use, but even so we have something to spare for the required band-widths.

Circuits C and D.

The most severe damping occurs in the case of the tuned circuit D which is associated with the diode detector. Now it is a good practice to keep the damping of a pair of circuits as equal as possible so that slight mistuning will not cause asymmetry in the response curve. To achieve equal damping in this case, it is necessary to bring C down to a dynamic impedance of 125,000Ω. It will then equal that of D, which is 700,000Ω shunted by 125,000Ω.

Fig. 26.

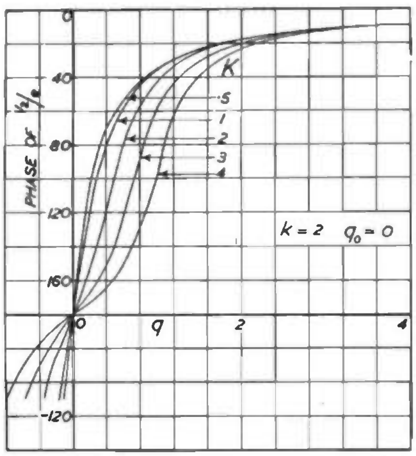


Fig. 27.

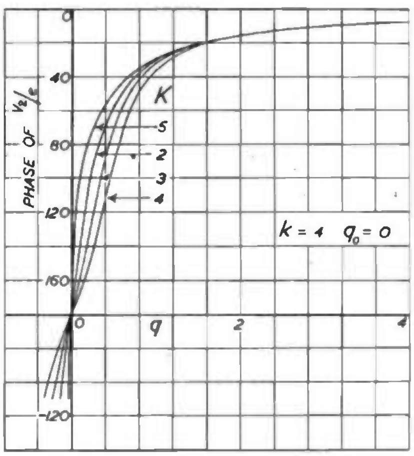
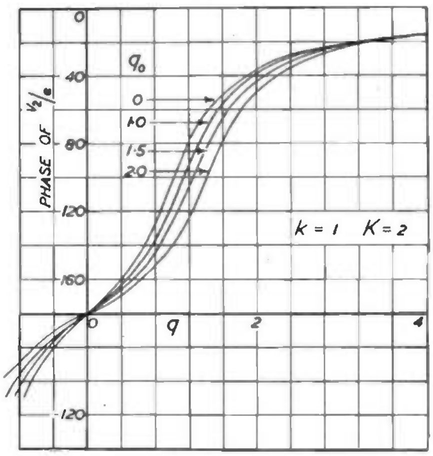


Fig. 28.



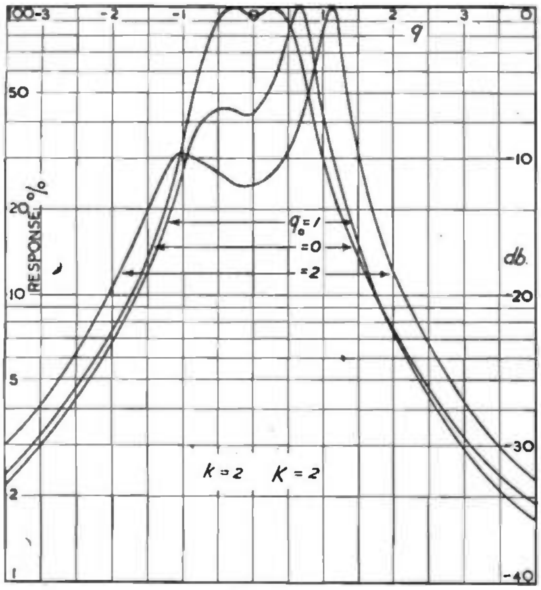


Fig. 24.

Fig. 29 (right).

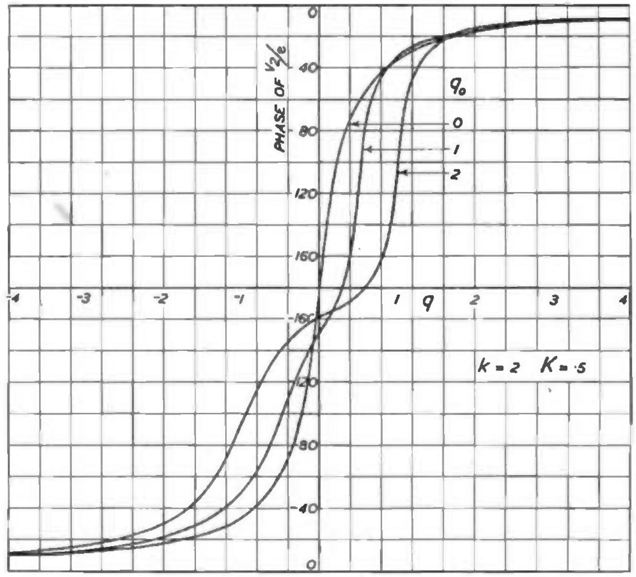
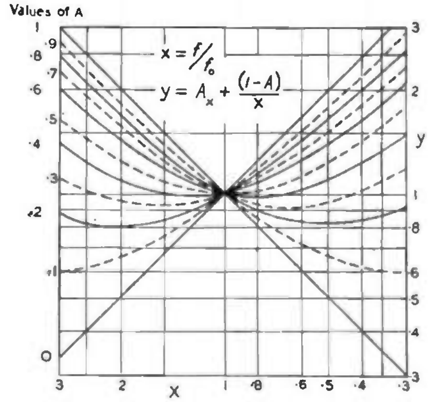


Fig. 33 (right).



The value of 125,000Ω represents a Q of 20. Therefore if both circuits have this Q, the coupling will be exactly critical, *i.e.*, $K = 1$ (K = percentage coupling × Q = 5/100 × 20).

To reduce the dynamic impedance of C we must add a damping resistance. This will also have the effect of stabilising the variations in damping due to changes in valve impedance. If the coupling is taken as critical at full volume (300,000Ω damping) then the required resistance is approximately 200,000Ω.

At minimum volume the effective impedance is made up of 700,000Ω due to coil losses, 200,000Ω due to the damping resistance, and 1,000,000Ω due to the valve impedance. These three in parallel give 135,000Ω. This is only a small increase in dynamic impedance and may be regulated so that the coupling can still be considered to be critical.

On the curves for critical coupling ($K = 1$) and equal damping ($k = 1$) we now examine for the attenuation at ± 2.5 kc/s. and ± 10 kc/s. The band-width of a single circuit in the present case is 5 kc/s., therefore the required q values are ± 0.5 and ± 2.

Fig. 30.

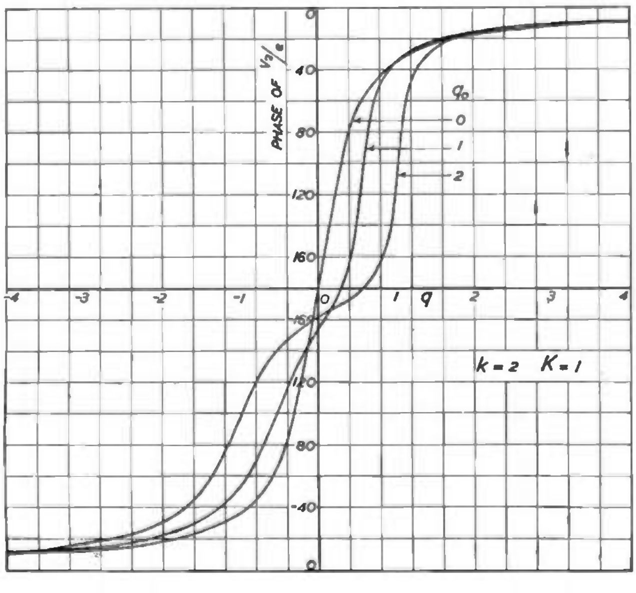
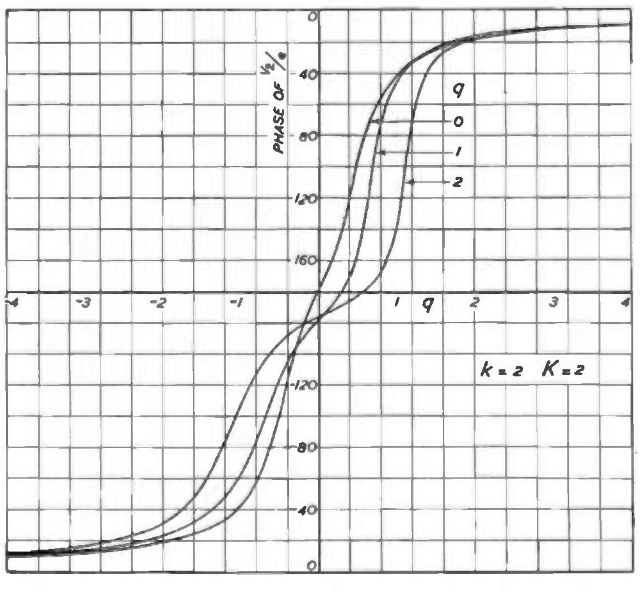


Fig. 31.



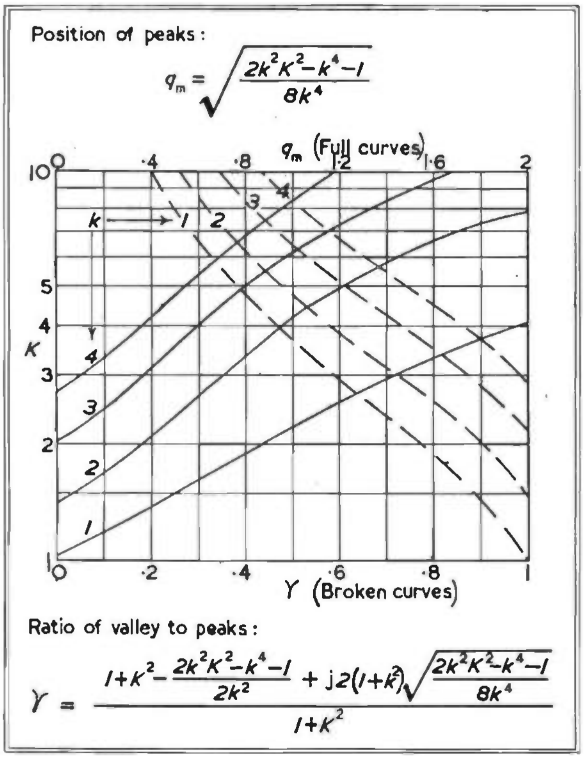


Fig. 32.

The attenuations are therefore 0.97 db. and 18.15 db.

There is nothing to be gained by increasing the coupling since this only reduces the attenuation at ± 10 kc/s. If we reduce the coupling the gain on tune is reduced. For instance, if $K = 0.5$ then the gain on tune is down to 80 per cent. The attenuations are then 4.4 db. and 23 db., showing that the selectivity ratio is inferior to the critically coupled case. Reduced coupling has, therefore, no advantage.

Circuits A and B

The more variable circuit is A, for its effective Q varies between 45 and 80 according to the bias on the valve. This variation is great because we are using a high dynamic impedance coil together with a wide range in grid bias.

By shunting the circuit with 500,000Ω the limits of effective Q become 28 and 40.

Since circuits C and D are critically coupled we can afford to overcouple these circuits to an extent so that the maximum state of overcoupling produces a valley 2 db. down on tune. This figure is obtained with $K = 2$ (when the dampings are equal).

Now K = percentage coupling $\times \sqrt{Q_1Q_2}$

$$\therefore \sqrt{Q_1Q_2} = 40$$

Q_1 is 40 at its maximum value, therefore the secondary circuit B should be damped to the same extent. Circuit B has a Q of 60 and this will be reduced to 40 by a damping resistance of 750,000Ω.

Then at minimum bias we have:

$$K = 0.05\sqrt{28 \times 40} = 2.1$$

also
$$k = \frac{40}{28} = 1.2$$

Inspection of the curves shows that we are still overcoupled. In fact, "transitional" coupling would occur at

$$K = \sqrt{\frac{k^4 + 1}{2k^2}} = 1.03$$

which is very little different from the equal circuit case. Moreover, the overall response curve will satisfy the conditions laid down in Section 3.2 for all values of gain.

3.4 Practical Considerations

Measurement of Circuit Dampings

(a) Circuits C and D

The dynamic impedances of the circuits alone are each found to be 700,000Ω by measurements on a Q-meter. For this purpose the condenser of the Q-meter may be substituted for the condenser across the coil, *i.e.*, the coils are measured on their own at 100 kc/s.

To measure the impedance of D in circuit we disconnect the tuning capacity of circuit C so that the latter is now aperiodic over the tuning range. Then by injecting a modulated signal from a signal generator straight on to the grid of V_2, a resonance curve is taken of D. From this curve the band-width 3 db. down can readily be found. This proved to be 5 kc/s., showing that the dynamic impedance was 125,000Ω.

In doing this experiment the beat frequency oscillator V_4 should be left working since the injected voltage from this also increases the damping. To avoid confusion with the beat frequency, the beat oscillator should be detuned until the beat frequency is off the L.F. range.

The impedance of C is found in a similar fashion. In this case the condenser of D is temporarily disconnected.

The points to watch in these measurements are:

(i) Neither the grid nor the anode circuits of V_2 must be overloading at any frequency.

(ii) It is most convenient (and also better practice) to keep the output constant and vary the input.

(iii) A 0.1 μF condenser should be used in series with the signal generator to avoid shorting the bias.

(b) Circuits A and B

The dynamic impedances of these circuits are measured in the same way as that used for circuits C and D. Since measuring the dynamic impedances involves taking a response curve, we wish the response of circuits C and D to be quite flat over the working range.

It so happened that in this case detuning C and D was not good enough, while damping the circuits sufficiently gave too little output. The best and simplest step in such cases is to replace the I.F. assembly by a resistance load.

In this manner the amplification after the grid of V_2 can be made quite constant over the necessary range of frequencies.

Of course, once the I.F. circuits have been designed there is no need to make a temporary replacement of C and D in order to be able to trim A and B.

Trimming

Obviously, the circuits nearest the output stage should be trimmed first.

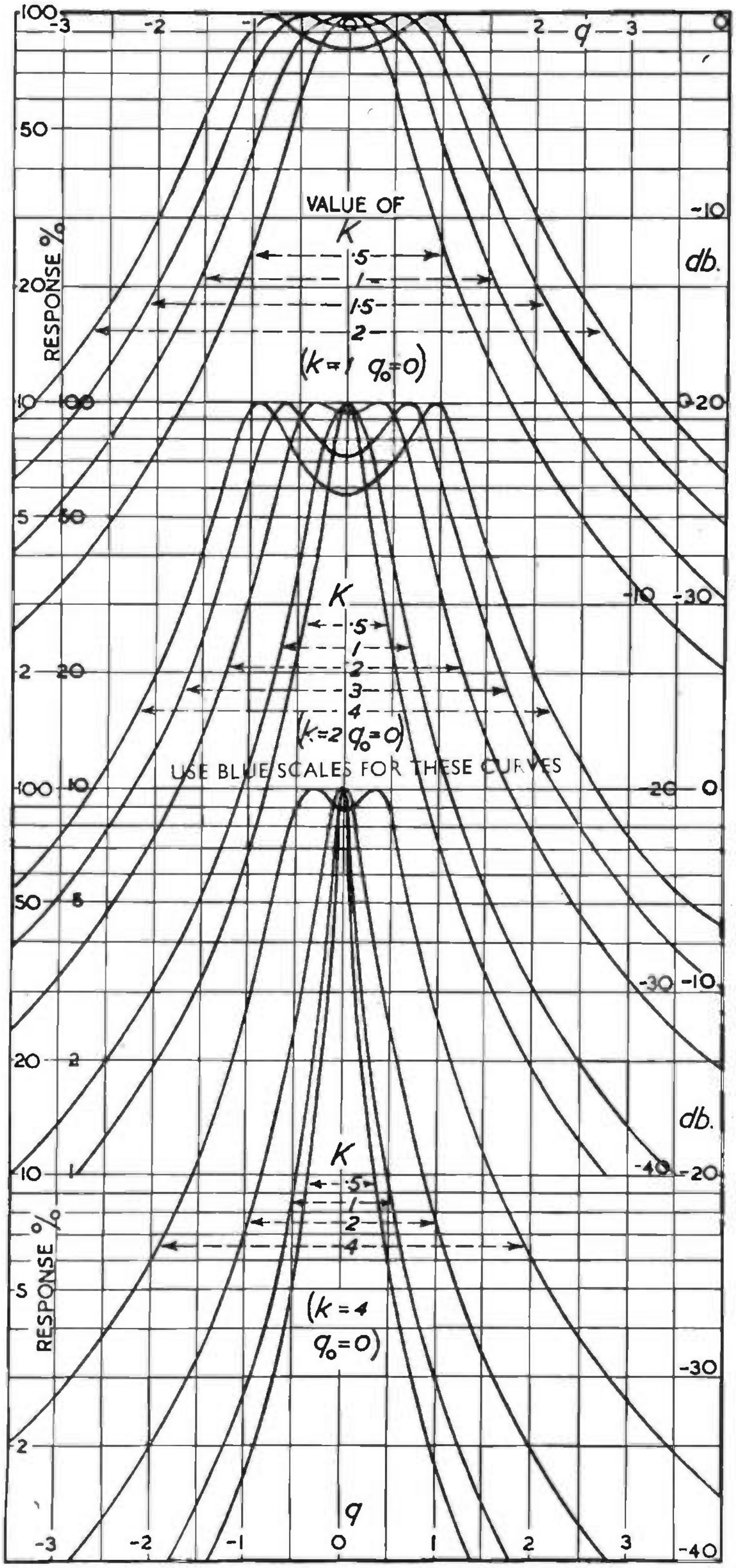


Fig. 19.

Fig. 20.

Fig. 21.

Since C and D are critically coupled we may trim these circuits directly with an injected voltage at 100 kc/s. on the grid of V_2. While doing this the oscillator circuit of V_4 should be in operation but considerably detuned.

In trimming A and B we again have an oscillator present (the 1,600 kc/s. oscillator) which should be left working but detuned.

The trimmers in this example would usually detune far enough to permit the detuning method described in Section 1.4 to be used. If, however, the resultant response curve should prove unsatisfactory, then it is preferable to damp each circuit in turn.

All the above operations should be carried out at full gain (minimum bias). The taking of the overall response curve should then be repeated at minimum gain (maximum bias) to verify that the changes are not serious. In each case the bias must be from a fixed source of voltage with the normal A.V.C. control disconnected.

REFERENCES

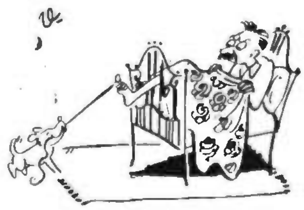
C. B. Aiken, "Two-Mesh Tuned Coupled Circuit Filters," *Proc. I.R.E.*, Feb., 1937, Vol. 25, No. 2, p. 230.

R. T. Beatty, "Two Element Band Pass Filters," *Wireless Engineer*, Oct., 1932, Vol. 9, p. 546.

For an extensive list of references, the reader may refer to the "Radio Designer's Handbook" (edited by F. Langford Smith), p. 130.

Keeping Down to Earth

Surely it is common sense that Nature intended us to sleep in contact with the earth. Instead, we build artificial dwellings, insulated from the earth, and then we wonder why we get all sorts of nervous ailments. Sleeping two storeys up, I nevertheless manage to keep my body at earth potential by attaching the wireless earth. Sometimes I wrap the bare wire round my wrist, and sometimes I wrap it round my big toe.



This simple expedient does away at one sweep with thousands of years of artificial living, and anyone who tries it will notice that his dreams are much more vivid.

—A letter in *Picture Post*, 16/2/36.

MAY MEETINGS

Institution of Electrical Engineers

All meetings of the London Section will be held at The Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2.

Ordinary Meeting

Date: May 9. Time: 5.30 p.m.
Annual General Meeting
Date: May 9. Time: 6.30 p.m.
Held at:
The Kingsway Hall, London, W.C.2.
Lecture:—The Faraday Lecture:
"Atoms, Electrons and Engineers."
By:
T. E. Allibone, D.Sc., Ph.D.

Radio Section

Date: May 1. Time: 5.30 p.m.
"Radar Navigation."
Introduced by:
Dr. R. A. Smith.
Followed by papers on:
"Gee," by R. J. Dippy.
"Oboe," by F. E. Jones.
"H2S," by C. J. Carter, M.A.
"200 Mc/s. Radar Interrogation Beacon System," by K. A. Wood.

Date: May 21. Time: 5.30 p.m.
Discussion:
"New Insulating and Dielectric Material in Radio Engineering."
Opened by:
Dr. J. C. Swallow and G. P. Briton, B.Sc.(Eng.).

Measurements Section

Date: May 24. Time: 5.30 p.m.
Lecture:
"The Measurement of Time."
By:
Sir Harold Spencer Jones, M.A., Sc.D., F.R.S.
The Secretary:
The Institution of Electrical Engineers, Savoy Place, Victoria Embankment, London, W.C.2.

Cambridge Radio Group

Date: May 17. Time: 6 p.m.
Held at:
University Engineering Laboratory, Trumpington Street, Cambridge.
Lecture:
"Plastics for the Engineer."
By:
I. W. A. Kirkwood, M.I.E.E. and P.D. Richie, B.Sc., Ph.D.
Group Secretary:
D. H. Hughes, c/o Pye Ltd., Radio Works, Cambridge.

Institute of Physics

Manchester and District Branch

Date: May 17. Time: 7 p.m.
Held at:
Large Physics Theatre, Manchester University.
Lecture:
"Electronic Semi-Conductors."
By:
R. W. Sillars, D.Phil., A.M.I.E.E.
Note.—This is a joint meeting with the Institution of Electronics.
Hon. Secretary:
Dr. F. A. Vick, O.B.E., F.Inst.P., Physics Dept., The University, Manchester, 13.

The Television Society

Date: May 3. Time: 5.30 p.m.
Held at:
The Institution of Electrical Engineers, Savoy Place, London, W.C.2.
Lecture:
"Colour Television."
By:
J. E. B. Jacob, B.Sc., A.M.I.E.E., L. C. Jesty, B.Sc., M.I.E.E., R. B. Mackenzie, B.Sc., and A. E. Sarson, B.Sc.
Note.—This is a joint meeting with the British Kinematograph Society.
Lecture Secretary:
G. Parr, 68 Compton Road, N.21.

BOOK REVIEWS

Electronic Engineering Master Index

Edited by F. A. Petraglia. (Electronics Research Publishing Company, New York, 1945, $17.50, British price £5 5s. approx.) 318 pp.

This book is not, as a quick glance at its title might indicate, an index for *Electronic Engineering*, but rather a subject index to all radio and electronic literature published during the period 1925-1945. In fact, references to *Electronic Engineering* are entirely omitted, but its American editor apologises that owing to paper restrictions the number of entries from foreign periodicals has had to be limited. It covers seven of the leading American journals, including *Proc. I.R.E.* and *Electronics*, and to a much lesser extent an imposing array of others, which, however, are also almost entirely American. The only two British sources covered in any reasonable detail are *Wireless Engineer* and *Journal of the I.E.E.* Foreign language references are very few and the titles of these might perhaps have been better if translated.

A short periodical list names some sixty journals which are indexed, giving publisher's name and address, subscription rates, etc. The article references are listed alphabetically by title under subject headings, a typical one being:

FILAMENTS: Calculation of the inductance of circular filaments in any desired position. F. W. Grover, bibliog., diags., *Proc. Inst. Radio Eng*, 32: 620, October, 1944.

Listing some 15,000 articles and monographs, the book is divided into two sections covering 1925-1934 and 1935-1945 to facilitate searching of the many entries that appear under some subject headings. A cross-reference system between subject headings is useful but is not too rigorous. For example, failing to find Varian and Varian's classic klystron paper "A High-frequency Oscillator and Amplifier" under "Klystron," one turns to "Velocity Modulation" and finds it there, but no cross-reference here to "Klystron" aids the uninformed to find cognate articles. An eight-page index to the subject headings in the main body of the text completes the book. It is proposed to publish annual cumulative issues to bring the work up to date and it is promised that the 1946 issue will contain many references (about a third more) which had to be omitted from the present one.

Checking at random, the book seems very easy to use, and a few test references were quickly found, the information given being quite accurate, but it is thought that the references might be better arranged in date sequence rather than alphabetically according to the first word of the title. An author index would also have been a great help, but here again we are promised this in the next issue. The printing of the book is not all that could be desired, misprints and omitted figures are not uncommon. At least one reference even has the date missing. The book generally gives the impression that it has been produced too quickly and one may reasonably feel that if publication had been delayed until more paper was available and the missing features had been included, a much more useful volume would have resulted.

By any standards, even present-day ones, the price of £5 5s. is high, and puts it out of reach of the average individual worker. Libraries and firms will assuredly buy it and find it of great use, but its price should be reduced to make it a popular text. No doubt an enormous amount of bibliographical work has been carried out in compiling 15,000 references, but the present reviewer, at any rate, feels that purchasers are paying dearly for it. As a portable, handy supplement to the *Wireless Engineer* abstracts and *Science Abstracts* it has at present no rival, and it is to be hoped that the next issue—at a lower price—will attend to the criticisms mentioned above and be a first-class reference guide.

E. D. HART.

An Introduction to the Theory and Design of Electric Wave Filters

F. Scowen. (Chapman & Hall, Ltd., 15s. net.) 164 pp. (with a Foreword by A. J. Gill).

This book by a member of the staff of the Post Office Research Station is, as pointed out by the author, not intended to replace the well-known standard books on this subject. It is not a general treatise on electric networks (resonant circuits, coupled circuits as filters, equalisers, transients in networks, are not dealt with), but has a limited objective—the design of filters. Within these self-imposed limits the author has written an admirably lucid book which any reader, whether or not already familiar with filter problems, should find interesting, useful, and stimulating.

After a short mathematical and electrical introduction an analysis of ladder half-sections leads to a discussion of low pass, high pass, band pass and band stop half-sections. This discussion being based on image characteristics, formulae for insertion loss and insertion phase shift are derived, and the effect of dissipation on filter sections is shown. Parallel and series connexion of filters is treated at some length, and lattice type filters and Cauer's theory are briefly discussed. In Chapter 14 templates are introduced for obtaining the image attenuation and phase shift coefficients of *m*-derived sections as functions of frequency, a variation of *m* being represented by a corresponding shift of the templates. In Chapter 16 the actual design procedure, based on templates and nomograms, is described and analysed step by step. This chapter, and also the last two chapters which deal with the characteristics of coils and condensers and their screening, measurement and adjustment, as well as with measurements on complete filters, make the book eminently practical.

In his insistence on studying design procedures and simplifying them by means of graphical methods, the author is in agreement with modern ideas on network design which have emerged in the last decade. Perhaps he will be able to include in a second edition also an account of another modern development of filter theory, the analytical study of filter design based solely on insertion characteristics.

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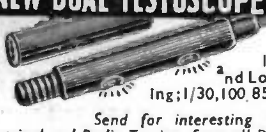

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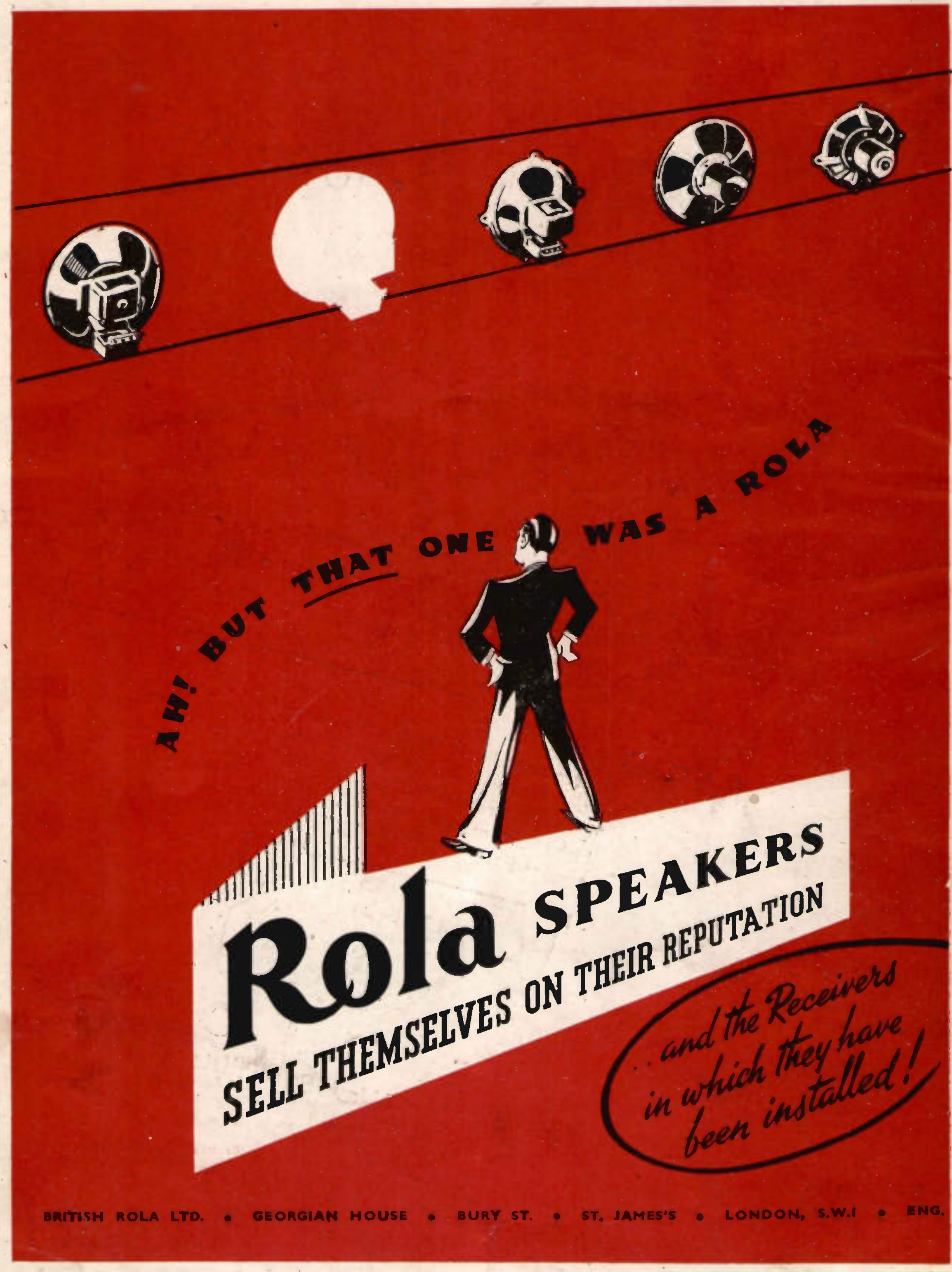

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