JOURNAL OF
The British Institution of Radio Engineers
(FOUNDED IN 1925 - INCORPORATED IN 1932)
"To promote the general advancement of and to facilitate the exchange of information and ideas on Radio Science."
Vol. IX (New Series) No. 12 DECEMBER 1949

DEMAND FOR PROFESSIONAL ENGINEERS

The Ministries of Education, Labour and National Service have this month issued three reports which are of particular interest to all who are concerned with education and vocational training.

The report on education for the commercial professions also refers to training for management. The Committee, under the Chairmanship of Sir Alexander Carr-Saunders, states that it would like to see more graduates entering business with qualifications *other* than in science and engineering.

The other reports are submitted to the Minister of Labour by Lord Hankey, Chairman of the Technical Personnel Committee. The main and sub-Committees were appointed in 1947 to examine present and future demands for professionally qualified physicists and engineers. Members of the Committee included Vice-Admiral J. W. S. Dorling, C.B. (Member), who is Director of the Radio Industry Council.

The report in electrical engineering includes radio engineering and estimates the probable demand for personnel ranging "... from sales engineering to fundamental research."

The estimated annual demand for such professionally qualified engineers is quoted as a total of 1,670 of which the requirement for public service is 660. The report states that :

"Discussions with the Radio Industry Council showed that it is not always easy to differentiate between requirements for electrical engineers and for physicists and some representatives of the industry preferred to think in terms of radio engineers. The Committee which was making a parallel enquiry into the demands for physicists decided to set up a special sub-panel to enquire into the demands of the Radio Industry. This sub-panel examined a summary of the replies which has been received in answer to a questionnaire sent out by the Radio Industry Council and also took oral evidence from representatives of some of the leading manufacturers of radio and electronic equipment."

The separate estimated requirements of the Radio Industry have not been quoted, but the report states that the electrical industry as a whole (presumably including the Radio Industry as well as all the research associations) has an estimated demand of 900 professionally qualified engineers per annum.

The Engineering Report has made particular reference to qualification by means of National Certificate Courses which provide the major source of qualified personnel. The estimate states that about 600 engineers qualify each year by means of Higher National Certificate Courses as against 500 from the Universities and 450 from other sources. Whilst attention is thereby drawn to the National Certificate Scheme the Committee does not examine the curriculum of those courses.

The need for education, examinations and practical training in radio engineering has not apparently been investigated. The increased number of entries for the City and Guilds Telecommunications Group Certificates and the Graduateship Examination of the British Institution of Radio Engineers obviously warrant more detailed consideration since those examinations are the most prolific and popular sources of qualification for the radio engineering student.

If only for economic reasons, the radio engineering student finds it impossible to complete an electrical engineering course before studying one or more of the specialized branches of radio engineering. This reason alone might well hamper development and expansion of the industry by creating a further lack of suitably qualified personnel; in this respect the report is most disappointing.

NEW MEMBERS OF THE COUNCIL

G. L. Hamburger was born in Vienna on June 26th, 1914. He received his technical education at Vienna University, obtaining the degree of Dipl. Ing in 1938. On coming to this country in 1939 he first held a position as Television Research Physicist with Baird Television Ltd., and then took a post at the British Electrical and Allied Industries Research Association before joining the staff of Central Rediffusion Services Ltd. as Senior Development Engineer in charge of complete development projects.

He has carried out considerable research on Radio Interference and was responsible for ERA Reports MT/79, MT/81 and MT/83. Subsequently he has written papers which have been published in *Electronic Engineering and Wireless Engineer*. A number of Mr. Hamburger's papers have been published in the *Journal of the Brit.I.R.E.* and he was awarded the Norman Partridge Memorial Premium in 1948 for his paper "An Automatic Audio Frequency Response Curve Tracer" which was first presented at the 1947 Brit.I.R.E. Convention.

Elected an Associate Member of the Institution in 1943 he was transferred to full Membership in 1947. He has served on the Programme and Papers Committee regularly since 1945 and has recently been elected Chairman of the Committee.

N. C. Cordingly was born in Morden, Surrey, on January, 1910. He received his technical education at the Northern and Northampton Polytechnics.

He served an X-ray engineering apprenticeship with Newton & Wright Ltd., and in 1937 became head of the Research Department, later holding the position of Chief Engineer. To-day he is manager of the X-ray tube and valve division of the newly formed A.E.I. Company, Newton Victor Ltd.

During the war he served with the R.A.F., and for the first two years was engaged on experimental and operational flying with night fighter radar interception devices in Fighter Command. He was awarded the M.B.E. in 1942. From 1943 until the end of hostilities in Europe, he served as a Wing Commander in H.Q. 100 Group, where as Chief Radar Officer he was responsible for airborne radar and radio counter measure aids used by offensive night fighters in support of Bomber Command. It was for his work in this connection that he received a mention in despatches and the award of the O.B.E. in 1946.

He was elected a full member of the Institution in 1945 and has served on the Membership Committee since 1947. He was elected its Chairman in 1948.

E. T. A. Rapson was born in Plymouth on July 23rd, 1899. He served an apprenticeship as an electrical engineer to the Admiralty in Devonport dockyard and in 1920 was awarded a Royal Scholarship to the City and Guilds Engineering College, London. From this college he received his M.Sc. (Eng.), A.C.G.I. in Electrical Engineering and D.I.C. in Radio Engineering.

After a short period at the G.E.C. Research Laboratories, Wembley, he was appointed chief lecturer in electrical engineering at Hull Technical College. In 1933 he was appointed Head of the Radio Engineering Department at Southall Technical College and in 1945 he was made Head of the combined Departments of Radio Engineering and Electrical Engineering at this college.

Mr. Rapson was elected a full Member of the Institution in 1943, and joined the Education and Examinations Committee later that year. He served as Chairman of the Committee from 1945 to 1948.

He has been the author of several books on radio and electrical engineering including, "Problems in Radio Engineering" and "Experimental Radio Engineering."

RADIATION PATTERNS AND GAIN OF A FOUR-ANTENNA ARRAY LOCATED AT THE CORNERS OF A SQUARE AROUND A CENTRAL PARASITIC ANTENNA*

by

G. Boudouris† (*Associate*)

SUMMARY

An array of four driven antennas, located at the corners of a square, around a central parasitic antenna, is analysed. All antennas are taken to be of one-quarter wavelength and grounded to a perfectly conducting plane. It can be easily proved that, with the antennas shorter than one-quarter wavelength, grounded to an imperfectly conducting earth, the shape of the radiation patterns and the field strength gain remain practically unaffected because the field strength is then reduced uniformly in the same ratio.

The procedure followed in this analysis is, first, to calculate the total impedance at the base of each antenna as a function of the antenna diagonal spacing. This spacing is the fundamental variable used in all subsequent calculations.

Next, the ratio of the parasitic antenna induction current to the current fed into each of the four driven antennas is determined. An equation is obtained, giving the field strength produced at an arbitrary point in space. This equation gives immediately the horizontal and vertical radiation patterns in terms of the diagonal spacing of the array. Under certain conditions it exhibits pronounced directive characteristics.

Finally, a formula giving the root mean square field strength in the horizontal plane is obtained. This formula is transformed later in order to give the root mean square field strength which is produced from the total power fed into the array. The same total power fed into a single antenna of the same design produces a different horizontal field. Comparing the two fields produced by the array and the single antenna respectively, a relation giving the average field strength gain is obtained.

It is confirmed that this average gain, under certain favourable conditions, having regard to the diagonal spacing, is increased as much as 10 to 20 per cent. An even greater field strength gain, up to 60 per cent., is obtained in certain directions, with a given diagonal spacing of the array.

TABLE OF CONTENTS

* Manuscript received July 7th, 1949.
U.D.C. No. 621.396.677.2.
† Lecturer at the Radio Technical School, Athens.

Introduction

In 1944, the retreating Germans completely destroyed one of the two towers of the Athens broadcasting station (500 metres wavelength); the other tower was not blown up completely.

Personnel of the Royal Corps of Signals, in order to get the station working as soon as possible, built up an array similar to the one to be analysed. The array consisted of four antennas hanging from the end of a cross, fixed on the top of the semi-destroyed tower. The antennas were tuned to one-quarter wavelength and were fed with equal (in phase) currents. The results of this arrangement were not satisfactory, because the diagonal antenna spacing was only 10° (14 metres), but agreed with the present general analysis. Slightly better results than those calculated were obtained, because the lower parasitic element had a physical height of 80 metres, that is an effective height shorter than the effective height of the tuned driven antennas. Thus, the parasitic element had a relatively reduced influence and did not comply with the normal role of a parasitic antenna of the same effective height having a close coupling, as outlined herein. In spite of the above stated facts, the general results obtained from such an array were similar to the conclusions of this analysis. The problem was studied and analysed further in order to suggest new methods of arranging arrays of this kind.

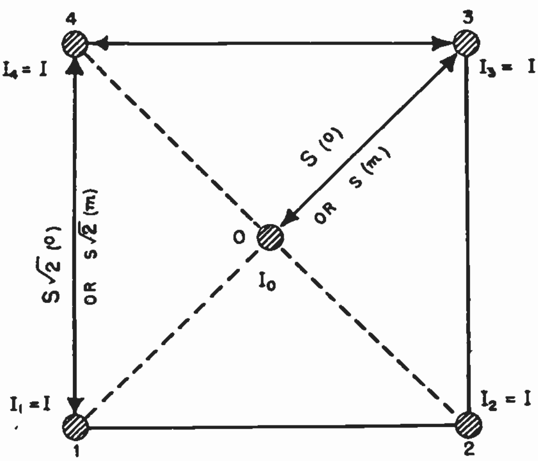

Fig. 1.—Antenna spacings of the array.

1.0. Calculation of the Total Impedance at the Base of each Antenna in Terms of the Half-diagonal Spacing of the Array

Let S be the half-diagonal spacing, in metres, of two opposing antennas (Fig. 1). The same distance measured in phase angle, degrees or radians, is:

$$S = 360\frac{s}{\lambda}\,(\text{degrees}) = 2\pi\frac{s}{\lambda}\,(\text{radians}) \quad (1)$$

where λ is the wavelength, in metres. This half-diagonal spacing is the fundamental variable of the following analysis.

The notation used in subsequent equations is as follows:

Z_0 is the self-impedance at the base of the parasitic antenna;

Z_{11} is the self-impedance at the base of each of the four driven antennas;

Z_{12} is the mutual impedance between two adjacent antennas;

Z_{13} is the mutual impedance between two diagonally opposed antennas;

Z_{10} is the mutual impedance between one of the four driven antennas and the parasitic element. ....(2)

Provided that all antennas are of one-quarter wavelength and grounded over a perfectly conducting plane, they have equal self-impedances:

$$Z_0 = Z_{11} = Z_{22} = \ldots$$

Also, because of the circular symmetry of the array, we have for the mutual impedances:

$$Z_{10} = Z_{20} = \ldots, Z_{12} = Z_{23} = \ldots, Z_{13} = Z_{24}.$$

In addition the mutual impedance between one antenna and another is bilateral,

i.e., $Z_{12} = Z_{21}$, etc.

Thus, the symbols defined in (2) fulfil all requirements.

The self-impedance and mutual impedance for quarter-wavelength antennas grounded over a perfectly conducting plane is one-half of the corresponding impedance of half-wave antennas in free-space.

For convenience, Carter's relationship, giving Z_{11}, is reproduced below:[1]

$$Z_{11} = 15[\tau + \log_e(2\pi) - Ci(2\pi) + jSi(2\pi)] = 36{\cdot}6 + j21{\cdot}25 = 42{\cdot}25\,\underline{|30{\cdot}15^\circ}\text{ ohms} \quad \ldots(3)$$

where

$\tau = 0{\cdot}577$ (Euler's constant),

$$Si(u) = \int_0^u \frac{\sin x}{x}\, dx \text{ (the sine integral)}$$

and

$$Ci(u) = \int_0^u \frac{\cos x}{x}\, dx \text{ (the cosine integral).}$$

Values for these integrals must be taken from tables, or, from the curves of Fig. 2.[2]

The mutual impedance of two identical antennas of one-quarter wavelength and grounded to a perfectly conducting plane is also given by Carter thus :—

$Z_{m,n} = R_{m,n} + jX_{m,n}$ ohms

with $R_{m,n}$ and $X_{m,n}$ having the values :

$$R_{m,n} = 15 \left[\begin{array}{l} 2Ci(S_{m,n}) \\ \quad - Ci(\sqrt{(S_{m,n})^2 + \pi^2} + \pi) \\ - Ci(\sqrt{(S_{m,n})^2 + \pi^2} - \pi) \end{array} \right],$$

$$X_{m,n} = 15 \left[\begin{array}{l} - 2Si(S_{m,n}) \\ + Si(\sqrt{(S_{m,n})^2 + \pi^2} + \pi) \\ + Si(\sqrt{(S_{m,n})^2 + \pi^2} - \pi) \end{array} \right] \qquad \ldots\ldots(4)$$

where $S_{m,n}$, the spacing between the two antennas m and n, is in radians. Values of mutual impedance between two antennas for spacings up to 4π (two wavelengths) are given in Fig. 3A and for greater spacings in Fig. 3B.

Equations (4) give :

for $S_{m,n} = S$, the mutual impedance is Z_{10},

for $S_{m,n} = S\sqrt{2}$, the mutual impedance is Z_{12},

and

for $S_{m,n} = 2S$, the mutual impedance is Z_{13}.

The total impedance of one antenna in the presence of the other four may now be computed from equations (3) and (4). Owing to the circular symmetry of the array, it is obviously sufficient to calculate the total impedance of one driven antenna, as is obtained in equation (1) for example.

In accordance with the laws of coupled circuits, applied to each one of the driven antennas :

$$U_1 = Z_{11}I_1 + Z_{12}I_2 + Z_{13}I_3 + Z_{14}I_4 + Z_{10}I_0 \qquad \ldots\ldots(5)$$

while for the parasitic element :

$$0 = Z_0I_0 + Z_{10}I_1 + Z_{20}I_2 + Z_{30}I_3 + Z_{40}I_4.$$

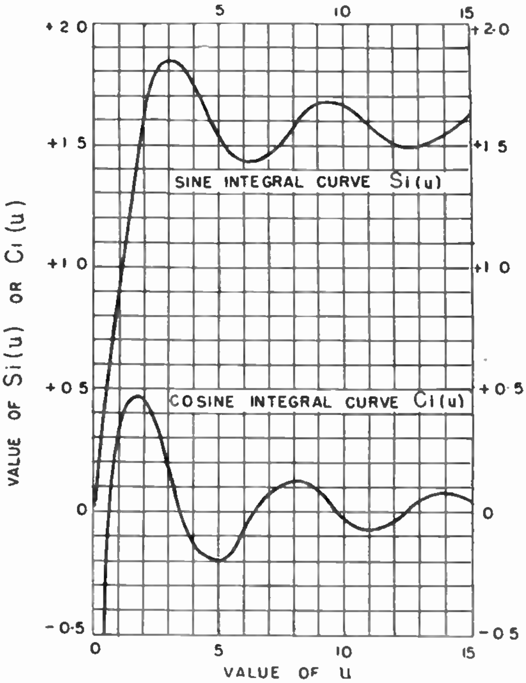

Fig. 2.—Curves of Sine and Cosine Integrals (from C. E. Smith, "Appl. Mathematics," McGraw-Hill Co., N.Y., 1945, p. 294).

It is assumed that the four driven antennas are fed with equal and in-phase currents :

$$I_1 = I_2 = I_3 = I_4 = I \qquad \ldots\ldots(6)$$

and $U_1 = U_2 = U_3 = U_4 = U$.

Also

$$Z_{11} + Z_{12} + Z_{13} + Z_{14} = Z_{1234} \qquad \ldots\ldots(7)$$

Equation (5) may now be written :

$$U = Z_{1234}I + Z_{10}I_0 \qquad \ldots\ldots(8)$$

$$0 = Z_0I_0 + 4Z_{10}I \qquad \ldots\ldots(9)$$

From Equation (9) :

$$I_0 = -\frac{4Z_{10}I}{Z_0} \qquad \ldots\ldots(10)$$

so that Equation (8) becomes :

$$\frac{U}{I} = Z_{1234} - \frac{4(Z_{10})^2}{Z_0}.$$

The total impedance, Z, at the base of one driven antenna is finally given by the ratio U/I :

$$Z = Z_{1234} - \frac{4(Z_{10})^2}{Z_0} \quad \ldots\ldots\ldots\ldots\ldots(11)$$

This relationship is analysed in Fig. 4 which gives the resistance and reactance of the total impedance of one driven antenna in the presence of the other four. The required values of Z_0, Z_{10} and Z_{1234} are calculated as above. The diagram for Z will be used later for the calculation of the array gain.

The factor $-4(Z_{10})^2/Z_0$ of equation (11) expresses the effect of the parasitic element on the total impedance of one of the driven antennas. In the equation $Z=R+jX$, R is the total radiation resistance of one of the driven antennas, providing that the antenna is a perfect conductor. The influence of the other four antennas on the radiation resistance of one of the driven ones is particularly interesting. For small antenna spacings, that is for $S \rightarrow 0$, the radiation resistance R approaches zero (Fig. 4). Very close coupling is not suitable because in such cases the parasitic element almost entirely balances the energy of the driven antennas. For S=73°, 154° and 255° the radiation resistance of a driven antenna in the presence of the other four is equal to the radiation resistance of one single antenna of the same design with the other antennas remote, that is 36·6 ohms. Between 73° and 154° the coupled radiation resistance is positive. Between 154° and 255° the coupled radiation resistance becomes negative, bringing the total radiation resistance R to a second relative minimum of 14·5 ohms for half-diagonal spacing S=200°.

The relative maxima of R occur at S=110° and 310°. Thus the total radiation resistance R oscillates around the characteristic value of 36·6 ohms as shown in Fig. 4.

Similarly the reactance X oscillates relative to the reactance of the same antenna, that is around the characteristic value of 21·25 ohms, as shown in the same figure.

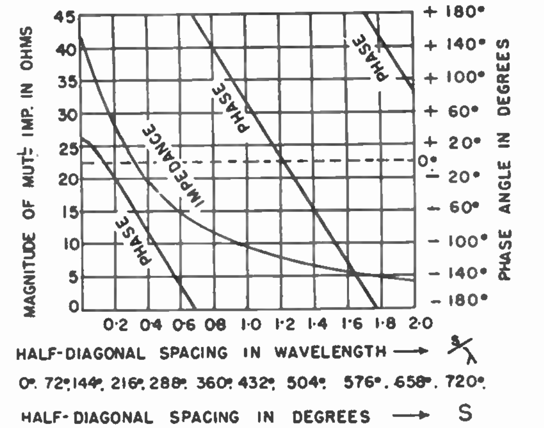

Fig. 3A.—Mutual impedance between two vertical grounded antennas λ/4 against S from Carter's relations.

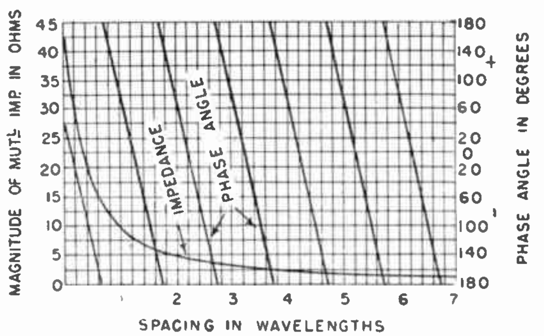

Fig. 3B.—Mutual impedance between two vertical grounded antennas λ/4 against the spacing S and for spacings up to 7 wavelengths.

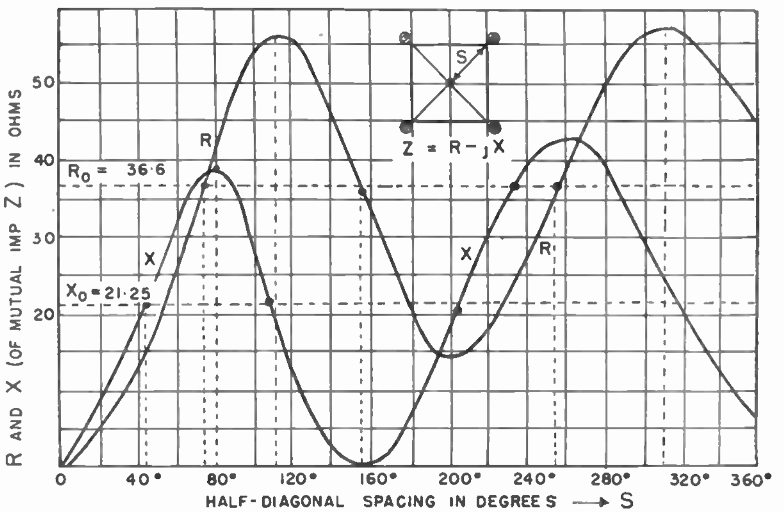

Fig. 4.—Input (radiation) resistance R and reactance X of each one of the driven antennas in terms of S.

2.0. Current Ratio I_0/I in Terms of the Half-diagonal Spacing S.

On drawing radiation patterns, it is essential that the ratio I_0/I, where I_0 is the induction current of the parasitic antenna and I the current fed into each of the four driven antennas, be calculated.

From equation (10) :

$$A = \frac{I_0}{I} = \frac{-4Z_{10}}{Z_0},$$ where, from equation (3) :

$$Z_0 = 42{\cdot}25 \underline{|+30^\circ}.$$

Therefore

$$\frac{1}{Z_0} = 0{\cdot}0237 \underline{|-30^\circ}, \text{ and :}$$

$$A = \frac{I_0}{I} = 0{\cdot}0948\ Z_{10} \underline{|+150^\circ} \quad \ldots\ldots(12)$$

Equation (12) is developed graphically in Fig. 5, where the ratio A is given in its real and imaginary parts, α and β respectively.

Thus, the current ratio is :

$$\frac{I_0}{I} = A = \alpha + j\beta \quad \ldots\ldots\ldots\ldots\ldots\ldots(13)$$

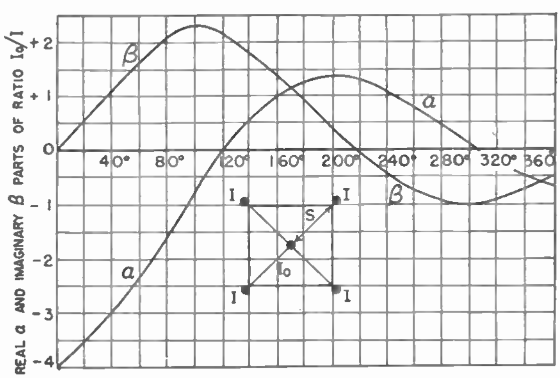

Fig. 5.—Ratio of currents $I_0/I = A = \alpha + j\beta$ in terms of S (see Fig. 12).

The half-diagonal spacing S is again the fundamental variable : it affects the ratio of currents through the mutual impedance Z_{10}.

As shown in the diagram, for very close couplings ($S \to 0$) the parasitic current approaches the value of $-4I$. This current, which is nearly equal to the total current (4I) fed into the array tends to cancel the radiation of the driven antennas. With greater spacings the magnitude of the parasitic currents is reduced, while the currents themselves are not in exact opposition to the feed currents. Thus the parasitic element is taking part in the formation of the radiation patterns and, under certain conditions, it will augment the radiation of the array as a whole. The two components of the parasitic current, that is the real component αI and the imaginary βI, vary with S in an oscillatory manner as shown in Fig. 5.

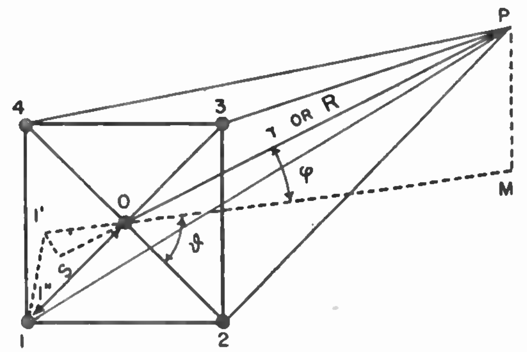

Fig. 6.—Distances of the arbitrary point P from the array antennas.

3.0. Radiation Field Strength at an Arbitrary Point in Space

A suitable system of spherical co-ordinates is assumed ; point P is fixed in the space within this system by its distance r in metres from the origin O (the centre of the array), the elevation angle φ and the horizontal angle θ measured to one of the diagonal lines of the array (Fig. 6). Distance (OP) = R may be measured in degrees or radians, according to the relation :

$$R = \frac{360r}{\lambda}\ \text{(degrees)} = \frac{2\pi r}{\lambda}\ \text{(radians)} \quad (14)$$

All distances of point P from the four corners of the square must be calculated in degrees or radians. Taking the length (1P), the half-diagonal (1 O)=S is projected vertically on the horizonal line OM, where M is the horizontal projection of point P. The projection is defined as $(1'\,O) = S\sin\theta$. $(1'\,O)$ is now projected on the line OP. This projection is : $(1''\,O) = (1'\,O)\cos\varphi = S\sin\theta\cos\varphi$. Therefore $(1''\,P) = (1'\,O) + (OP) = R + S\sin\theta\,.\cos\varphi$. Providing that point P is always taken at a distance great compared with the array spacing, a satisfactory approximation is obtained if we put (1M)=(1′M), and in consequence :

$$\left.\begin{array}{ll} & (1P) \approx (1'P), \text{ or } (1'P) \approx (1''P) \\ \text{Finally}: & (1P) = R + S\sin\theta\cos\varphi \\ & (2P) = R - S\cos\theta\cos\varphi \\ & (3P) = R - S\sin\theta\cos\varphi \\ & (4P) = R + S\cos\theta\cos\varphi \end{array}\right\} \quad ..(15)$$

The field strength radiated in a certain direction by a quarter-wavelength antenna grounded over a perfectly conducting plane is given by

$$E_0 = -j\frac{60I_0}{r}\cos\varphi \underline{|-R} \left(\text{in V/m}\right) \quad ..(16)$$

where I_0 is the root mean square value of the input current in amperes at the base of the antenna, r the distance of point P from the antenna in metres, R the same distance measured in wave-angles and φ the elevation angle of P.

Equation (16) immediately gives the parasitic antenna field strength at point P. In this equation I_0 may be replaced by AI. Equation (16) may also be used to give the field strength of the other four antennas, considering the difference in phase arising from the different distances of point P from the antennas, according to equations (15). The denominator r remains in equation (16), because the field strength is slightly affected by the above-mentioned differences in distances. Thus, all fields at point P form a resultant field-strength, given by the following relations in magnitude and phase :

$$\left.\begin{array}{l} E_0 = -j\dfrac{60AI}{r}\cos\varphi \underline{|-R} \\ E_1 = -j\dfrac{60I}{r}\cos\varphi \underline{|-R-S\sin\theta\cos\varphi} \\ E_2 = -j\dfrac{60I}{r}\cos\varphi \underline{|-R+S\cos\theta\cos\varphi} \\ E_3 = -j\dfrac{60I}{r}\cos\varphi \underline{|-R+S\sin\theta\cos\varphi} \\ E_4 = -j\dfrac{60I}{r}\cos\varphi \underline{|-R-S\cos\theta\cos\varphi} \end{array}\right\} (17)$$

If these five field strengths are added, the electric field strength E at point P is obtained. The phase parts of the above relations may be be developed as follows :

$$\begin{aligned} &\underline{|-R-S\sin\theta\cos\varphi} \\ &\quad = e^{-R-S\sin\theta\cos\varphi} = e^{-R}e^{-S\sin\theta\cos\varphi} \\ &\quad = [\cos(S\sin\theta\cos\varphi) \\ &\qquad - j\sin(S\sin\theta\cos\varphi)]\underline{|-R}, \text{ etc.} \end{aligned}$$

It will be noted that the factor $-j\dfrac{60I}{r}\underline{|-R}$ appears in all equations. Thus the final form of the relation giving the radiation field strength of the array at point P in space, is :

$$E = E_0 + E_1 + E_2 + E_3 + E_4 \left(\text{in V/m}\right) \quad ..(18)$$

$$= -j\frac{60I}{r}\Big[A + 2[\cos(S\sin\theta\cos\varphi) + \cos(S\cos\theta\cos\varphi)]\Big]\cos\varphi\underline{|-R}.$$

On drawing the radiation patterns, we are not particularly interested in the absolute value of the field strength E in V/m, but merely in the shape of the radiation field. Thus the common factor $-j\,60I\underline{|-R}/r$ may be omitted. The relative electric field strength ε of the array, at P then becomes :

$$\varepsilon = [\alpha + 2[\cos(S\sin\theta\cos\varphi) + \cos(S\cos\theta\cos\varphi]]\cos\varphi + j\beta\cos\varphi \quad ..(19)$$

where $A = \alpha + j\beta$. Moreover, in drawing the patterns, the magnitude $|\varepsilon|$ of the relative field strength is more interesting than the complex expression of ε. Finally :

$$|\varepsilon| = [[\alpha + 2\{\cos(S\sin\theta\cos\varphi) + \cos(S\cos\theta\cos\varphi\}]^2 + \beta^2]^{\frac{1}{2}}\cdot\cos\varphi \quad ..(20)$$

This relation gives the magnitude of the relative field strength produced by the array at any point in space. $|\varepsilon|$ is a positive pure numeric. This relative number, apart from being a function of directions θ and φ, is a function of the half-diagonal spacing S, providing that α and β are functions of S. Therefore, for a certain spacing S, equation (20) gives horizontal and vertical radiation patterns of the array, as outlined further on.

4.0. Horizontal and Vertical Radiation Patterns for Various Antenna Spacings

If the angle of elevation $\varphi = 0$ is placed in equation (20), various horizontal patterns of the radiation field are obtained by changing the horizontal angle θ and taking S as a parameter. Due to the array symmetry, the field patterns need only be calculated between 0° and 45°. For a certain value of S, the corresponding values of α and β can be obtained from Fig. 5 (see 2.0.). Thus the formula for calculating horizontal patterns is :

$$|\varepsilon_{hor}| = \left[\left[\alpha + 2\{\cos(S\sin\theta) + \cos(S\cos\theta)\}\right]^2 + \beta^2\right]^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots(24)$$

where $0 \leqslant \theta \leqslant 45°$.

In order to draw vertical patterns, starting from a certain direction θ to the horizontal plane, S and θ are kept as parameters and the elevation angle φ is altered between 0 and 90°.

Vertical patterns are particularly interesting towards the characteristic directions of diagonals (θ = 0) and bisectors (θ = 45°). The following formulæ, derived from equation (20), are given for drawing the radiation patterns in the above mentioned directions :

$$|\varepsilon_{ver.d}| = \left[\left[\alpha + 2\{1 + \cos(S\cos\varphi)\}\right]^2 + \beta_2\right]^{\frac{1}{2}} . \cos\varphi \text{ towards the diagonal } \theta = 0° \quad \ldots\ldots\ldots\ldots(22)$$

and

$$|\varepsilon_{ver.b}| = \left[\left[\alpha + 4\cos(0{\cdot}707\,S\cos\varphi)\right]^2 + \beta^2\right]^{\frac{1}{2}} . \cos\varphi \text{ towards the bisector } \theta = 45° \quad \ldots\ldots\ldots\ldots(23)$$

where $0 \leqslant \varphi \leqslant 90°$.

In the following patterns (Fig. 7) equations (21), (22) and (23) are developed for the characteristic cases of arrays with half-diagonal distances of S = 90° and 270°.

In order to obtain a more general picture of the manner in which the horizontal distribution of the field is changed in terms of S, it is assumed φ = 0 and θ = 0 in equation (20). The following relation now gives the variation of the horizontal field in the diagonal directions against S :

$$|\varepsilon_{hor.d}| = \left[\left[\alpha + 2\{1 + \cos S\}\right]^2 + \beta^2\right]^{\frac{1}{2}} \quad ..(24)$$

For φ = 0 and θ = 45°, equation (20) gives the variation of the horizontal field in the directions of the bisections in terms of S :

$$|\varepsilon_{hor.b}| = \left[\left[\alpha + 4\cos(0{\cdot}707\,S)\right]^2 + \beta^2\right]^{\frac{1}{2}} \quad ..(25)$$

Equations (24) and (25) are developed graphically in Fig. 9.

As is shown by the equations (21), (22) and (23) the expressions of field strength on the horizontal or on the vertical plane include terms of the general form cos (Xsin Y) or cos (X cos Y).

Thus the different patterns may present the

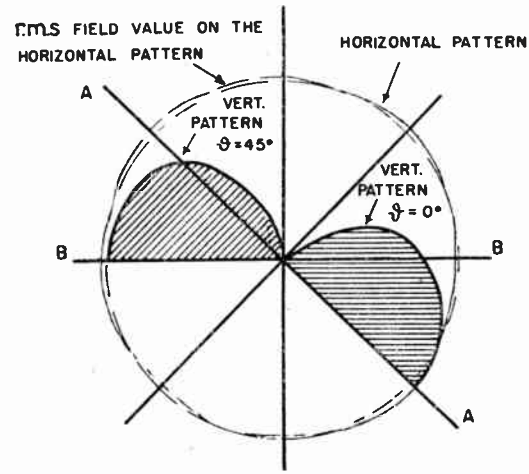

Fig. 7A.—Horizontal and vertical patterns of the array in the special case S = 90° (no directive characteristics).

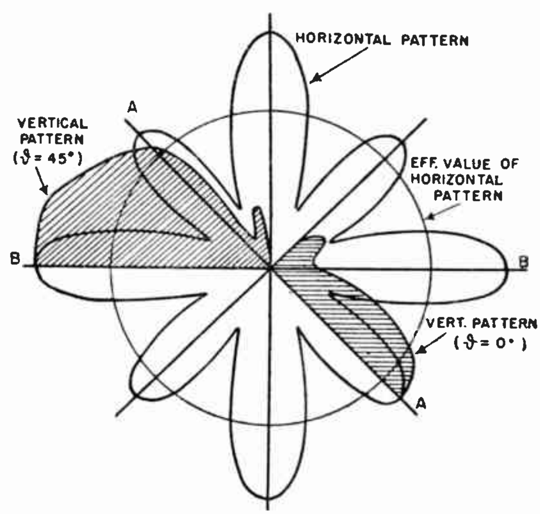

Fig. 7B.—Horizontal and vertical patterns of the array in the special case S = 270° (considerable directive characteristics).

lobes shown, as for example, in the special case S=270° (Fig. 7*B*).

This is, however, not always the case. In the region S=90°, for example, the horizontal patterns have a regular and almost circular shape. The choice of the suitable array arrangement is finally determined by the desirable form of the horizontal field pattern and by the gain conditions, as discussed below.

5.0. Root Mean Square Value of the Field Strength in the Horizontal Plane

The root mean square value of the field strength in V/m in the horizontal plane $|E_{rms}|$ is defined as the radius of the circle that covers the same area as the actual horizontal patterns of the array (Fig. 7). This definition is mathematically expressed by the equation :

$$|E_{rms}| = \left[\frac{1}{2\pi} \int_0^{2\pi} |E|^2 \, . \, d\theta \right]^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots (26)$$

where the magnitude of the root mean square value is referred to. This value will be used in the next paragraph as a comparison term to calculate the average field strength gain of the array in the horizontal plane.

Equation (18) gives the full expression of the field strength in the horizontal plane ($\varphi = 0$) :

$$E = j \frac{60 I}{r} \Big[[\alpha + 2 \cos (S \sin \theta) + 2 \cos (S \cos \theta)] + j\beta \Big] \underline{|- R.}$$

Hence, the magnitude of the horizontal field in V/m is given by the relation :

$$|E|^2 = \left(\frac{60 I}{r} \right)^2 \Big[\alpha^2 + \beta^2 + 4\alpha \cos (S \sin \theta) + 4\alpha S \cos (S \cos \theta) + 8 \cos (S \sin \theta) \cos (S \cos \theta) + 4 \cos^2 (S \sin \theta) + 4 \cos^2 (S \cos \theta) \Big]$$

Substituting $|E|^2$ in equation (26), we obtain:

$$|E_{rms}| = \frac{60 I}{r} \Big[\frac{1}{2\pi} \int_0^{2\pi} \alpha^2 \, d\theta + \frac{1}{2\pi} \int_0^{2\pi} \beta^2 \, d\theta + \frac{1}{2\pi} \int_0^{2\pi} 8 \cos (S \sin \theta) \cos (S \cos \theta) \, d\theta + \frac{1}{2\pi} \int_0^{2\pi} 4\alpha \cos (S \sin \theta) \, d\theta + \frac{1}{2\pi} \int_0^{2\pi} 4\alpha \cos(S \cos \theta) \, d\theta + \frac{1}{2\pi} \int_0^{2\pi} 4 \cos^2 (S \sin \theta) \, d\theta + \frac{1}{2\pi} \int_0^{2\pi} 4 \cos^2 (S \cos \theta) \, d\theta \Big]^{\frac{1}{2}}.$$

Calling the above integral expressions $F_1, F_2 \ldots\ldots F_7$ respectively, we have :

$$|E_{rms}| = \frac{60 I}{r} \left[F_1 + F_2 + F_3 + F_4 + F_5 + F_6 + F_7 \right]^{\frac{1}{2}} \quad \ldots\ldots\ldots\ldots\ldots (27)$$

Integral expressions are calculated as follows :

$$F_1 = \frac{1}{2\pi} \int_0^{2\pi} \alpha^2 \, d\theta = \frac{1}{2\pi} \alpha^2 . \left[\theta \right]_0^{2\pi} = \alpha^2.$$

$$F_2 = \frac{1}{2\pi} \int_0^{2\pi} \beta^2 \, d\theta = \frac{1}{2\pi} \beta^2 \left[\theta \right]_0^{2\pi} \beta^2$$

$$F_3 = \frac{2}{\pi} \int_0^{2\pi} 2 \cos (S \sin \theta) \cos (S \cos \theta) \, d\theta$$

$$= \frac{2}{\pi} \int_0^{2\pi} \cos \left[S\sqrt{2} \sin \left(\theta + \frac{\pi}{4} \right) \right] d\theta + \frac{2}{\pi} \int_0^{2\pi} \cos \left[S\sqrt{2} \sin \left(\theta - \frac{\pi}{4} \right) \right] d\theta$$

$$= \frac{4}{\pi} \int_0^{2\pi} \cos (S \sqrt{2} \sin \theta_1) \, d\theta_1$$

$$= \frac{8}{\pi} \int_0^{\pi} \cos (S \sqrt{2} \sin \theta_1) \, d\theta_1.$$

From the mathematical analysis of Bessel functions :

$$\frac{1}{\pi}\int_0^{\pi} \cos (x \sin \theta)\, d\theta = J_0 (x) \quad \ldots .(28)$$

where $J_0 (x)$ is the value of Bessel function of first kind and order zero at position x. Values of the function $J_0(x)$ are obtained either from tables or from the curve of Fig. 8.

Thus,

$$F_3 = 8J_0 (S \sqrt{2}).$$

From this is obtained :

$$F_4 = \frac{2\alpha}{\pi}\int_0^{2\pi} \cos (S \sin \theta)\, d\theta$$

$$= \frac{4\alpha}{\pi}\int_0^{\pi} \cos (S \sin \theta)\, d\theta = 4\alpha J_0 (S).$$

$$F_5 = \frac{2\alpha}{\pi}\int_0^{2\pi} \cos \left[S \sin \left(\frac{\pi}{2} - \theta\right) \right] d\theta$$

$$= \frac{4\alpha}{\pi}\int_0^{\pi} \cos (S \sin \theta_1)\, d\theta_1 = 4\alpha J_0(S) = F_4.$$

$$F_6 = \frac{2}{\pi}\int_0^{2\pi} \cos^2 (S \sin)\, d\theta$$

$$= \frac{1}{\pi}\int_0^{2\pi} [1 + \cos (2S \sin \theta)]\, d\theta$$

$$= \frac{1}{\pi}\int_0^{2\pi} d\theta + \frac{2}{\pi}\int_0^{\pi} \cos (2\, S \sin \theta) d\theta$$

$$= 2 + 2J_0 (2S).$$

$$F_7 = \frac{2}{\pi}\int_0^{2\pi} \cos^2 (S \cos \theta)\, d\theta = F_6.$$

Transferring the F values in equation (27).

$$|E_{rms}| = \frac{60\, I}{r}\left[\alpha^2 + \beta^2 + 8J_0 (S \sqrt{2}) + 8\alpha J_0 (S) + 4J_0 (2S) + 4\right]^{\frac{1}{2}} \ldots\ldots\ldots (29)$$

Omitting the common factor 60 I/r, the relative magnitude of the root mean square field strength in the horizontal plane is obtained.

$$|\varepsilon_{rms}| = \left[\alpha^2 + \beta^2 + 8J_0 (S\sqrt{2}) + 8\alpha J_0 (S) + 4J_0 (2S) + 4\right]^{\frac{1}{2}} \ldots\ldots\ldots\ldots\ldots\ldots (30)$$

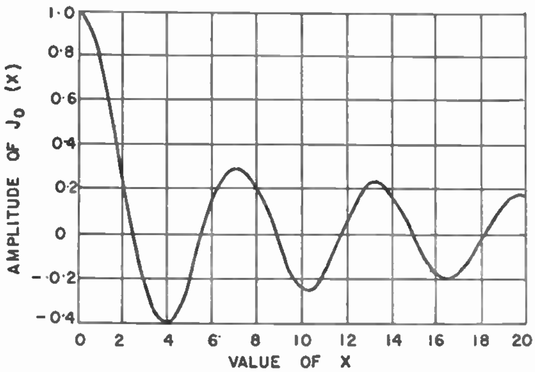

Fig. 8.—Values of Bessel functions of the first kind and zero order, J_0 (x) (from C. E. Smith, "Appl. Math.," McGraw-Hill, 1945, *p.* 255).

The magnitude of the actual root mean square field strength $|E_{rms}|$ in V/m may be found from the relative value of equation (30) multiplied by the common factor referred to above.

$$|E_{rms}| = \frac{60\, I}{r}\, |\varepsilon_{rms}| \ldots\ldots\ldots\ldots\ldots\ldots\ldots (31)$$

All quantities on the r.h.s. of equation (30) are already known as functions of the half-diagonal spacing S, expressed in radians. Thus, the drawing of a diagram for the relative root mean square field strength variations on the horizontal plane as a function of the half-diagonal spacing S is made possible (Fig. 9).

Figure 9 shows that for very close antenna coupling ($S \rightarrow 0$), the root mean square value of the field strength approaches zero. This is because, for close coupling, the parasitic element tends to entirely balance the radiation of the driven antennas. See remarks in 1.0 and 2.0 regarding this subject.

For increasing antenna spacings, the relative root mean square value of the field strength on the ground surface reaches a first maximum of 2·38 for S=100°, then is reduced to a minimum of 1·2 for S=200°, increasing again to a second maximum value of 2·45 for S=300°.

It will be observed that the relative root mean square value $|\varepsilon_{rms}|$ is smaller than both the relative values of the field strength at the horizontal plane in the directions $\theta=0$ and $\theta=45°$

for the entire region from $S=120°$ up to $S=340°$. This suggests that the horizontal pattern, in this region, has considerable directive characteristics, as for example, for $S=270°$ (Fig. 7*B*). On the contrary, for $S=90°$ we have :

$$|\varepsilon_{hor.b}| < |\varepsilon_{rms}| < |\varepsilon_{hor.d}|$$

in which case the pattern appears to have more regular circular shape (Fig. 7*A*).

Finally, in the range of very close couplings, for S less than 45°, the three values $|\varepsilon_{hor.d}|$, $|\varepsilon_{hor\ b}|$, and $|\varepsilon_{rms}|$ are almost identical and the horizontal patterns are practically circular.

6.0. Calculation of the Average Field Gain due to the Array compared with that for a Single Antenna of Constant Total Input Power

A total radio frequency power defined as $P=4(R+R_1)\,I^2$ (watts) is required to be fed into the four driven antennas of the array in order to produce the equal and in-phase currents I.

In the above relation, the following symbols have been used :

R_1 is the radiation resistances of a driven antenna in the presence of the other four (see Fig. 4).

R_l is the coil and ground resistance for each single antenna.

I is the root mean square value of the input current at the base of each antenna.

Thus,

$$I = \frac{1}{2}\sqrt{\frac{P}{R+R_l}} \quad \ldots.(32)$$

Substituting this value of I in equation (31), the root mean square value of the field in V/m of the horizontal pattern as a function of the input power is obtained.

$$|E_{rms}| = \frac{60}{2r}\sqrt{\frac{P}{R+R_l}}\,|\varepsilon_{rms}| \quad \ldots\ldots\ldots\ldots.(33)$$

Considering the same total power P fed into a single antenna, the input current at the base of the antennas will be such that :

$$P = (R_r + R_l)\,I_a^2,\quad I_a = \sqrt{\frac{P}{R_r+R_l}} \quad \ldots.(34)$$

where R_r is the radiation resistance of the single antenna, R_l is the loss resistance, as defined above, and I_a the r.m.s. value of the input current at the base of a single antenna.

The field strength produced by a single antenna, fed with the same input power and at the same distance *r*, is :

$$|E_a| = \frac{60\,I_a}{r} = \frac{60}{r}\sqrt{\frac{P}{R_r+R_l}} \quad \ldots\ldots\ldots\ldots(35)$$

Dividing (33) by (35) the average field strength gain of the array in excess of a single quarter-wave length antenna fed with the same power is immediately obtained.

Gain

$$g = \frac{|E_{rms}|}{|E_a|} = \frac{1}{2}\sqrt{\frac{R_r+R_l}{R+R_l}}\,|\varepsilon_{rms}|,$$

$$\text{or,}\quad g = \frac{|\varepsilon_{rms}|}{2}\cdot\sqrt{\frac{1+\eta}{\frac{R}{R_r}+\eta}}\,, \quad \ldots\ldots\ldots\ldots(36)$$

where $\eta = R_l/R_r$. All terms on the right-hand side of equation (36) are defined as previously. Values for $|\varepsilon_{rms}|$ and R as functions of the half-diagonal spacing S are given by Figs. 9 and 4 respectively. The value of R_r for quarter-wavelength antennas is $R_r=36{\cdot}6$ ohms. Consequently, a family of curves may be drawn, giving

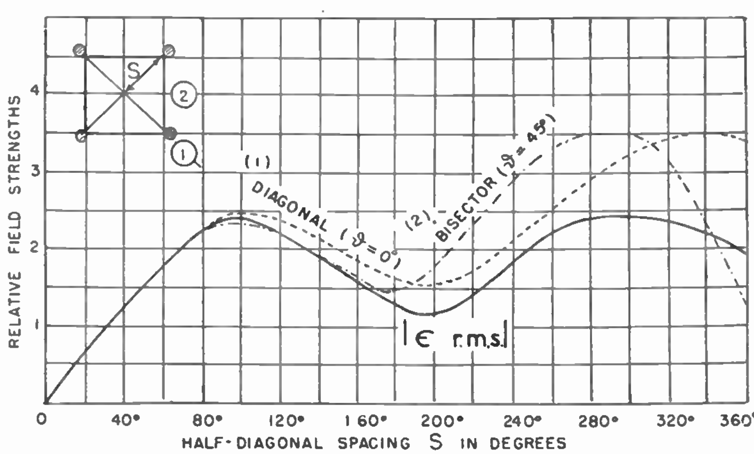

Fig. 9.—Relative field strengths towards the diagonals and bisectors, and relative r.m.s. field strength in the horizontal plane.

the average field strength of the array gain (g) as a function of the half-diagonal spacing S, with η as parameter. This has been done in Fig. 10.

It is obvious, from Fig. 10, that the most suitable arrangement of the array is obtained when the half-diagonal antenna spacing is between 90° and 100° (that is from $\lambda/4$ up to $\lambda/36$). The exact choice of the suitable spacing depends upon the coil and ground resistance of each antenna. For a suitable choice of spacing, the average field strength gain may be from 8 to 17 per cent. Providing that the average gain in power is proportional to the square of the average gain in field, an average power gain of from 17 to 36 per cent. may be achieved.

A second region of increased array gain is found for an increased half-diagonal antenna spacing from 270° to 340° (that is $3\lambda/4$ up to $34\lambda/36$). The average field gain in this region may reach from 11 to 21 per cent. Thus, the average gain in power may be from 23 up to 46 per cent. Yet, the diagram of Fig. 9, for this region and for the special case S=270°, appears to develop outstanding directive characteristics on the horizontal pattern.

Consequently, the arrangement of the array in this region of the increased gain must be considered favourable, not because it uniformly covers a radio range, but owing to the characteristic directive radiation.

Fig. 10 shows that an arrangement of the array with very small spacings or with half-diagonal distances widely extended around 180° ($\lambda/2$) is unfavourable. Similar remarks were made in the preceding paragraphs.

In Fig. 10 and for S=73°, 154° and 255°, all the gain curves meet at a common point. This is obvious, as was pointed out in 1.0 (see Fig. 4) since, for the above values of S, the radiation resistance of one antenna of the array, in the presence of all the other four antennas, is equal to that of one single antenna one-quarter-wavelength ($R=R_r$). Consequently, no matter what the value of the parameter π may be, equation (36) always gives the same average gain $|\varepsilon_{rms}|:2$. It may be observed that, for favourable arrangement of the array, the average gain increases for increased coil and ground resistances.

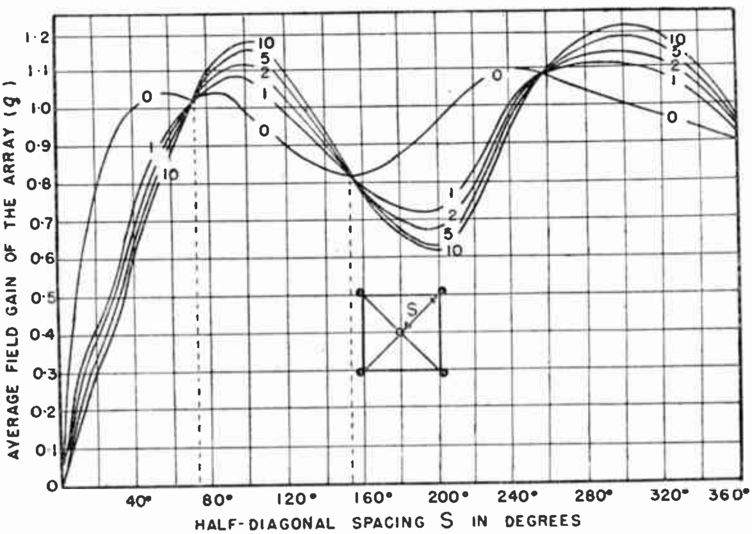

Fig. 10.—Average field gain curves in terms of S and with $\eta = R/R_r$ = 0,1,2,5,10 as parameter.

7.0. Field Gain in Certain Favonrable Directions and for a Particnlar Arrangement of the Array

From equation (18) the magnitude of the field strength in a certain direction on the horizontal plane ($\varphi=0$) is :

$$|E_{hor}| = \frac{60\,I}{r}\Big[\big[\alpha+2\,\{\cos(S\sin\theta) + \cos(S\cos\theta)\}\big]^2+\beta^2\Big]^{\frac{1}{2}}$$

$$= \frac{60\,I}{r}\,|\varepsilon_{hor}| \quad \ldots\ldots\ldots(37)$$

where $|\varepsilon_{hor}|$ is the relative field strength towards the chosen direction (see equation (21)).

If the root mean square value of the current I, taken from equation (32) is substituted in equation (37), the field strength in this horizontal direction in V/m is obtained as a function of the total power fed into the array.

$$|E_{hor}| = \frac{60}{2r}\sqrt{\frac{P}{R+R_l}}\,|\varepsilon_{hor}| \ldots(38)$$

Dividing equation (38) by (35) the array gain for the horizontal direction (θ) is :

$$g_\theta = \frac{|E_{hor}|}{|E\alpha|} = \tfrac{1}{2}\sqrt{\frac{R_r+R_l}{R+R_r}}\cdot|\varepsilon_{hor}|$$

$$\text{or} \quad g_\theta = \frac{|\varepsilon_{hor}|}{2}\sqrt{\frac{1+\eta}{\frac{R}{R_r}+\eta}} \quad \text{..............(39)}$$

where R_l is the coil and ground resistance and the parameter $\eta = \frac{R_r}{R_l}$ is as defined in the previous paragraph.

Equation (39) corresponds to equation (36), though it refers to the field gain towards a certain direction and not to the average field gain of the array.

Under favourable array arrangements the special gain g_θ may be, for certain suitable directions, much higher than the average gain g.

An array arrangement with half-diagonal spacing $S=270°$ is considered. For $\eta=1$ and towards the suitable direction $\theta=45°$ (bisector direction) the following expression, from equation (39) and the patterns of Fig. 7 and 4 may be obtained

$$g_{45°} = \frac{3{\cdot}43}{2}\cdot\sqrt{\frac{1+1}{\frac{45}{36,\,36}+1}}$$
$$= 1{\cdot}62, \text{or } 62 \text{ per cent} \quad \text{............(40)}$$

This result underlines the directive characteristics that the array may develop under certain conditions and towards certain directions in the horizontal plane. It must be remembered, however, that the general advantages obtained from such a suitable arrangement of the array depend upon the average gain g given in the previous paragraph.

8.0. Array Arrangement with Radiators Shorter than One-quarter Wavelength

The foregoing analysis concerns arrays consisting of five antennas of one-quarter wavelength over a perfectly conducting plane, located at the corners and the centre of a square. Certain complementary modifications of the practical arrangement of the array may now be considered. It will be seen that no alterations will be made to the results obtained.

In this paragraph it is assumed that the five radiators of the array are not exactly one-quarter wavelength, but that they are all shorter.

It can be readily shown that the radiation resistance R_r of a single antenna, shorter than one-quarter wavelength, made of thin wire, over a perfectly conducting plane, may be assumed to vary as the square of the effective height of the antenna :

i.e. R_r is approximately proportional to H^2, ...(41)

where $H<\lambda/4$ is the physical antenna height. It is also shown later that the coupled resistance of two identical short antennas may be assumed to vary as the square of the common height of the two antennas.

Let E_2 be the field strength along the axes of antenna (2) induced by the current of antenna (1). U_2 is the total voltage induced on antenna (2), I_1 is the root mean square value of the input current at the base of element (1) and h is the effective height of each antenna.

Then : E_2 is proportional to hI_1
$U_2 = hE_2$ proportional to h^2I_1
$Z_{12} = U_2/I_1$ proportional to h^2.

Thus the total mutual impedance, and its resistance part, varies as h^2, or approximately as the square of the physical height (H^2) of the antennas. Approximation may reach a few per cent. According to these calculations the current distribution along a short antenna is considered as linear from the top (current zero) to the base of the element (maximum current).

In conclusion, the two terms of the ratio R/R_r, in equation (36), giving the average gain of the array, both vary as the square of the antenna height. Consequently the ratio is assumed to be constant when the antenna heights are shortened simultaneously and equally in all the antennas. Apart from the ratio R/R_r, $|\varepsilon_{rms}|$ and η of equation (36) remain almost unaffected by the simultaneous shortening of the antennas.

Under these conditions equation (36) and the pattern of Fig. 10 give a good approximation of the array field strength gain compared with the field of one short antenna of the same design, fed with the same total radio-frequency power.

9.0. Effect of Limited Ground Conductivity upon Radiation Patterns

Poor ground conduction reduces the field radiation strength, in V/m. Providing that the influence is uniform, the horizontal radiation patterns take the same shape. Also, the average field gain remains unchanged for different arrangements of the array.

Thus all conclusions reached in the preceding analysis regarding the shape of the horizontal radiation patterns and the gain predominate in the present arrangements of the array with antennas shorter than one-quarter wavelength over an imperfect conducting plane.

10.0. General Conclusions

An array of four driven antennas located at the corners of a square, with a central parasitic antenna, may develop, under suitable antenna spacings, a remarkable average field strength gain and also may present directive characteristics in the horizontal plane.

For a diagonal spacing (2S) of approximately half-wavelength the average field gain may be brought up to 17 per cent., while the shape of the horizontal pattern remains practically circular.

For a diagonal antenna spacing of about one and a half wavelengths the array gain may be 24 per cent. The horizontal radiation pattern in this case presents directive characteristics.

It is observed that a higher gain is obtained for relatively increased coil and ground resistance. No gain is obtainable, for any other array arrangement, except for the above stated antenna spacings. It is particularly interesting that the array gain, which varies as the antenna spacing, starts from zero owing to the negative action of the parasitic element. In general, the development of the analysis shows the effect of the induction current of the parasitic element on the radiation patterns and field gain of the array.

11.0. Acknowledgment

The writer wishes to express here his gratitude to Mr. Michael Anastassiadis, Professor of Radio-Engineering at the Athens University, President of the Radio-Technical School of Athens and Member of the British Institution of Radio Engineers, who suggested the subject of this thesis and followed its advancement.

12.0. Bibliography

1. P. S. Carter, " Circuit Relations in Radiating Systems and Applications to Antenna Problems," *Proc.I.R.E.* (*N.Y.*), Vol. 20, 1932, pp. 1104-1041.
2. C. E. Smith, " Applied Mathematics for Radio and Communication Engineers," McGraw-Hill, Ltd., 1945.

DISCUSSION ON

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

by

E. H. Frost-Smith, B.A.

(A paper read before the London Section on October 13th, 1949, and published in the October issue of the Journal)

Mr. P. D. Atkinson: The curves in Fig. 19 indicate that, at a given supply frequency, there is an optimum core area, and that if the core area is increased above this optimum value the useful power output is reduced; the analysis given supports this conclusion. This is only true, however, for the restricted case considered and if the problem is analysed in more general terms a different conclusion is reached.

The restrictions imposed by the author are that E_s, R_L and the working flux density are fixed while the core area and consequently T_2 are varied. Let us consider the effect of core dimensions and supply frequency on the output power when E_s and R_L are not fixed.

Now, in considering the output characteristic of a magnetic amplifier, we are usually concerned with two criteria of performance, namely the maximum power output and the control ratio $\frac{i_s}{i_o}$. The control ratio is important because, if it falls below about 5, the practical value of the device is greatly reduced, for the bottom bend and the top bend of the curve of input current against output current merge, the linear region disappearing.

Now, taking the expressions for X_s, $\overline{E}_s$ and i_o given in the paper, and introducing "l" for the mean magnetic path, we have :—

$$X_s = C_1 . \frac{a}{l} . T_2^2 . f \quad \ldots\ldots (1)$$

$$\overline{E}_s i_o = a . l . [k_1 . f^2 . b + k_2 f] \quad \ldots\ldots (2)$$

$$\overline{E}_s = C_2 . a . f . T_2 \quad \ldots\ldots (3)$$

The constants C_1, C_2, k_1 and k_2 depend on the magnetic properties of the core material. C_1 will also depend to some degree on core geometry; in the following it is assumed that variations of the ratio $\frac{a}{l}$ will not significantly affect C_1 (see curve "b" of Fig. 17 of the paper.)

Control Ratio

The best possible control ratio, termed the limiting control ratio, will be obtained when $R_L < X_s$. Normally, at power frequencies, heating of the windings would limit the output current before X_s had a serious effect; however, we are concerned here with the maximum possible control ratio.

Then,

$$\Delta_L = \text{Limiting control ratio} = \frac{E_s}{X_s} . \frac{1}{i_o}.$$

Substituting from equations (1), (2) and (3)

$$\Delta_L = \frac{C_2^2}{C_1} . \frac{1}{k_1 f b + k_2} \quad \ldots\ldots (4)$$

Thus for useful values of Δ_L there is an upper limit to the supply frequency which can be used with a given core material and lamination thickness; this upper limit is independent of "a," "l" and "T_2."

Power Output

There are a number of ways of expressing the maximum power output; one of the most useful is :

$$P = R_L [i_s - i_o]^2 \quad \ldots\ldots (5)$$

or

$$P = \left[1 - \frac{1}{\Delta}\right]^2 . R_L . i_s^2 \quad \ldots\ldots (6)$$

Now

$$i_s = \frac{\overline{E}_s}{\sqrt{R_L^2 + X_s^2}} \quad \ldots\ldots (7)$$

Thus if we make $X_s = n . R_L$

$$P = \frac{\overline{E}_s^2}{R_L} \frac{\left[1 - \frac{1}{\Delta}\right]^2}{1 + n^2}$$

$$\therefore P = \left[\left[1 - \frac{1}{\Delta}\right]^2 . \frac{n}{1+n^2}\right] . C_1^2 . a . l . f \quad (8)$$

Now the expression $\left[\left[1-\frac{1}{\Delta}\right]^2 \frac{n}{1+n^2}\right]$ is a function of the control ratio and the ratio " n " which will also be mainly governed by the need to obtain a reasonable control ratio. Thus for a fixed control ratio and supply frequency :—

$$P \propto a \,.\, l.$$

At frequencies such that Δ can be made reasonably large $\left[1-\frac{1}{\Delta}\right]^2 \rightarrow 1$. P is then a maximum when $n = 1$

and $P \doteqdot \frac{C_1^2}{2} \,.\, a \,.\, l \,.\, f$ ....(9)

Thus if the restrictions imposed in the paper are removed, the results given in Figs. 19 and 20 are modified to the following :—

(1) For a given core material there is an upper limit of frequency above which the control ratio becomes impracticably small. The control ratio and the limiting frequency are independent of core dimensions.

(2) For practical values of control ratio the maximum power output, neglecting limitations due to heating, is proportional to the product of the volume of iron and the supply frequency.

Mr. E. H. Frost-Smith : Mr. Atkinson analyses the problem relating to the maximum power controlled, and he does so without imposing any limitations on the supply voltage and load resistance. In this way he arrives at the conclusion that there is an upper limit to the supply frequency at which the device can be usefully employed for a given thickness of laminations, and furthermore that this upper limit is independent of " a " and " T_2." The last of these conditions only holds provided that no restrictions are placed on the A.C. power supply and this analysis may be true for power frequencies in cases where a large quantity of power is available and therefore where considerations of efficiency are of secondary importance.

At higher frequencies, however, there is usually only a limited supply of power available, and, in these circumstances, it is necessary to obtain the maximum useful output while taking into consideration the limitations imposed by the source. The assumption made in this paper is that the power available given by $P_1 = \frac{\bar{E}_s^2}{R_L}$ is fixed. (Equation (9) may be written $\frac{1}{R_i} = \frac{a}{P_1 R_L}[k_1 f^2 b + k_2 f]$ and equation (12) may be written $X_s = \frac{k_3 P_1 R_L}{af}$). This leads to the results given in equations (13) and (14).

It is of interest to note that the value obtained for the control ratio $\Delta = \frac{\bar{i}_s}{i_o}$ is given by :—

$$\Delta^2 = \frac{R_i^2}{X_s^2 + R_L^2}$$

and if we now assume that $\frac{\bar{E}_s^2}{R_L}$ = const, and substitute for R_i and X_s from equations (9) and (12) we have

$$\Delta^2 = \frac{P_1^2}{[k_1 f b + k_2]^2\,[k_3^2 P_1^2 + a^2 f^2]}$$

This shows that Δ decreases with increasing " a." Furthermore if the optimum value for " a " is taken from equation (13), and substituted in our expression for Δ, we have, to a first approximation :

$$\Delta = \frac{1}{\sqrt{k_3(k_1 f b + k_2)}}.$$

As the frequency increases it is clear that Δ decreases and this implies that if we allow a minimum value for Δ there is as Mr. Atkinson states an upper limit to the supply frequency at which the device is effective for a given thickness of lamination. Under the conditions imposed by a limited power supply, however, this upper frequency limit is not independent of core area.

I agree with Mr. Atkinson that a more useful criterion of power output is obtained by considering $(i_s - i_o)^2$ rather than $i_s^2 - i_o^2$. It will be seen from the paper that both criteria are considered. If the power swing is taken to be $R_L(i_s - i_o)^2$, a slightly smaller value for optimum area is obtained and consequently a slightly larger value for Δ.

Mr. R. Benjamin : For the investigation of electro-physiological phenomena, in biological and medical research, there is a great demand for a high-gain amplifier with a flat response characteristic from a few kilocycles per second down to D.C. (or a few cycles *per minute*). What contribution, in the author's opinion, could the magnetic amplifier make in this field?

Mr. E. H. Frost-Smith: As is shown in the paper, a single transductor unit operating from a supply frequency of about 20 kc/s, can have a flat response from D.C. up to about 1 kc/s for a power gain of about 500 with a corresponding increase in response for a reduced power gain. If two units are connected in cascade the response is approximately halved and the power gain would be given by $2{\cdot}5\times10^5$. The response can then be increased up to about 3-4 kc/s by reducing the gain to about $\frac{1}{10}$ its original value, i.e. about $2{\cdot}5\times10^4$. I should like to make it clear, however, that up to the present little has been done on cascading transductors at high frequencies and for this reason the figures given above may only be taken as very approximate. Nevertheless I am inclined to say that assuming the zero stability and noise level are within tolerable limits the magnetic amplifier should have an application in the field of work suggested by Mr. Benjamin.

Mr. F. W. Atkin (A.M.): Am I correct in assuming that the audio-frequency input is superimposed upon the D.C. control current, whilst, on the output side, the "supply" (or carrier) current is rectified to produce the audio-frequency output?

Mr. E. H. Frost-Smith: In this particular demonstration the audio-frequency signal alone is applied to the control winding, but in order to bias the amplifier to operate linearly an additional winding is added which carries a steady biasing current.

A more usual arrangement, however, particularly when self-excitation is employed is to arrange two transductors to give a balanced output; in this case it may be possible to dispense with the biasing supply.

The effect of the audio frequency input is to modulate the carrier which is then rectified to produce the audio frequency output.

Mr. F. W. Atkin (A.M.): Does the magnetic amplifier in its modern form have application as a modulator of carrier frequency currents? For example, in a radio transmitter a large amount of carrier power might be modulated by a very small amount of audio frequency input power. Very large power gains are obtainable from magnetic amplifiers, and if, as the lecturer has so convincingly shown, the device has possibilities as an amplifier of audio-frequency power, it should be possible to replace the expensive valve modulating equipment in a high-power transmitter, which is required when using high-level modulation, by a comparatively simple and inexpensive magnetic modulator.

In this connection, the work many years ago of E. F. W. Alexanderson would appear to show that high-power magnetic modulators present no inherent difficulty. Alexanderson was granted a patent in the U.S.A. as early as 1911, covering a magnetic modulator. The carrier, in those days, was produced by a high-frequency alternator also developed by Alexanderson, and according to a paper published in the *General Electric Review*, 19, p. 215, 1916, it was stated that the output of a 75-kW high-frequency alternator (at about 40 kc/s) was successfully modulated by a single-stage magnetic amplifier. A power gain of 350 was quoted for the latter. Mr. Frost-Smith has shown by his paper, and by the demonstrations he has given to-night, that he has made an invaluable contribution to our knowledge of magnetic amplifiers, and has opened up some extremely stimulating lines of investigation from which I, for one, foresee results of great value.

Mr. E. H. Frost-Smith: In reply to Mr. Atkin's second point, I think it is true to say that with our modern magnetic alloys and improved techniques the magnetic modulator might well give striking results as an audio frequency modulator applied to an R.F. carrier particularly for the longer transmission wavelengths.

I believe I am right in stating that the toroidal cores employed originally by Alexanderson were constructed of ordinary soft iron tape.

One of the chief difficulties arising out of the use of magnetic amplifiers at high carrier frequencies is imposed by poor rectifier characteristics. In the case of the magnetic modulator, however, no rectifier is required and therefore that difficulty at any rate is removed.

Unfortunately owing to the manner whereby the transductor operates the current in the A.C. windings which corresponds to the unmodulated carrier is not sinusoidal but, as we have shown, is rich in odd harmonics.

The carrier frequency will therefore require to be filtered after modulation in order to remove the H.F. odd harmonics which might cause interference with other wavebands. Whether or not this would seriously affect the reproduction of the audio signal is an interesting matter for speculation.

Mr. A. J. Tyrrell (Member): I understand from the description and method of operation of the magnetic amplifier that the main limitations on its performance are due to the frequency of the carrier, which up to the present is limited to about 20 kc/s, and the losses in the iron cores. Mr. Frost-Smith mentioned that he has used Ferroxcube with little success. This is interesting, since Ferroxcube has the familiar BH characteristic of an ungapped iron circuit while it permits frequencies up to 500 kc/s to be used with relatively negligible iron losses. Can Mr. Frost-Smith explain this phenomenon?

Also, I gather that one of the most useful characteristics of the magnetic amplifier is its robustness, due to the elimination of thermionic valves, but since it requires a carrier frequency, presumably generated by thermionic valves, it would appear that the thermionic valve is transferred from the amplifier to the carrier generator and we have not gained very much.

Finally, can Mr. Frost-Smith give us some information on the practical industrial use of the magnetic amplifier, particularly applications where the special characteristics of the magnetic amplifier give it advantages over more familiar types of amplifier?

Mr. E. H. Frost-Smith: Ideally the power amplification of a transductor is given by equation (5) in the paper; this is only true, however, if we assume that the core has infinite permeability prior to saturation and a sharp knee on the B/H curve. In the case of mumetal this is a fairly close approximation to the truth.

Although Ferroxcube has, I believe, very exceptional characteristics, I doubt whether the permeability even approaches that of mumetal with the result that the advantages arising from low losses largely disappear due to the comparatively inferior B/H characteristic. However, at this stage in my investigations I would go no further than to say that up to the present I have achieved more success with mumetal than Ferroxcube.

Mr. Tyrrell's second point, is of course an obvious objection to the system in its present form. There is no doubt, however, that if we do wish to generate high supply frequencies without using electronic oscillators there are ways of achieving this.

Two methods have already been mentioned by Mr. Atkin. A third method that seems quite promising is to saturate an iron cored coil with a low frequency sinusoidal magnetizing current. The voltage appearing across the coil will consist of a number of pulses. This voltage waveform is rich in harmonic content and subsequent filters would enable one to select any desired frequency. The efficiency of this device is astonishingly high and it was originally used as a high frequency generator for the group of transmitters used by the German Post Office at Konigs Wusterhausen. The efficiency is quoted at about 70 per cent (see "Wireless," by L. B. Turner, C.U.P. p. 141).

Regarding possible applications of the magnetic amplifier. In addition to those already discussed this evening, it might be worth while mentioning its use in aircraft. During the war the Germans employed a magnetic amplifier as part of the control system in their long-range rockets. In this application the robustness of the device is a consideration of primary importance. Also, as Dr. Barlow has told us, it may have very great value in its application to strain gauge measurement in instances where we may be concerned with both steady and varying strains. Finally the magnetic amplifier is already extensively used in various types of servo mechanism such as those employed for temperature control, voltage and frequency control, etc.

NOTICES

Air Commodore Wansbrough

It has been announced that Air Commodore R. C. Wansbrough, M.A. (Member), has been appointed to the position of personal assistant to Mr. E. J. Emery (Member) who is the Managing Director of E.M.I. Sales and Service, Ltd. Air Commodore Wansbrough had a distinguished career in the R.A.F. and also served in the R.F.C. during World War I. During the last war he was Deputy Director of Radio Repairs at the Ministry of Aircraft Production and subsequently Director of Radio at the Air Ministry. He also held a number of other positions.

Measurement of Productivity

The Joint Committee of the Institution of Production Engineers and the Institute of Cost and Works Accountants, which was set up in January 1949, have issued an Interim Report on their investigations into methods of measuring productivity.

They recommend the provision of better cost and statistical information for supervisory staff, and advocate the establishment of uniform principles of work measurement together with a unified system of training for time study engineers.

The Committee are convinced that a common measurement of productivity should be made available to Managements for the improvement of productivity. It should at the same time be simple enough to be grasped and used by supervisory staff.

T.C.M. Co. Changes

The Directors very much regret to announce that Sir Geoffrey Clarke, C.S.I., has tendered his resignation, on medical advice, as Managing Director, and from the Board of Directors of The Telegraph Construction & Maintenance Co., Ltd., and its associated and subsidiary companies, with effect from January 1st next.

The Directors have had much pleasure in appointing Mr. John Norman Dean, B.Sc., A.R.I.C., as Managing Director of The Telegraph Construction & Maintenance Co., Ltd., and Selborne Plantation Co., Ltd., in succession to Sir Geoffrey Clarke.

Merchant Venturers Technical College

The Corporation of Bristol has recently taken over control of most of the Merchant Venturers Technical College which used to be under the control of the Society of Merchant Venturers.

The Engineering Faculty, however, is being administered by the University and is entirely separate from the rest of the college. It now forms part of the University Engineering Laboratories.

The part under the control of the Bristol Corporation is now known as the College of Technology.

The Third Amateur Radio Exhibition

The Third Amateur Radio Exhibition organized by the Incorporated Radio Society of Great Britain was held at the Royal Hotel, Woburn Place, London, from November 23rd to November 26th. The exhibition was opened by Lord Sandhurst, O.B.E.

There were altogether 28 stands in the exhibition and a large variety of equipment was displayed by a number of firms. Both the Air Ministry and the G.P.O. were exhibitors and produced very interesting displays.

Scientific Films Census

In connection with the Information Service of the Scientific Film Association, a national survey is being made of makers, owners and users of scientific and similar films.

Although information has been collected already from over four hundred scientific film-makers and distributing agencies, it is believed that there are many more whose names and films are known only to a limited number of people. The Association wishes to bring up to date its records in the documentary, instructional, educational and scientific film fields, so that it may be in a better position to answer the many inquiries which are made to its Secretariat from day to day.

The kind of statement needed should give the maker's name and address, the title of the film, its gauge and length or running time, and preferably a brief synopsis.

Further details of the work of the Association may be obtained from the Secretary, at 4 Great Russell Street, London, W.C.1.

B.B.C. Staff Change

The Senior Superintendent Engineer, Mr. Leslie Hotine, is leaving the B.B.C. after more than twenty-six years' service. Mr. Hotine joined the Corporation in 1923 as Engineer-in-Charge of the Glasgow Station and was successively Engineer-in-Charge of Daventry and of Brookmans Park. He then joined the Head Office staff as Superintendent Engineer, Transmitters, and continued in that post until 1943 when he was appointed Senior Superintendent Engineer.

New Permanent Headquarters for Television

The B.B.C. announces that they have decided to develop their 13-acre White City site in two stages. Mr. Graham Dawbarn, C.B.E., M.A., F.R.I.B.A., has been appointed architect for the first stage, in association with Mr. M. T. Tudsbery, C.B.E., M.I.C.E., the Corporation's Civil Engineer.

The appointment has been made from names put forward by the R.I.B.A., who were informed of the nature and scope of the project. The first stage will absorb some seven acres and will be devoted to Television.

The decision to develop the site in this manner, instead of holding a planning competition for the whole as was originally intended, has been taken in order to preserve the flexibility necessary to meet changing demands in the most efficient manner.

Recording of Television

The B.B.C. announces that after several months' work it is now possible to telefilm a broadcast and reproduce it again days or weeks afterwards, with little loss of the original picture quality.

The recording system uses a continuous-motion camera in which the movement of the film is chased by an optical image of the television picture reflected from a rotating mirror drum. By this means, all the 405 interlaced lines of the picture are recorded on the film, and the difficulties of relating the television frame frequency to the picture repetition frequency on the film are overcome. The method was proposed by H. W. Baker, Engineer-in-Charge Alexandra Palace, and H. G. Whiting, now Engineer-in-Charge of the new Sutton Coldfield station, in collaboration with D. R. Campbell, one of the senior engineers at Alexandra Palace. It was perfected by W. D. Kemp, of the Planning and Installation Department of the B.B.C. It is covered by a patent application and is one of several that have been, and indeed are still being, investigated.

C. O. Stanley's Address

The address by Mr. C. O. Stanley, C.B.E., Chairman and Managing Director of Pye, Ltd., on "Television—Today and Tomorrow," which was delivered after the Annual General Meeting of the Institution on September 22nd, 1949, will not be published in the Institution's Journal since it has already been produced in booklet form by W. Heffer & Sons, Ltd., of Cambridge. Copies of the booklet can be obtained on application to the offices of the Institution.

New Egyptian Transmitters

The Egyptian Government has placed with Standard Telephones and Cables Limited, London, a contract for the supply of two high-power short wave broadcasting transmitters.

These transmitters, of a type similar to those used by the B.B.C., have two channels, an output power of 100-140 kW, and will operate in the 13/49-metre band.

The broadcasting station building, situated at Abu Zabal about 20 km from Cairo, is now under construction.

Electronic Aids to Industry

The Report on Electronic Aids to Industry (pp. 446-464) was produced by the Technical Committee of the Institution. The first draft was prepared in 1947 and in addition to the members of the Committee, past and present, several members who are specialists in particular fields assisted in its preparation.

The Council wishes to thank the members of the Committee, listed below, who served on the Committee during the preparation of the Report.

P. Adorian (*Member*)
J. L. Brown (*Associate Member*)
E. Cattanes (*Member*)
F. W. Dawe (*Member*)
F. G. Diver (*Member*)
H. E. Drew (*Member*)
A. W. Grantham (*Member*)
L. Grinstead (*Member*)
T. D. Humphreys (*Member*)
M. M. Levy (*Member*)
J. A. Sargrove (*Member*)
W. W. Smith (*Member*)
J. L. Thompson (*Member*)
A. J. Tyrrell (*Member*)
C. E. Tibbs (*Associate Member*)
Prof. E. Williams (*Member*)

ELECTRONIC AIDS TO INDUSTRY

A Survey prepared by the Technical Committee

SUMMARY

The survey is intended to give an outline of the various methods by which radio or electronic devices may be applied to industrial processes. The application of each electronic device is illustrated by one or two examples and the chief value of the survey lies in the extensive bibliography to each section. Although these are not exhaustive, they serve as a guide to any further information required on the subject.

TABLE OF CONTENTS

INTRODUCTION

In October, 1944, the Institution published the first of the Post-war Reports in which the whole field of applications of radio and electronic technique was briefly covered.

The section dealing with industrial electronics aroused the most interest; the purpose of this report is to show in greater detail the main applications of electronics and examples are given of the ways in which electronic equipment can aid manufacturing techniques in almost every industry.

It is emphasized that this is the first report by the Committee on the subject; it is not presented as a comprehensive report but it is the intention of the Technical Committee to issue supplementary reports on the subject as is found necessary.

As far as possible the bibliography has been selected as a principal guide to those seeking more detailed technical information on the subject matter. It is also intended to bring this section up to date periodically.

Perhaps one of the major omissions from this first report is servo mechanisms. Such omissions are temporary as it is the intention of the Institution to publish separate papers on such important electronic devices within the course of the next year.

Since "electronics" has been a widely and often wrongly used word in recent years it may be of interest to repeat the definition used in Part I of the Post-war development Report in which the word "electronics" was stated as describing ". . . . the wider uses of the radio valve and kindred devices; it is radio technique at work in new ways and in widely diverse fields."

JOURNAL ABBREVIATIONS

Annales of the A.A.P.S.S.	*Annales of the American Academy of Political and Social Science*
A.S.T.M. Bulletin	*Bulletin of the American Society for Testing Materials*
Audio Eng.	*Audio Engineering*
B.E.A.M.A. Jnl.	*British Electrical and Allied Manufacturers Association Journal*
Bell Lob. Rec.	*Bell Laboratories Record*
B.S.T.J.	*Bell System Technical Journal*
Brit. Jnl. of Rad.	*British Journal of Radiology*
Chem. and Met. Eng.	*Chemical and Metallurgical Engineering*
F.M. and Televis.	*Frequency Modulation and Television*
G.E. Review	*General Electric Review*
J.Brit.I.R.E.	*Journal of the British Institution of Radio Engineers*
J.A.S.A.	*Journal of the Acoustical Society of America*
J.Brit. Kine Soc.	*Journal of the British Kinematograph Society*
J.I.E.E.	*Journal of the Institution of Electrical Engineers*
Jnl. of Sci. Instr.	*Journal of Scientific Instruments*
Jnl. of S.M.P.E.	*Journal of the Society of Motion Picture Engineers*
Jnl. of Appl. Phys.	*Journal of Applied Physics*
Jnl. of the Am. Opt. Soc.	*Journal of the American Optical Society*
Phil. Mag.	*The London, Edinburgh and Dublin Philosophical Magazine and Journal of Science London*
Philips Tech. Rev.	*Philips Technical Review*
Phys. Rev.	*Physical Review*
P.O.E.E.J.	*Post Office Electrical Engineers Journal*
Proc. I.R.E. (Aust.)	*Proceedings of the Institution of Radio Engineers (Australia)*
Proc. I.R.E. (N.Y.)	*Proceedings of the Institute of Radio Engineers (New York)*
Proc. Phys. Soc.	*Proceedings of the Physical Society*
Proc. of the A.A.A.S.	*Proceedings of the American Academy of Arts and Science*
Proc. of the N.E.C.	*Proceedings of the National Electronics Conference*
Rev. of Sci. Instr.	*Review of Scientific Instruments*
Transactions of the A.S.M.E.	*Transactions of the American Society of Mechanical Engineers*
Transactions of the A.E.S.	*Transactions of the American Electrochemical Society*
Transactions of the A.I.E.E.	*Transactions of the American Institute of Electrical Engineers*
Transactions of the A.S.M.	*Transactions of the American Society of Metals.*

1. AMPLIFIERS

An electronic amplifier comprises one or more thermionic valves or transistors with coupling circuits to secure greater voltage, current or power than is available from a chosen point in an associated circuit.

The construction of the amplifier, and particularly the design of its coupling circuits, will depend on the frequency range required for distortionless amplification of the input signal, since all types of amplifier are limited in the range of frequencies they can handle.

Accordingly several types of amplifier exist and are named to indicate the usual band of frequencies for which they can be used :

- Direct-current (zero c/s to a few Mc/s)
- Audio-frequency (20 c/s to 30 kc/s)
- Video-frequency (10 c/s to 3 or 4 Mc/s)
- Intermediate-frequency (a centre frequency in the range 110 kc/s to 200 Mc/s with band-width from 10 kc/s to 5 Mc/s)
- Radio-frequency (16 kc/s to 600 Mc/s in bands with max. min. tuning ratio of about 3/1).

In all industrial applications the amplifier is preceded by a transducer which produces the necessary input voltage either directly or indirectly as a result of change of a circuit parameter from a physical change in the associated circuit. Thus, changes in speed, temperature, illumination, colour, pressure, humidity, weight, conductivity, etc., can be made to operate controlling devices or recorders.

Direct-Current Amplifier Circuits for Use with the Electrometer Tube. D. B. Penick. *Rev. of Sci. Instr.*, April 1935, p. 115.

Multi-Stage Photo-Cell Current Amplifier. W. Richter. *Electronics*, August 1935, p. 245.

A Vacuum Tube Microvoltmeter for the Measurement of Bioelectric Phenomena. H. Burr, C. T. Lane and L. F. Nims. *Yale Journal of Biology and Medicine*, October 1936, p. 1.

Amplification of Galvanometer Deflections. A. H. Taylor. *Rev. of Sci. Instr.*, April 1937, p. 124.

D.C. Amplifier for Measuring Potentials in Living Organisms. C. T. Lane. *Electronics*, June 1937, p. 31.

Direct-Current Amplifier with a Standard Tube to Measure Ionisation Currents. H. Tatel, H. S. Moncton and O. Lohr. *Rev. of Sci. Instr.*, January 1938, p. 229.

An Improved Amplifier for Electro-Encephalography. F. P. Herrnfeld and H. Sjaardema. *Journal of Experimental Psychology*, 1940, Vol. 27, p. 208.

High Gain D.C. Amplifier for Bioelectric Recording. H. Goldberg. *Electrical Engineering*, January 1940 (Transactions), p. 60.

Sensitive D.C. Amplifier with A.C. Operation, S. E. Miller. *Electronics*, November 1941, p. 27.

Direct-Current Amplifier and Its Application to Industrial Measurements and Control. D. C. Gall. *J.I.E.E.*, Part II, October 1942, p. 434.

Amplifying and Recording Technique in Electro-Biology, with Special Reference to the Electrical Activity of the Human Brain. G. Parr and W. G. Walter. *J.I.E.E.*, Part III, September 1943, p. 129.

Wide-Range Electronic Generator : Oscillator and Amplifier for Medical and Other Research. E. Mittelman, F. S. Grodins and A. C. Ivy. *Electronics*, December 1943, p. 132.

Strain-Gauge Amplifier. N. G. Branson. *G.E. Review*, April 1945, p. 55.

Survey of D.C. Amplifiers, M. Artzt. *Electronics*, August 1945, p. 112.

Biological Amplifiers. D. H. Parnum. *Wireless World*, November 1945, p. 337, and December 1945, p. 373.

Electro-Encephalograph Amplifier. Denis L. Johnston. *Wireless Engineer*, August 1947, p. 231.

Vacuum Tube Amplifiers. Valley and Wallman. McGraw-Hill, 1947.

The Transitor. *Bell Lab. Rec.*, August, 1948. p, 321.

The Physical Principles Involved in Transitor Action. J. Bardeen and W. H. Brattain. *B.S.T.J.*, April 1949, p. 239.

2. BALANCING MACHINES

These are machines for the determination of the position of out-of-balance occurring in rotating bodies, and its amount.

The methods adopted comprise :

- Analysis of the frequency and amplitude of the amplified response from an electromagnetic pick-up.
- Cathode-ray tube indication of amplified response from a photo-electric cell, viewing the rotated body by reflected light.
- Direct viewing of the rotating part illuminated by a stroboscopic light source.

True dynamic balance of rotating parts may often be closely approached by adding or removing metal at positions indicated by these balancing machines.

The machines are mainly used for balancing electrical armatures and rotors, flywheels and crankshafts.

2. BALANCING MACHINES (*contd.*)

Balancing Rotors by Means of Electrical Networks. J. G. Baker and F. C. Rushing. *Journal of the Franklin Institute*, Vol. 222, 1936, p. 183.

Vibration Pick-Up Used to Balance Motor Rotors. *Electronics*, March 1938, p. 38.

Electronic Machine Balances Rotating Parts. *Electronics*, January 1943, p. 101.

Dynamic Balancer. *Jnl. of Sci. Instr.*, September 1945, p. 179.

Resonance Testing Equipment. *Electronic Engineering*, December 1945, p. 812.

Precision Balancing at Mass-Production Speed. S. Bousky. *Electronics*, September 1947, p. 98.

3. CARRIER-CURRENT CONTROL APPARATUS

This equipment commonly comprises high frequency transmitters and receivers specially adapted for communication over wire networks usually associated with electrical power distribution.

The essential difference between this apparatus and normal radio communication equipment lies in the provision of filter circuits to avoid interaction between currents of power frequency and carrier frequency.

The two main purposes of carrier-current apparatus are to carry out remote switching and to obtain indication of the functioning of distant equipment.

Carrier-current control apparatus therefore finds its chief application in supervisory systems for electricity sub-stations and remote-control switching of unattended pumping stations and street-lighting systems.

Carrier Current Differential Protection for Transformer Banks. *Electrical Engineering*, August 1943, p. 545.

4. CATHODE-RAY OSCILLOSCOPES

Oscilloscopes of this type comprise a cathode-ray tube with built-in power supplies and a time-base generator. Frequently there are self-contained amplifiers so that the apparatus may be used directly for the study of electric wave-forms of very small amplitude.

The electron beam of the cathode-ray tube has negligible inertia and may be deflected by magnetic or electric fields at extremely high speeds. The beam impinges on a fluorescent screen at the end of the tube and produces a visual image tracing out the deflecting voltages or currents.

The versatility of the oscilloscope is such that it is extensively used for a large variety of industrial applications, not only in the purely electrical field, but for the determination of mechanical characteristics such as pressure, strain, acceleration, torsion, and vibration through the agency of an appropriate transducer. There are also many uses in the medical and physiological fields including cardiography and encephalography.

The Cathode-Ray Oscillograph in Industry. W. Wilson, Chapman & Hall, London.

Development of Cathode-Ray Tubes for Oscillographic Purposes. R. T. Orth, P. A. Richards and L. B. Headrick. *Proc.I.R.E.* (N.Y.), November 1935, p. 1308.

Cathode-Ray Engine Pressure Measuring Equipment. H. J. Schrader. *R.C.A. Review*, October 1937.

Cathode-Ray Tubes. M. Von Ardenne, Pitman, 1939.

Ultra-High-Frequency Oscillography : Electron-Optical Spectral Analysis. H. E. Hollman. *Proc.I.R.E.* (N.Y.), May 1940, p. 213.

Cathode-Ray Oscillograph Used to Measure Short Time Intervals. H. D. Brailsford. *Electronics*, September 1940, p. 76.

Three-Tube Oscillograph Recorder for Aeroplane-Strut Testing. *Jnl. of Sci. Inst.*, January 1941, p. 13.

Application of Cathode-Ray Oscilloscope in Engineering. W. Wilson. *J.Brit.I.R.E.*, Vol. 2, 1941-2, p. 122.

Lesser Known Aspects of Measurement with the Cathode-Ray Oscillograph. T. D. Humphreys. *J.Brit.I.R.E.*, Vol. 2, 1941-2, p. 82.

The Cathode-Ray Oscillograph in Industry. W. Wilson. *B.E.A.M.A. Journal*, April 1941, p. 58, and May 1941, p. 75.

Combination Vacuum Tube Switch for Double-Trace Cathode-Ray Oscillograph, Audio-Amplifier and Mixer. H. K. Hughes and R. G. Koch. *Rev. of Sci. Instr.*, April 1941, p. 183.

Cathode-Ray Oscillograph for Frequency Comparisons. *Electronics*, April 1942, p. 94.

Wide-Band Oscilloscope for Problems in Television and Other Fields. E. D. Cook. *Proc.I.R.E.* (N.Y.), August 1943, p. 410.

Applications of Cathode-Ray Tubes. B. Dudley. *Electronics*, October 1943, p. 49.

The Cathode-Ray Tube in Mechanical Testing. E. Cattanes. *Electronic Engineering*, December 1943, p. 277.

4. CATHODE-RAY OSCILLOSCOPES (*contd.*)

Very-High-Frequency Use of Oscilloscopes. Stanley Cutler. *Electronics*, March 1944, p. 124.

Cathode-Ray Armature Fault Finding Apparatus. W. Wilson. *Electronic Engineering*, October 1944, p. 188.

General Electric Six-Element Oscillograph. *Rev. of Sci. Instr.*, November 1944, p. 329.

Oscilloscope for Pulse Studies. H. Atwood and R. P. Owen. *Electronics*, December 1944, p. 110.

Testing Magneto Coils for Aircraft ; including a Surge-Generator/Cathode-Ray-Tube Equipment for short-time testing of coils before assembly in Magneto. Rohats. *G.E. Review*, March 1945, p. 49.

Oscillograph for the Direct Measurement of Frequency Employing a Signal Converter. P. Nagy and M. J. Goddard. *Wireless Engineer*, September 1945, p. 429.

Visible Speech Cathode-Ray Translator. R. R. Riesz and L. Schoot. *J.A.S.A.*, July 1946, p. 50.

Recording of Transients. W. Nethercot. *Electrical Times*, November 14th, 1946, p. 648.

Wave Monitor. H. L. Mansford. *Electronic Engineering*, 1947, September/October, p. 272, p. 328.

A New Oscilloscope with D.C. Amplification. J. H. Reyner. *Electronic Engineering*, October 1946, p. 297.

General Purpose Oscilloscope. J. F. O. Vaughan. *Wireless World*, May 1948, p. 159.

Principles and Practice of Panoramic Display. D. W. Thomasson. *J.Brit.I.R.E.*, Vol. 8, 1948, p. 171.

Cathode-Ray Oscilloscope. S. A. Knight. *Wireless World*, December 1948, p. 432.

C.R.T. Displays. Soller. M.I.T. Radar Series No. 22 McGraw-Hill, 1949.

5. COLORIMETERS

Electronic colorimeters are instruments for indicating the light transmission characteristics of clear solutions and solids.

They comprise essentially a suitable light source, with colour filters as necessary, a photo-electric cell, and a calibrated amplifier with an output meter.

Colorimeters may, with appropriate safeguards, also be employed for colour comparison purposes when they are usually termed colour comparators.

Colorimeters specially arranged to be sensitive to fluorescent light sources are usually termed fluorimeters.

These instruments are widely used in biological and pathological investigations as hæmoglobinometers for blood testing and for analytical determinations in industrial chemistry, particularly the dyeing industry.

Colour Matching of Porcelain. R. F. Bisbee. *Electrical Journal*, December 1934, p. 482.

Photo-Electric Colorimeter with Logarithmic Response. R. H. Muller and G. F. Kinney. *Jnl. of Am. Opt. Soc.* October 1935, p. 342.

Photo-Electric Colour Measuring Device Used for Process Control. *Electronics*, January 1936, p. 36.

Cross-Beam Reflectometer for Surface Comparisons. *Electronics*, June 1937, p. 30.

Transparency Meter Tests with Photo-Cell. *Electronics*, July 1937, p. 28.

General Electric Spherical Reflectometer for Light Transmission and Reflection Measurements. *Electronics*, October 1937, p. 46.

Colour Matching in the Paper Industry. E. Deeter. *Electronics*, September 1938, p. 18.

Reflectance Comparator Matches Colour of Porcelain Enamel. F. H. Catlin and F. L. Michael. *Steel*, October 6th, 1941, p. 85.

Photo-Electric Colorimeter for Rapid Reactions. B. Chance. *Rev. of Sci. Instr.*, April 1942, p. 13.

Brightness Rating of Metal Surfaces Measured by Reflected Light. A. M. Suggs. *Product Engineering*, May 1942, p. 253.

Measuring Haze of Transparent Plastics. *Modern Plastics*, August 1942, p. 80.

Photo-Electric Device for Recording Variations in Concentration of Coloured Solution. *Jnl. of Sci. Instr.*, May 1944, p. 84.

6. COUNTERS

Electronic counting is generally carried out by means of chains of thermionic valves with feed-back circuits so arranged that only one output pulse is delivered for a continuous series of input pulses in rapid succession.

The relatively small number of output pulses can then be registered by a mechanical counter.

The input pulses may be derived by mechanical means such as the reciprocating motion of a lever or by electrical means, e.g. from a photo-electric cell viewing a succession of moving bodies or other repetitive actions.

By arranging that counting is carried out for predetermined periods, integrating instruments are obtained, e.g., electronic tachometers.

6. COUNTERS (*contd.*)

Alternatively, apparatus may be controlled by a predetermined number of impulses at a specific frequency which affords an accurate method of process timing.

Electronic counters find application in many industries where, by reason of fragility, small size, remote location or perhaps high temperature, articles cannot be counted by the usual mechanical means. Such counters are especially suited to very high speed operation and can operate continuously for long periods without attention.

Counters arranged to count in the scales of ten are usually referred to as " decade " counters, but they can also be arranged to count in scales of 2 (binary), 5, 12 or any other quantity if desired.

In addition to pure counting, the apparatus may easily be arranged to operate periodically a diverting system in order to secure batching of goods flowing along a production line.

Photo-Electric Scales for Process of Weighing. *Chem. & Met. Eng.*, October 1935, p. 571.

Tube Controlled Candy Wrapper. F. A. Hall. *Electronics*, August 1937, p. 18.

Hints on Uses of Photo-Electric Counting in a Sugar Refinery. H. A. Delius. *Electrical World*, March 1937, p. 886.

Electronic Counting Circuits. *Electronics and Television & Short-Wave World*, June 1940, p. 261.

An Electronic Integrator for Counting Circuit Contacts. G. W. Kenrick. *Electronics*, March 1941, p. 33.

Electronics Applied to Packaging Machinery. E. F. Cornock. *Electronics*, March 1941, p. 24.

Photo-Electric Star Counter. S. W. McCuskey and R. M. Scott. *Rev. of Sci. Instr.*, December 1941, p. 597.

Electrical Counting. W. B. Lewis. Cambridge University Press, 1942.

Photo-Electric Relay for Batch Weighing. *Electronics*, February 1943, p. 112.

Traffic Count Printed Hourly by Photo-Electric Recorder. *Electronics*, May 1943, p. 130.

Packaging Machines Controlled by Phototubes. W. D. Cockrell. *Electronics*, October 1943, p. 94.

A Four-Tube Counter Decade. John T. Potter. *Electronics*, June 1944, p. 110.

Electronic Tachometer. *Electronic Industries*, March 1945, p. 80.

Wire Footage Counter. *Electronic Industries*, April 1945, p. 81.

Post-War Applications of Electronics in the Handling of Materials. B. G. Higgins. *Mechanical Handling*, April 1945, p. 176.

Cold Cathode Counter Control. *Electronic Engineering*, June 1945, p. 553.

Electronic Counting. *Communications*, August 1945, p. 42.

Design of Counter Circuits. *Radio*, February 1946, p. 25.

Photo-Electric Fish Counter. L. V. Whitney and A. D. Hasler. *Electronics*, March 1946, p. 178.

Decade Counting Circuits. Victor H. Regener. *Rev. of Sci. Instr.*, May 1946, p. 185.

Electronic Counters. I. E. Grosdoff. *R.C.A. Review*, September 1946, p. 438.

Reversible Decade Counting Circuit. Victor H. Regener. *Rev. of Sci. Instr.*, October 1946, p. 375.

An Electronic Decimal Counter Chronometer. S. S. West. *Electronic Engineering*, January/February 1947, p. 3, p. 58.

Predetermined Counters. J. J. Wild. *Electronics*, March 1947, p. 120.

Scale of N Counting Circuits. Bradford Howland. *Electronics*, July 1947, p. 138.

Card Counter. A hand-applied device for counting cards at a rate of up to 1,000 per second. *Electronics*, August 1947, p. 194.

Decade-Ring Scaling Circuit. Seren. *Rev. of Sci. Instr.*, September 1947, p. 654.

A Hexade Scaling Circuit. Langberg. *Rev. of Sci. Instr.*, p. 796, October 1947.

The Model 200 Pulse Counter. Higinbotham, *Rev. of Sci. Instr.*, October 1947, p. 706.

Predetermined Counter for Process Control. R. J. Blume. *Electronics*, February 1948, p. 88.

High-Speed Revolution Counter. A. B. Kaufmann. *Electronics*, September 1948, p. 80.

Electronic and Nuclear Counters. S. A. Korff, Van Nostrand, 1948.

Large-Scale Digital Calculating Machinery. Harvard University Press, 1949.

7. CURVE TRACERS

Apparatus for producing a graph representing the instantaneous relationship of two variables, e.g. the frequency/amplitude relation of the voltage at a chosen point in an electrical circuit, the graph being delineated upon the screen of a cathode-ray oscilloscope.

The results may be interpreted by direct viewing or by photographic record. Generally the apparatus contains means of calibrating the scales separately but it may be provided with automatic self-scaling devices.

7. CURVE TRACERS *(contd.)*

This apparatus is particularly useful for indicating or measuring the performance of electrical equipment such as amplifiers, loud-speakers, telephone lines and wire broadcasting networks.

An Audio-Frequency Response Curve Tracer. J. B. Sherman. *Proc.I.R.E.* (N.Y.), June 1938, p. 700.

Frequency Response Curve Tracer. S. F. Carlisle, Jr., and A. B. Mundell. *Electronics*, August 1941, p. 22.

Frequency Response Curve Tracer. H. B. Shaper. *Electronics*, March 1945, p. 118.

Automatic Audio-Frequency Response Curve Tracer. G. L. Hamburger, *J.Brit.I.R.E.*, Vol. 8, 1948, p. 154.

8. DENSITOMETERS

Electronic densitometers make use of photo-electric cells to measure or compare trans-mission of light through a sample and thereby provide an indication of opacity. Colour filters may be employed with the photo-cells to secure different characteristics.

The sensitivity of such apparatus can be made quite high and it can be used in conjunction with amplifiers and/or relays for the purpose of controlling processing machinery.

These instruments can be employed to secure consistent densities in photographic, chemical concentration or other processing provided that it is dependent on the degree of opacity or turbidity. Equipment of this kind is used for indicating or recording the density of smoke from industrial chimneys.

Linear Photoelectric Densitometer. C. W. Miller. *Rev. of Sci. Instr.*, April 1935, p. 125.

Simple Photoelectric Turbiditimeter. S. Silverman. *Rev. of Sci. Instr.*, February 1941, p. 77. Also *Electronics*, April 1941, p. 100.

Measuring the Fineness of Portland Cement : Proposed Revised Tentative Method of Test for Fineness of Portland Cement By Means of the Turbiditimeter (C 115038 T). *Concrete*, September 1941, p. 233.

Precision Direct-Reading Densitometer. M. H. Sweet. *Journal of the S.M.P.E.*, February 1942, p. 148. Also *Electronics*, July 1942, p. 68.

Stop Calibration of Photographic Objectives : Principle of Null-Indicating Densitometer Adapted to Measurement of Camera Lens Iris Settings. E. W. Silvertooth. *Journal of the S.M.P.E.*, August 1942, p. 119.

Photoelectric Densitometer. C. C. Smith. *Electronics*, December 1942, p. 79.

Combustion Indicator Tests Diesel Engine Exhaust Smoke. *Electronics*, May 1943, p. 116.

Photoelectric Smoke Meter. *Diesel Power*, May 1943, p. 408.

Smoke Detector for Ducts. *Electronics*, June 1943, p. 212.

An Improved Short Time Turbiditimetric Assay for Penicillin. J. R. McMahan. *Journal of Biological Chemistry*, Vol. 153, 1944, p. 249.

Microdensitometer With D.C. Amplifier. S. R. Winters. *Electronics*, July 1944, p. 225.

Smoke Density Indicator and Recorder for Industrial Plants. *Electronics*, February 1945, p. 148.

Direct-Reading Colour Densitometer. M. H. Sweet. *Electronics*, March 1945, p. 102.

Logarithmic Photometer. M. H. Sweet. *Electronics*, November 1946, p. 105.

Sensitive Photoelectric Photometer. F. T. Gucker. *Electronics*, July 1947, p. 106.

Applications of Attenuating Current Amplifiers to Optical Measurements. E. J. Harris. *Electronic Engineering*, December 1948, p. 396.

9. DIELECTRIC HEATERS

This apparatus comprises a radio-frequency oscillator with coupling circuits terminating in two metallic plates to act as electrodes. Any material having a reasonably high dielectric loss may be heated by being placed between the two electrodes to form an imperfect capacitor. The heat is generated within the material itself under the influence of the electric field alternating at a frequency in the range 2 to 100 Mc/s.

Dielectric heaters are extremely useful for internally heating substances of poor thermal conductivity especially where the thickness of the material would necessitate a high surface temperature and a long time delay for heat applied by other methods to reach the central portions.

The equipments are widely used in industry for the preheating of plastic moulding materials, welding of thermoplastics, gluing of timber, vulcanizing of rubber and the heating and sterilization of foodstuffs.

Heating Wood With Radio-Frequency Power. J. P. Taylor. *Transactions of the A.S.M.E.*, April 1943, p. 201.

9. DIELECTRIC HEATERS (*contd.*)

Molding With Radio Frequency. W. M. Witty. *Modern Plastics*, May 1943, p. 83.

Radio Frequency Heating Speeds Plastic Molding. J. P. Taylor, *Electronics*, September 1943, p. 102.

Radio-Frequency Heating Applied to Wood Glueing. R. A. Bierwirth and C. N. Hoyler. *Proc.I.R.E.* (N.Y.), October 1943, p. 529.

High Frequency Bug Eliminator. *Electronic Industries*, March 1944, p. 122.

High Frequency Heating of Conductors and Non-Conductors. R. M. Baker and C. J. Madsen. *Electrical Engineering*, February 1945, p. 50.

Dielectric Heating in the Woodworking Industry. *Electronics*, April 1945, p. 180.

Electronic Welding of Glass. E. M. Guyer. *Electronics*, June 1945, p. 92.

Defrosting Frozen Food for Bakeries. *Electronics*, June 1945, p. 154.

Survey of Dielectric Heating. M. J. Maiers. *Electrical Engineering*, June 1945, p. 210.

Dielectric Heating by the Radio Frequency Method. L. Grinstead. *J.Brit.I.R.E.*, May-July 1945, p. 128.

Calculations for Dielectric Heating by H.F. Current. A. J. Maddock. *Electronic Engineering*, August 1945, p. 635.

H.F. Heating for Raising Temperature of Thermo-Setting Moulding. A. E. L. Jervis. *Electronic Engineering*, December 1945, p. 819.

Capacity Current Heating. Resume of Published Information. Technical Report No. Y/T6 by the *B.E.A.I.R.A.*, 1945.

Rubber Preheating. E. Mittelman and G. P. Bosomworth. *Electronics*, March 1946, p. 128.

R.F. Heating in Bakery Industry. *Electronics*, April 1946, p. 166.

U.H.F. Heating of Frozen Foods. P. W. Morse and H. E. Revercomb. *Electronics*, October 1947, p. 85.

Electronic Heating in the Furniture Industry. E. S. Winlund. *Electronics*, May 1946, p. 108.

Radio Frequency Welding of Plastics. L. Grinstead and H. P. Zade. *J.Brit.I.R.E.*, Vol. 9, 1949, p. 322.

10. DOSEMETERS. (Dosimeters)

These instruments consist essentially of a detector device in the form of an ionization chamber and electro-meter of the electronic type and a direct-current amplifier for magnifying the extremely small ionization currents produced by X-ray or Gamma-ray radiations.

Some dosemeters include a small amount of radio-active material for use as an ionization reference against which the instrument may be calibrated.

Their main use is for control purposes in the field of radiotherapy where it is essential to be able to measure radiators (quantity or rate).

An Instrument for Measuring Ionisation Currents. D. E. Lea. *Jnl. of Sci. Instr.*, Vol. 14, 1937, p. 89.

The Meter X: A Portable Direct-Reading X-ray Intensity Meter. Zucker and Sampson. *A.S.T.M. Bulletin*, August 1941, p. 41.

Safety With X-rays: The Detection and Measurement of Radiation. Long. *Electronic Engineering*, July 1943, p. 52.

Radiation Measurement Set. *Rev. of Sci. Instr.*, March 1944, p. 74.

A Feed-Back Amplifier for Ionisation Currents. F. T. Farmer. *Brit. Jnl. of Rad.*, January 1946, p. 27.

Counting Rate and Frequency Meter. E. Lorenz, J. Weikel and S. G. Norton. *Rev. of Sci. Instr.*, July 1946, p. 276.

Design and Operation of an Improved Counting Rate Meter. A. Kip, A. Bousquet, R. Evans and W. Tuttle. *Rev. of Sci. Instr.*, September 1946, p. 323.

Electronic X-ray Counter. *Instruments*, March 1947, p. 270.

11. ELECTROMETERS

The modern electronic electrometer of high sensitivity uses a special highly-insulated electron valve of low inter-electrode capacitance having a grid leakage resistance of 10^6 megohms or more and extremely low grid current (10^{-13} to 10^{-14} amps) to ensure that negligible power will be absorbed from any source of voltage to which it is applied.

These electrometers are used for the measurement of electric potential differences of low energy level such as are obtained from nerve impulses, and are included in a variety of instruments, e.g. pH meters, dosemeters and megohmeters.

Measuring 10^{-17} of an Ampere. B. J. Thompson. *Electronics*, Vol. 1., 1930, p. 290.

A Vacuum Tube Electrometer. H. Nelson. *Rev. of Sci. Instr.*, Vol. 1, 1930, p. 281.

Amplification of Small Direct Currents. L. A. Du Bridge. *Phys. Rev.*, Vol. 37, 1931, p. 392.

11. ELECTROMETERS *(contd.)*

Improved Balanced Circuit for Use With Electrometer Tubes. L. A. Turner and C. O. Siegelin. *Rev. of Sci. Instr.*, Vol. 4, 1933, p. 429.

On Use of Vacuum Tube Electrometer With Extremely High Input Resistance. R. E. Burroughs and J. E. Furgeson. *Rev. of Sci. Instr.*, Vol. 4, 1933, p. 406.

Ballistic Measurement With Electrometer Tube Circuits. R. H. Varian and J. C. Clark. *Rev. of Sci. Instr.*, September 1935, p. 284.

Electrometer Detects Faulty Insulators. A. Algenberg. *Electrical World*, April 11th, 1936, p. 1060.

General Theory of Electrometer Design. W. W. Hansen. *Rev. of Sci. Instr.*, April, 1936, p. 182.

An Improved Vacuum Tube Microammeter. A. W. Vance. *Rev. of Sci. Instr.*, Vol. 7, 1936, p. 489.

An Electrometer for Measurement of Voltages on Small Ionisation Chambers. F. T. Farmer. *Proc. Phys. Soc.*, 1942, p. 435.

Radium Therapy. G. W. Wilson. Chapman and Hall, 1944.

Electrometer Input Circuits. A. Thomas. *Electronics.* December 1946, p. 130.

The Tolerance Dose and the Prevention of Injuries Caused by Ionising Radiation. R. N. Sieveit. *Brit. Jnl. of Rad.*, August 1947, p. 306.

Experiments on the Biological Action of Fast Neutrons. J. S. Mitchell. *Brit. Jnl. of Rad.*, September 1947, p. 368.

12. ELECTRON MICROSCOPES

Glass lenses, which are a feature of the optical microscope, are replaced in the electron microscope by electric or magnetic fields which serve to control a beam of electrons generated by an electron gun using a structure similar to that employed in a C.R. tube. The very short wave-length (compared with that of light) of the electron beam, under the influence of a very high accelerating voltage, enables resolutions to be obtained which are some 100 times better than those of the optical microscope.

The maximum useful magnification of an optical microscope is between 1,000 and 2,000, but with the electron microscope satisfactory magnifications of 50,000 to 100,000 or even more are obtainable.

These instruments are of immense value in medical and biological research and are rapidly becoming an essential aid in the metallurgical and other industrial spheres.

Electron Microscope for Practical Laboratory Service. V. K. Zworykin, J. Hillier and A. W. Vance. *Electrical Engineering*, April 1941, *Transactions*, p. 157.

Surface Studies With Electron Microscope. V. K. Zworykin and E. G. Ramberg. *Jnl. of Appl. Phys.*, September 1941, p. 692.

Electron Microscope in Metallurgical Research. C. S. Barrett. *Jnl. of Appl. Phys.*, October 1941, p. 691.

The Electron Microscope. E. F. Burton and W. H. Kohl. (Has 233-page bibliography.) Reinhold Publishing Corporation, New York, 1942.

Electron Microscope Used as a Diffraction Camera. J. Hillier, R. F. Baker and V. K. Zworykin. *Science*, Supplement 12, July 3, 1942.

Films of Thickness Tenth of the Length of Yellow Light Waves Found Best for Showing Metal Details in Electron Microscope. *Blast Furnace and Steel Plant*, August 1942, p. 876.

Electron Microscope Study of Surface Structure. R. D. Heidenreich and V. C. Peck. *Phys. Rev.*, September, 1942, p. 292.

Electron Microscopy in Chemistry. V. K. Zworykin. *Electronics*, January 1943, p. 64.

Bibliography of Electron Microscopy. C. Marton and S. Sass. *Jnl. of Appl. Phys.*, October 1943, p. 522 and August 1944, p. 575.

Compact High Resolving Power Electron Microscope. V. K. Zworykin and J. Hillier. *Jnl. of Appl. Phys.*, December 1943, p. 658.

Electron Microscope and its Application to Engineering Problems. A. G. Quarrell. *Engineer*, December 24, 1943, p. 499.

Electron Microscope. W. Wilson. *Electrical Review*, February 18, 1944, p. 218.

Electron Microscope Determination of Surface Elevations and Orientations. R. D. Heidenreich and L. A. Matheson. *Jnl. of Appl. Phys.*, May 1944, p. 423.

Electron Microscope and Metals. R. G. Picard and P. C. Smith. *Metals and Alloys*, September 1944, p. 636.

Extending Microscope Examination of Metals. F. Keller and A. H. Geisler. *Jnl. of Appl. Phys.*, October 1944, p. 696.

A New Swiss Electron Microscope. F. Neurath. *Electronic Engineering*, July 1945, p. 610.

Preparation of Specimens for Electron Microscope. *Electronic Engineering*, December 1945, p. 807.

A New Electron Microscope With Continuously Variable Magnification. *Philips Tech. Rev.*, Vol. 9, No. 2, 1947.

Electron Microscope. *R.C.A. Review*, March, 1947, p. 29.

Electron Microscope. *Electronic Engineering*, August 1947, p. 248.

The Design and Construction of a New Electron Microscope. M. E. Haine. *J.I.E.E.*, Vol. 94, Part I, No. 82, October 1947, p. 447.

13. ELECTRONIC SWITCHES

These devices are arrangements of thermionic valves to permit rapid switching of circuits at speeds up to 100,000 times per second or even higher.

The technique consists in combining several differing input signals each of which is applied to one control electrode of a multigrid valve switched off or on by predetermined signals applied to another of the control electrodes.

Such arrangements form the basis of simple counters and computers but are more usually employed with cathode-ray oscilloscopes to allow simultaneous observation of a number of interrelated phenomena. They can also be used as trigger and synchronizing devices.

Angle Switching of Synchronous Motors. C. W. Drake. *Electrical Journal*, May 1936, p. 213.

Some Electronic Switching Circuits. C. C. Shumard. *Electrical Engineering*, May 1938, p. 209.

Trigger Circuits. H. J. Reich. *Electronics*, August 1939, p. 14.

Electronic Switch for Fluorescent Lamps. R. F. Hays. *Electronics*, May 1940, p. 14.

An Electronic Switch and Square-Wave Generator. J. R. Cosby and C. W. Lampson. *Rev. of Sci. Instr.*, April 1941, p. 187.

Electronic Switch for the Simultaneous Observation of Two Waves With the Cathode-Ray Oscillograph. H. J. Reich. *Rev. of Sci. Instr.*, April 1941, p. 191.

Four Circuit Electronic Switch for Observing Four Independent Electrical Phenomena on a Cathode-Ray Tube Screen. E. Moen. *Electronics*, May 1941, p. 50.

Electronic Switching Simplifies Power Line Communications. J. D. Booth, *Electronics*, August 1942, p. 44.

Dual-Triode Trigger Circuits. B. E. Phelps. *Electronics*, July 1945, p. 110.

Four-Channel Electronic Switch. N. A. Moerman. *Electronics*, April 1946, p. 150.

Design and Use of Directly Coupled Pentode Trigger Pairs. Victor H. Regener. *Rev. of Sci. Instr.*, May 1946, p. 180.

Electronic Commutation for Telemetering. L. L. Rauch. *Electronics*, February 1947, p. 114.

A Laboratory Four-Channel Electronic Switch. Replogle and Albers. *Rev. of Sci. Instr.*, February 1947, p. 114.

Electronic Switch for the Production of Pulses. C. R. Smitley and R. E. Graber. *Electronics*, April 1947, p. 128.

Electronic Switching. *Electronic Engineering*, September 1947, p. 282.

Electronic Trigger Circuit as an Aid to Neurophysiological Research. H. W. Shipton. *J.Brit.I.R.E.*, Vol. 9, 1949, p. 362.

14. FACSIMILE EQUIPMENT

Most existing facsimile apparatus involves comparatively slow electro-mechanical scanning of an image, e.g. printed paper matter, with transmission of the resulting electric signals via radio or wire lines in order to secure at a distance a reasonably permanent copy of the original.

In order to accelerate the rate of transmission developments are proceeding in the application of television technique for this purpose.

The principal applications of these equipments lie in the transmission of pictures for reproduction in newspapers and written documents between business premises. The process is often termed photo-telegraphy or picture-telegraphy.

Facsimile Telephotographs. W. G. H. Finch. *Electronics*, July 1936, p. 32.

Facsimile Tests : Finch Telecommunications Laboratory Testing Radio Facsimile Transmissions from Ground to Plane. *Aviation*, October 1938, p. 48.

Radio Facsimile. An assemblage of papers from Engineers of the R.C.A. Laboratories relating to the radio transmission and recorded reception of permanent images. *R.C.A. Institutes Technical Press*, 1938.

Facsimile and its Future Uses. J. V. L. Hogan. *Annales of the A.A.P.S.S.*, January 1941, p. 162.

Facsimile Speeds Air Reconnaissance. *Electronics*, May 1941, p. 30.

Standards on Facsimile. Definition of terms. Published by the I.R.E. (N.Y.), 1942.

Standards of Facsimile. Temporary test standards. Published by the I.R.E. (N.Y.), 1943.

Train Orders by Facsimile Telegraphy. G. H. Ridings. *Electrical Communication*, Vol. 21, No. 2, 1943, p. 95.

Sending Train Orders by Facsimile Telegraphy. *Electronics*, September 1943. p. 148.

Rock Island Tests Facsimile and Carrier Te'ephone on Moving Train. *Railway Age*, August 26th, 1944, p. 355.

Facsimile Equipment Communication Units. Roland C. Davies and Peter Lesser. *Electronic Industries*, February 1945, p. 96.

Facsimile Transmitter and Receiver. *Radio News*, March 1945, p. 43.

Transmission of Color Pictures by Facsimile. *Electronics*, April 1945, p. 236.

A New Facsimile Dispatch and Report System. (The Alden System.) Milton Alden, *F.M. and Televis.*, August 1945, p. 32 and September 1945, p. 36.

Facsimile Methods for Broadcast Work. A general account of the " Faximile " and " Telefax " systems. *Electronic Industries*, June 1946.

Reuters' Wireless Services. W. West. *P.O.E.E.J.*, July 1946, p. 48.

14. FACSIMILE EQUIPMENT (contd.)

Transmission of Finger-Prints by Radio. *Nature*, October 12th, 1946, p. 525.

The Development of Photo-Telegraphy. W. C. Lister. *Electronic Engineering*, February 1947, p. 37.

Commercial Applications for Picture Telegraphy. R. C. Walker, *Electronic Engineering*, February 1947, p. 44.

Secret Message Transmission by Facsimile. Telegraph and Telephone Age. August 1947, p. 8.

Finch Facsimile-In-Colour Process. *Tele-Tech.*, September, 1947, p. 29.

Ultrafax. D. S. Bond and V. J. Duke. *J.Brit.I.R.E.*, Vol. 9, 1949, p. 146.

15. FLAW DETECTION

There are two principal methods by which crack detection in metals, both ferrous and non-ferrous, can conveniently be carried out.

The first method employs comparison between a sound and a faulty piece of material by observing the different induction effects when each is placed in a coil fed with a given alternating current of suitable frequency.

The second method is based on observation of the transmission through the material of a supersonic wave generated by an oscillator with a quartz crystal transducer. The reflected wave from any irregularity in the material is detected by a similar quartz crystal and observed on a C.R. oscilloscope or by other suitable means.

The main application of this technique is in the detection of cracks or other flaws in drawn wires and in metal castings and forgings.

Apparatus For Detection of Splits in Tungsten Wire. D. T. O'Dell. *Jnl. of Sci. Instr.*, September 1943, p. 147.

Supersonic Flaw Detector. *Electronic Engineering*, January 1946, p. 14.

Supersonic Inspection of Strip Materials. *Electronics*, March 1946, p. 166.

16. GEIGER-MULLER COUNTERS

These are special counters using a gas-filled tube so arranged that current passes only when the gas is ionized in the presence of radio-activity.

This form of electroscope is very sensitive and some types will respond to a single ionizing particle or photon.

The resulting electrical impulses from the Geiger-Muller tube are usually applied to counters of the type described elsewhere in the report to obtain a record of radio-activity and a measure of its intensity.

Considerable developments have taken place in the use of this apparatus for biological, therapeutic and atomic research.

Improved Counting Rate Meter. R. D. Evans and R. L. Alder. *Rev. of Sci. Instr.*, November 1939, p. 332.

A Direct-Reading Counting Rate Ratio Meter. R. D. Evans and R. E. Meagher. *Rev. of Sci. Instr.*, November 1939, p. 339.

A Comparison Between a Geiger-Muller Counter, a Secondary-Electron Multiplier Tube, and Photographic Film, for Detecting Weak X-rays. Eisenstein and Gingrich. *Rev. of Sci. Instr.*, December 1941, p. 582.

Radiation Instruments Using Geiger-Muller Tubes. P. Weisz. *Electronics*, October 1942, p. 44.

Four-Pi Solid Angle Geiger-Muller Counters. J. A. Simpson. *Rev. of Sci. Instr.*, May 1944, p. 110.

A New Type of Counter For Ionising Particles. C. B. A. McCusker. *Jnl. of Sci. Instr.*, July 1944, p. 120.

Geiger-Muller Counters and Their Applications to Cosmic Ray Research. *Electronic Engineering*, March 1945, p. 405.

Geiger Counter Spectrometer for Industrial Research. H. Friedman. *Electronics*, April 1945, p. 132.

Modern Geiger-Muller Counters. A. Graves. *Electronics*, January 1947, p. 80.

17. INDUCTION HEATERS

This apparatus is essentially a radio-frequency generator, especially designed to produce heavy currents in inductor coils at frequencies ranging from a few kc/s up to a few Mc/s.

Metals can be rapidly heated in the field of such inductors by the currents induced in them. The heating rate is generally much higher than can be achieved by any other means, and some control of the depth of heating is possible by suitable choice of frequency and heating time.

The principal uses of these equipments are in the hardening, tempering, soldering and brazing of metals and in preheating of billets for forging. With control of heating depth and provision of rapid quenching means, skin hardening may therefore be achieved.

17. INDUCTION HEATERS (*contd.*)

Principles of Inductive Heating With High-Frequency Currents. E. F. Northrup. *Transactions of the A.E.S.* Vol. 35, 1919, p. 69.

Inductive Heating. E. F. Northrup. *Journal of the Franklin Institute*, February 1926, p. 221.

Heat-Treatment of Steel by High-Frequency Currents. G.Rabat and M. Losinsky. *J.I.E.E.*, Vol. 86, No. 518, 1940, p. 161.

Concentrator of Eddy Currents for Zonal Heating of Steel Parts. G. Rabat and M. Losinsky. *Jnl. of Appl. Phys.*, December 1940, p. 316.

Induction Heating Speeds Tin-Plate Output. *Electronic Industries*, December 1942, p. 46.

Electronic Generators Extend Induction Heating Field. H. C. Humphrey. *Electronics*, January 1943, p. 65.

Shells Annealed by Radio Frequency Induction Heating Machine. *Electronics*, January 1943, p. 110.

Tool Brazing Speeded by Electronic Induction Heating: New Grinding System. *Steel*, May 31st, 1943, p. 90.

Thin Case Hardening With Radio Frequency Energy. V. S. Sherman. *Electrical Communication*, Vol. 21, No. 2, 1943, p. 127.

High-Speed Soldering With Radio Frequency Power. J. P. Taylor, *Electronics*, February 1944, p. 114.

Silver Alloy Brazing With Induction Heating. A. M. Setapen, *Transactions of the A.E.S.*, Vol. 86, 1944, p. 277.

Surface Hardening of Metals. H. G. Gillespie, *Electronics*, July 1944, p. 102.

Design of Electronic Heaters for Induction Heating. J. P. Jordan, *Proc. I.R.E.* (N.Y.), August 1944, p. 449.

High Frequency Induction Heating. F. W. Curtis. McGraw-Hill Book Co. Inc., 1944.

Use of Radio Frequencies to Obtain High-Power Concentrations for Industrial-Heating Applications. W. M. Roberds. *Proc. I.R.E.* (N.Y.), January 1945, p. 9.

High-Frequency Heating of Conductors and Non-Conductors. R. M. Baker and C. J. Madson. *Electrical Engineering*, February 1945, p. 50.

Induction Heating ; History of its Development. T. F. Chesnut. *Iron Age*, March 1945, p. 46.

An Engineering Approach to Soldering With Tin-Lead Alloys. A. Z. Mample. *Metals and Alloys*, Vol. 21, No. 3, 4, March and April 1945, p. 702 and 1,000.

Induction Heating of Moving Magnetic Strip. R. M. Baker. *Transactions of the A.I.E.E.*, Vol. 64, No. 4, 1945, p. 184.

Induction Hardening of Plain Carbon Steels. D. L. Martin and Florence E. Wiley. *Transactions of the A.S.M.*, Vol. XXXIV, 1945, p. 351.

Radio Heating and Mass Production Soldering. C. E. Tibbs. *Electronic Engineering*, August 1945, p. 631.

Induction Brazing and Soldering. H. U. Hjermstad. *The Iron Age*, August 1945, p. 56.

Induction Heating in Electron Tube Manufacture. E. E. Spitzer. *Proc. I.R.E.* (N.Y.), March 1946, p. 110.

Hardening Small Parts With H.F. Heating. *Electronic Engineering*, January 1947, p. xvi.

Induction Heating. *Jnl. of Sci. Instr.*, August 1947, p. 201.

Induction Heating. *Electronics*, September 1947, p. 168.

18. METAL DETECTORS

These devices are based on the principle of distortion of a magnetic field when either ferrous or non-ferrous metal parts are introduced therein. The distortion of the magnetic flux results in a change of inductance of a coil or in a change of coupling between two coils which can be either recorded or used to operate a control mechanism.

In addition to the application of these instruments to the detection of buried metal objects, such as mines, they can be used to advantage for the location of unwanted metal in many industrial processes.

Fish Migration Study Aided by Electrical Development. *Electrical West*, April, 1936, p. 48.

Practical Metal Detector. W. Broekhuysen. *Electronics*, April 1938, p. 17.

Locating Buried Cables and Pipes. H. C. Marcroft. *Instruments*, May 1940, p. 132.

Surgical Applications for Electronic Metal Locator. *Electronics*, May 1943, p. 114.

Metal Locators. W. H. Blankmeyer. *Electronics*, December 1943, p. 112.

Electronic Locator for Salvaging Trolley Rails. J. G. Clarke and C. E. Spitzer. *Electronics*, January 1944, p. 129.

Metal Detector. *Jnl. of Sci. Instr.*, January 1946, p. 1.

Detector and Locator of Buried Metallic Objects. *Electrical Engineering*, March 1946, p. 75.

Metal Detector. *Jnl. of Sci. Instr.*, October 1946, p. 244.

19. MOISTURE METERS

The moisture meter is arranged to record the value of a low-frequency alternating current passed through a sample of the substance tested. The electrical circuit is so arranged as to respond partly to the resistance and partly to the capacitance of the sample in such proportions that the best scale of moisture content will result.

19. MOISTURE METERS (*contd.*)

The principal uses of these meters are found in the determination of moisture in wood, various grains, glues and sugar.

Electrical Moisture Meter. Hartshorn and Wilson. *J.I.E.E.*, Part 2, October 1945.

Moisture Meter. *Jnl. of Sci. Instr.*, August 1947, p. 219.

20. MOTOR SPEED CONTROL

The electronic control of D.C. motors may be obtained through the use of grid-controlled rectifiers.

This method permits the operation of D.C. motors from A.C. sources, avoiding the need of multiple dynamo electric machines—as in the Ward Leonard and similar alternative schemes—and provides a greater range of speed control than is otherwise available.

The speed range obtainable, at constant torque employing armature current control, is of the order of 20-1 below motor base speed.

This range is extended to an overall 40-1 by an additional 2-1 control exercised on the motor field and giving constant horse-power output above motor base speed.

Under all these conditions, the motor speed can be accurately pre-set and maintained to ± 1 per cent., regardless of load changes within the torque and power range and mains voltage variations up to 5 per cent.

These represent average performance figures and can for special purposes be improved upon with high accuracy controllers.

It is possible to provide electronically additional features to such controllers, such as armature IR—drop compensation, dynamic or regenerative braking, controlled acceleration during starting. Also, facilities can be provided for reversing, inching and remote control.

Electronic control can also be applied to A.C. commutator motors to give a reasonably flat speed torque characteristic and to maintain pre-set speed under load. In this case, the controller functions more as an adjustable electronic governor.

The methods described find their principal application in variable speed drives for machine tools.

Electronic Control of D.C. Motors. *Electronics*, May/June/July/Sept./Oct., 1943.

Variable Unbalanced Voltage Control. W. R. Wickerham. *Electrical Engineering*, March 1945, p. 98.

Electronic Control for Magnetic Clutches. R. L. Jaeschke. *Electronics*, August 1945, p. 102.

Cathode Ray Tachometer. *Electronics*, February 1947, p. 108.

21. NAVIGATIONAL AIDS

Radio aids to navigation, already established before the last war, have been profoundly modified by pulse techniques.

The Gee system, for short and medium ranges, provides a lattice of lines of constant path difference from two or more pairs of stations. The path difference from two stations is measured by observing the time delay between synchronized pulses received from each of the stations.

In the Loran system, for long ranges, stations operate in pairs so that only one hyperbolic position line is obtained in a single observation.

Other navigational systems not depending on pulse technique are the German Sonne system, an ingenious extension of the rotating beacon principle, and the Decca system which gives extremely high precision when reception is such that only ground waves from the transmitters are involved. Both of these are long range C.W. systems.

Radar pulse techniques have enabled great developments to take place in beam approach beacons, instrument landing systems, navigational computors, land surveying, radio altimeters, airfield control systems and glide path systems.

Radar for Civil Aviation. R. A. Smith. *Nature*, 1946, p. 151.

An Introduction to Loran. J. A. Pierce. *Proc. I.R.E.* (N.Y.), 1946, p. 216.

Radar Navigation. R. A. Smith. *J.I.E.E.*, Vol. 93, 1946, p. 331.

Gee—A Radio Navigational System. R. J. Dippy. *J.I.E.E.*, Vol. 93, 1946, p. 468.

H. S. Blind Bombing and Navigational System. C. J. Carter. *J.I.E.E.*. Vol. 93, IIIA, 1946, p. 449.

Aerials for Radar Equipment. J. A. Ratcliffe. *J.I.E.E.*, Vol. 93, 1946, p. 22.

21. NAVIGATIONAL AIDS (*contd.*)

Oboe A Precision Blind Bombing System. F. E. Jones. *J.I.E.E.*, Vol. 93, 1946, p. 496.

Radar Interrogator Beacon Systems. K. A. Wood. *J.I.E.E.*, Vol. 93, IIIA, 1946, p. 481.

Radio Aids to Navigation. R. A. Smith. Cambridge University Press, 1946.

A Review of Radio Aids to Aviation. C. B. Bovill. *J.Brit.I.R.E.*, Vol. 6, p. 250, 1946.

Radio Navigational Aids. W. J. O'Brien. *J.Brit.I.R.E.*, Vol .7, 1947, p. 215.

Wireless Direction Finding. R. Keen. Iliffe, 1947.

Radar Aids to Navigation. J. S. Hall. M.I.T. Radar Series, No. 2., McGraw-Hill, 1949.

Radar Beacons. Roberts. M.I.T. Radar Series, No. 3, McGraw-Hill, 1949.

Loran Longe Range Navigation. J. A. Pierce *et al.* M.I.T. Radar Series, No. 4., McGraw-Hill, 1949.

22. OSCILLATORS

Nearly all electronic oscillators involve the use of a thermionic valve with a frequency determining circuit and some means of feeding back to the control electrode a proportion of the output voltage suitably adjusted in amplitude and phase.

The frequency determining circuit is usually, but not invariably, arranged to deliver a sinusoidal output voltage at frequencies from a few cycles per second to many thousands of megacycles per second. Power outputs from a few milliwatts up to hundreds of kilowatts may be secured in this way.

The necessary high frequency stability may be secured by piezo-electric crystals or magnetostrictive bars as the controlling elements but, generally, the output is then restricted to a few watts.

Electronic oscillators find wide-spread use as carrier-power sources in communication equipments, as frequency standards for absolute comparison and measurements, in high-powered generators for R.F. heating and for a variety of control purposes in a vast range of electronic devices in industry.

The Dynatron, A Vacuum Tube Possessing Negative Resistance. A. W. Hull. *Proc. I.R.E.* (N.Y.), February 1918, p. 5.

Vacuum Tubes as Power Oscillators. D. C. Prince. *Proc. I.R.E.* (N.Y.), 1923, pp. 275, 405, 527.

Vacuum Tube Oscillators. J. W. Horton. *B.S.T.J.*, July 1924, p. 508.

On Relaxation Oscillators. B. Van der Pol. *Phil. Mag.*, November 1926, p. 978.

Magnetostriction Oscillators. G. W. Pierce. *Proc. of the A.A.A.S.*, 1928, p. 1.

A Dynamic Study of Magnetostriction. K. C. Black. *Proc. of the A.A.A.S.*, 1928, p. 49.

Convenient Method for Referring Secondary Frequency Standards to a Standard Time Interval. L. M. Hull and J. K. Clapp. *Proc. I.R.E.* (N.Y.), February 1939. p. 252.

Magnetostriction Oscillators. G. W. Pierce. *Proc. I.R.E.* (N.Y.), 1929, p. 42.

Applications of the Dynatron. M. G. Scroggie. *Wireless Engineer*, October 1933, p. 527.

Quartz Crystal Controlled Oscillator Circuits. H. R. Meahl. *Proc. I.R.E.* (N.Y.), June 1934, p. 732.

Negative Resistance and Devices for Obtaining it. E. W. Herold. *Proc. I.R.E.* (N.Y.), October 1935, p. 1,201.

Improved Magnetostriction Oscillators. G. W. Pierce and A. Noyes, Jr. *J.A.S.A.*, January 1938, p. 185.

New Type of Selective Circuit and Some Applications. H. H. Scott. *Proc. I.R.E.* (N.Y.), February 1938, p. 226.

Bridge Stabilized Oscillator. L. Meacham. *Proc. I.R.E.* (N.Y.), October 1938, p. 1,278.

Theory and Design of Valve Oscillators for Radio and Other Frequencies. H. A. Thomas. Published by Chapman & Hall, London, 1939.

Sine-Waves in RC Oscillators. P. S. Delaup, *Electronics*, January 1941, p. 34.

Phase-Shift Oscillators. E. L. Ginzton and L. M. Hollingsworth. *Proc. I.R.E.* (N.Y.), February 1941, p. 43.

Properties of Quartz Oscillators and Resonators in the Region from 300 to 5,000 kilocycles per second. R. Bechmann. *Wireless Engineer*, November 1942, p. 537.

Generation of High-Power Oscillations with a Magnetron in the Centimeter Band. N. F. Alekseev and D. D. Malairov. *Proc. I.R.E.* (N.Y.), March 1944, p. 136.

Magnetron Oscillator for Instruction and Research in Micro-Wave Technique. J. T. Tykociner and L. R. Bloom. *Proc. I.R.E.* (N.Y.), May 1944, p. 299.

Crystal Clock, N.B.S., Continuous Time Signal Service. *Instruments*, July 1947, p. 618.

On the Effect of Magnetism upon the Dimensions of Iron and Steel Bars. J. P. Joule. *Phil. Mag.* (III), 1947, p. 76.

23. pH METERS

These are meters for the measurement of electric potential difference between special electrodes in a solution and they enable an accurate determination of the hydrogen-ion concentration in the solution to be made.

23. pH METERS (*contd.*)

The potential difference thus obtained is applied to a direct current amplifier which operates a suitable indicating or recording device. Electrometers form an important part of some of these devices.

pH meters are invaluable in biological research, electrolytic processing, and for general chemical analysis wherever an indication of acidity or alkalinity of liquids is required.

Electronic pH Meter. R. Finlay. *Electronics*, November 1937, p. 39.

A Direct Reading pH Meter. R. H. Thorp. *Electronic Engineering*, September 1945, p. 671.

Direct Reading pH Meter. *Instrument Practice*, February 1947, p. 132.

pH Recording. *Marconi Instrumentation*, August-September 1948, p. 101.

24. PHOTO-ELECTRIC CONTROL

There are many applications of photo-electric cells, generally of the photo-emissive and photo-voltaic (or barrier-layer) types, to the control of industrial manufacturing processes.

The process to be controlled is monitored by a photo-electric cell the output of which, after suitable amplification, may be led to a counter or to special circuits arranged to introduce a corrective stimulus somewhere in the processing machinery. The output from the amplifier can also be applied to devices capable of selection or diversion to secure sorting or batching of mass-produced articles.

Apart from an almost unlimited scope in control operations described above, photo-electric cells find many additional uses in other fields, for example, safety devices for dangerous machines, printing, registration in textile manufacture, automatic machining to profiles, light control in factories, light meters, colour comparators and excess temperature indicators.

Method of Analysis of Boiler Scales and Sludges; Colorimetric and Turbimetric Methods in Conjunction with a Photo-Tester as Compared with Gravi-Metric Methods. F. K. Lindsey and R. G. Bielenberg. *Industrial and Engineering Chemistry* (Annual Edition), August 15th, 1940, p. 460.

Barrier Layer Photo Cell, Applications. J. A. Sargrove. *J.Brit.I.R.E.*, Vol. 2, 1941-2, p. 134.

Electronic Control of Tinning. E. H. Vedder. *Electronic Engineering*, June 1944, p. 30.

An Automatic Furnace Discharge Indicator. *BEAMA Journal*, October 1945, p. 331.

Phototube Weft Straightening in Textile Industry. *Electronics*, November 1945, p. 316.

Control of Rotating Mandrel. *Electronics*, April 1946, p. 164.

Photo-electric Controls for Colour Printing. J. Robins, L. E. Varden. *Electronics*, June 1946, p. 110.

Photo-electric Flame-Failure Safeguard. *Instruments*, March 1947, p. 226.

A.C. Behaviour of the Barrier Layer Photo Cell. J. A. Sargrove. *J.Brit.I.R.E.*, Vol. 7, 1947, p. 86.

Combustion Controller. *Instruments*, July 1947, p. 625.

Electronic Engraving System. *Electronics*, August 1947, p. 156.

Electronic Control of Cloth Guides on Tentering Machines. E. C. Halliday, F. Anderson, E. O. Garnett. *Electronics*, September 1947, p. 90.

Electronic Computor for Printing Control. J. W. Ludwig. *Electronics*, November 1947, p. 108.

25. PUBLIC ADDRESS SYSTEMS

These are systems for the reproduction of sound by loudspeakers via microphones and/or gramophone pickups and amplifiers for the purpose of entertainment or imparting information to the public.

Typical applications are paging in factories and hotels, sports commentating and railway train announcements at stations.

Sound Reproduction. P. G. H. Voight, B.Sc. *J.Brit.I.R.E.*, Vol. 1, 1939-40, p. 74.

Microphones and Receivers. L. C. Pocock. *J.Brit.I.R.E.*, Vol. 3, 1942-3, p. 197.

Public Address Systems. H. Brennan and A. Cross. *J.Brit.I.R.E.*, Vol. 3, 1942-3, p. 289.

The Amplification and Distribution of Sound. A. E. Greenlees, Chapman and Hall, 1948.

26. RADAR

The term Radar covers a very wide group of techniques based on the accurate timing of pulses of radio waves. It is the process of determining the position of an object in space by the use of radio waves with or without the active co-operation of the object.

26. RADAR (*contd.*)

Radar has, to date, mainly been used for military purposes, but considerable advances have been made in the adoption of radar techniques in other fields.

The apparatus basically comprises a high-powered oscillator arranged to deliver to an aerial system a succession of short pulses (a fraction of a microsecond to a few microseconds) under the influence of an accurately timed modulator system itself synchronized with the associated receiver. Reception of the reflected radio waves from the desired target is invariably displayed on cathode ray tube screens.

Meteorologists can now use radar for the location of rain clouds and the determination of their height and their courses, whilst in the marine field plan-position indicators are finding increasing application both on ship and shore.

Radar in War and Peace. R. A. Watson Watt. *Nature*, 1945, p. 319.

The Scientific Principles of Radiolocation. E. V. Appleton, *J.I.E.E.*, September, 1945, p. 340.

Wireless Echoes of Short Delay. E. V. Appleton and G. Builder. *Proc. Phys. Soc.*, 1932.

Aerials for Radar Equipment. J. A. Ratcliffe. *J.I.E.E.*, 1946, p. 22.

Radar for Civil Aviation. R. A. Smith. *Nature*, 1946, p. 151.

Strobe Principle in Radio and Radar. L. H. Bedford, O.B.E., M.A. *J.Brit.I.R.E.*, Vol. 8, 1948, p. 62.

Principles of Radar. D. Taylor and C. H. Westcott, Cambridge University Press, 1948.

Development of an Indicator for H_2S Equipment. R. T. Croft. *J.Brit.I.R.E.*, Vol. 9, 1949, p. 75.

Design and Characteristics of Marine Radar Equipment. A. Levin and A. C. D. Haley, M.A. *J.Brit.I.R.E.*, Vol. 9, 1949, p. 202.

Principles and Practice of Radar. H. E. Penrose. George Newnes Ltd., 1949.

27. REMOTE CONTROL

This is a general term denoting the remote operation of switches or other electrical or mechanical apparatus and/or monitoring of distant equipment.

Remote control can be carried out electrically by the transmission of direct current, power frequency, audio frequency or radio frequency current over wires or, alternatively by direct radio transmission. Control may be exercised manually but is frequently made automatic by changes of voltage, current, frequency, phase angle, or speed in the distant gear.

Instances of such controls may be found in the dialling of TIM, the remote indication of faults on lines and in equipment generally and in the operation of unattended electricity substations.

Remote Monitor for Direction Broadcasting. M. A. O'Bradovick. *Electronics*, September 1944, p. 131.

28. SOUND MEASUREMENT

The measurement of sound through the intermediary of a calibrated microphone and amplifier requires determination of frequency (pitch), amplitude (loudness), harmonic content (timbre) and, in many cases, the reverberation of surroundings.

Some typical applications are found in the correction of the acoustics of buildings, examination of the hearing characteristics of individuals, the response of loudspeakers and the measurement of noise generated by machinery.

Acoustics of Buildings. Watson, Wiley & Sons, 1930.

The Measurement of Reverberation. W. Tak. *Philips Tech. Rev.*, March 1946, p. 82.

Hearing Aid Receivers. *Wireless World*, October 1946, p. 338.

Sound-Level Meter. *Instruments*, May 1947, p. 451.

Musical Acoustics. *Audio Eng.*, June/July/August/September 1947.

Speech and Hearing. Fletcher. Van Nostrand, 1948.

29. SOUND RECORDING

Sound recording today, for the purpose of subsequent reproduction, is invariably performed electronically whether the record is made on tape, discs, wire or film. In all cases the apparatus required will include a high quality amplifier together with microphones and photo-electric or electromagnetic cutting heads.

There are many varied applications of the process such as the recording of speech and music for entertainment purposes, of telephone messages, of dictation, of procedure at sales conferences and of typical sounds of a process

29. SOUND RECORDING (*contd.*)

for training purposes, or for time and motion study.

A Discussion of Several Factors Contributing to Good Recording. *R.C.A. Review*, April 1942.

General Notes on Automatic Tape Recording of High Speed Morse Signals. *Marconi Review*, April-June 1945.

Recording Library. Installation in the Library of Congress, U.S. D. W. Aldous. *Wireless World*, August 1945, p. 250.

B.B.C. Disc Recording. H. Davies, L. D. Norton. *Wireless World*, January 1946, p. 14.

Sound Recording in Business. *Electronics*, April 1946, p. 250.

The German Magnetophon. R. A. Power. *Wireless World*, June 1946, p. 195.

16 mm. Sound-on-Film Recorders. J. Neil. *Electronic Engineering*, October 1946, p. 309.

Magnetic Playback-Recorder Using Paper Discs. *Communications*, April 1947.

Remote Control Telephonograf. (The Swiss Ipsophone). *Tele-Tech.*, April 1947.

The Design of a High Fidelity Disc Recording Equipment. H. Davies. *J.I.E.E.*, Part III, July 1947, p. 275.

Telephone Recording. K. L. MacIlvain. *Electronics*, August, 1947, p. 89.

A Bibliography of Magnetic Recording. D. W. Aldous. *Electronic Engineering*, December 1947, p. 390.

Phase Modulation Principles Applied to Sound Recording. D. A. Ball, N. Leevers and J. A. Sargrove. *J.Brit. Kine. Soc.*, June 1948, p. 189.

30. TITRATION CONTROL

An electronic method has been developed for indicating the degree of neutrality of solutions by measuring their conductivity. Although giving lower accuracy than that of the pH meter, this method permits continuous unattended operation.

The electrode method is used for checking the purity of water or chemicals and is adequate for the simpler chemical analysis.

Device for Indicating Small Changes in Electrolytic Resistance. J. S. Preston. *Jnl. of Sci. Instr.*, September 1946, p. 174.

Conductrimetric Analysis at Radio-Frequency. G. G. Blake. *Jnl. of Sci. Instr.*, April 1947, p. 101.

31. ULTRA-SONICS

Ultra-sonics is the name given to the technique of producing mechanical vibrations in solids, liquids and gases at frequencies usually above audibility extending up into the radio spectrum. The equipment comprises a valve oscillator and transducer generally of the quartz crystal type.

Applications of this technique are still being widely developed and show considerable promise in the directions of speeding up chemical reactions, stabilization or destruction of bacteria, rapid hardening of cement mixtures and the laundering of clothes. At present the main use is for depth-sounding and the location of submerged objects.

Ultrasonics. S. Ya. Sokolov. *Elektische, Nachrichten und Technik*, November 1924, p. 434.

Ultrasonic Vibrations and Their Applications. S. Ya. Sokolov. *Zavodskaya Laboratoriya* 1935, No. 5, p. 527.

Ultrasonic Method of Determing Internal Flaws in Metal Parts. S. Ya. Sokolov. *Zavodskaya Laboratoriya* 1935, No. 12, p. 1,468.

Ultrasonic Method of Examining Metals. N. F. Otpushchennikov. *Zavodskaya Laboratoriya*, 1937, No. 8, p. 999.

Determination of Defects in Metal Objects by the Ultrasonic Method. A. S. Shrayber. *Zavodskaya Laboratoriya* 1939, No. 8, p. 816.

Electro-Mechanical Transducers and Wave Filters. W. P. Mason. Van Nostrand, 1942.

Ultrasonics. L. Bergmann and H. S. Hatfield. Wiley and Sons, 1938.

Supersonic Fundamentals. V. J. Young. *Electronics*, March 1944, p. 122.

The Supersonic Reflectoscope for Interior Inspection. F. A. Friestone. *Metal Progress*, September 1945, p. 505.

Acoustic Locating System. E. A. Walker, P. M. Kendig. *Electronics*, February 1947, p. 125.

Ultrasonic Laundering. *Electronics*, August 1947, p. 136.

32. VIBRATION ANALYSIS

This is the technique for the measurement of the amplitude and frequency of the predominant frequencies within the spectrum of mechanical vibrations.

It is carried out by means of a transducer such as a resistance wire strain gauge or a light-

32. VIBRATION ANALYSIS (*contd.*)

contact piezo-electric pick-up or an electromagnetic device associated with an amplifier and harmonic analyser. Alternatively, the results may be recorded on a cathode ray oscillograph for subsequent graphical analysis.

The main applications of this technique occur in the study of predominant vibrations found in structures, motor car and aeroplane engines, in turbo-generators and other high-speed rotating machinery.

Waveform Analysis. R. G. Manley. Chapman & Hall, 1945.

Six-Channel Electronic Recorder. M. Scott. *Electronic Engineering*, August 1946, p. 233.

A Modern Vibration Measurement Laboratory. *Electronic Engineering*, March, April, May and June 1947. pp. 71, 109, 152, 189.

De Havilland Mobile Recording Unit. *Electronic Engineering*, May 1947, p. 154.

Six-Channel Portable Flight Vibration Recording Apparatus. *Electronic Engineering*, May 1947, p. 156.

Portable 2-Channel Recording Oscillograph for Battery Operation. *Instruments*, June 1947, p. 536.

Vibration and Sound. P. M. Morse. McGraw-Hill, 1948.

33. X-RAY APPARATUS

This equipment comprises an X-ray tube with its associated high voltage unit and timing devices. X-rays are of extremely short wavelength and are hence able to penetrate solid matter. X-rays are able to provide information, of a type not available by other methods, concerning the macroscopic, microscopic and submicroscopic structure of materials. These valuable properties of X-radiation are widely used in the non-destructive testing of materials.

Radiography and Fluoroscopy, in which a beam of X-rays, which has passed through an object under examination, is caused to fall on to a suitably sensitized photographic or fluorescent screen (phosphor) provides a shadow of the internal structures of the object, the character of which varies with the differential absorption of the beam which has taken place. Such an examination will reveal internal defects in castings and welds such as blow holes, inclusions or porosity in the ore case or lack of fusion, lack of penetration or inclusions in the other.

These methods of examination are not restricted to the metal industries but find considerable application in the plastics industry, in the manufacture of radio valves, sparking plugs, ignition distributors, condenser bushings and insulators, and even in the food industry.

Radiomicrography, which employs radiation of longer wavelength produced by exciting voltages of 5-20 kV, gives valuable complementary information to that obtained with the optical microscope in certain metallurgical fields.

X-ray diffraction or X-ray crystallography is capable of giving information regarding the submicroscopic structure of materials of a type not available by any other means of examination and this procedure has a place in almost any industry.

Industrial X-Rays for Examining Metal. *Electronics*, February 1933, p. 45.

A.S.T.M. Symposium on Radiography and X-Ray Diffraction, 1936.

Vegetable and Fruit Defects Studied with X-Rays. *Electronics*, December 1937, p. 8.

Trends in the Technique of Industrial Radiography. H. E. Seemann. *A.S.T.M. Bulletin*, March 1942.

Quartz Crystals Oriented by X-Ray Diffraction Method. *Electronics*, February 1943, p. 98.

Checking Grenade Fuses with X-Rays. *Electronics*, November 1943, p. 152.

X-Ray Tubes in Industry. Gilbert Sonbergh. *Electronic Industries*, November 1943, p. 80.

A.S.T.M. Symposium on Radiography, 1943.

Mobile Industrial X-Ray Unit. E. E. Charlton and W. F. Westendorp. *Electronics*, December 1944, p. 128.

X-Ray Inspection with Phosphors and Photoelectric Tubes. H. M. Smith. *G.E. Review*, March 1945, p. 13.

Industrial Fluoroscopy of Light Materials. S. W. Smith. *Proc. of the N.E.C.*, May 1945, p. 430.

Handbook of Industrial Radiology. J. G. Crowther, Arnold.

An X-Ray Method of Studying Skin Thickness of Bronze Castings. C. G. Lutts. *Non Destructive Testing*, Spring 1948, p. 13.

GENERAL REFERENCES

Papers

Industrial Applications of Electronics. G. Windred. *Power and Works Eng.*, February and March 1941, pp. 39, 53.

Some Industrial Applications of Electronics. J. H. Reyner. *J.Brit.I.R.E.*, Vol. 3, 1942/3, p. 160.

Industrial Applications of Electronic Devices. F. H. Annett. *Power*, Vol. 88, 1944, p. 63.

The Application of Electronics. W. Wilson, *B.E.A.M.A. Jnl.*, December 1946, p. 440.

Industrial Relay Control Circuits. R. R. Batcher. *Electronic Industries*, February 1946, p. 94.

Electronic Heating Conference. *Electronics.* November 1946, p. 184.

Industrial Applications of Electronic Techniques. H. A. Thomas. *J.I.E.E.*, Vol. 94, Part I, 1947, p. 309.

Industrial Electronic Apparatus. D. W. Thomasson. *Wireless World*, March 1948, p. 88.

Electronics in Heavy Engineering. W. Wilson. *J.Brit.I.R.E.*, Vol. 9, 1949, p. 278, No. 8.

Electronic Instrumentation for Chemical Laboratories. F. Gutman. *Proc.I.R.E.* (Aust.), September 1949, pp. 241.

Books

Industrial Electronics. F. H. Gullikson and E. H. Vedder. John Wiley N.Y., 1935.

Colorimetric Methods of Analysis. F. D. Snell and C. T. Snell. Von Nostrand, New York, 1936.

Fundamentals of Engineering Electronics. D. G. Fink. McGraw-Hill, 1938.

Aeronautical Radio Engineering. P. C. Sandretto. McGraw-Hill, 1942.

Optical Methods of Chemical Analysis. T. R. P. Gibb. McGraw-Hill, New York, 1942.

Experimental Electronics. R. H. Muller, *et al.* Prentice and Hall, 1943.

Electronic Engineering Handbook. R. R. Batcher and W. Moulic, Caldwell-Clements, 1944.

Industrial Electronic Control. W. D. Cockrell. McGraw-Hill, 1944.

Principles of Industrial Process Control. D. P. Eckman, Wiley and Sons, 1945.

Proceedings of the National Electronics Conference. Edited by R. E. Beam, 1946.

Theory and Applications of Thermionic Tubes. H. J. Reich, McGraw-Hill, 1946.

Electronic Control Handbook. R. R. Batcher and W. Moulic. Caldwell-Clements, 1946.

Electronic Engineering Principles. J. D. Ryder. Prentice and Hall, 1947.

Electronic Developments. R. G. Britton. G. Newnes, 1947.

Electronics for Industry. W. I. Bendz. Wiley, 1947.

R.F. Heating. G. H. Brown *et al.* Van Nostrand, 1947.

Fundamentals of Industrial Electronic Circuits. Walther Richter. McGraw-Hill, 1947.

Welding of Plastics. G. Haim and H. P. Zade. Crosby, Lockwood & Sons, 1947.

Handbook of Industrial Electronic Circuits. J. Markus and V. Zeluff. McGraw-Hill, 1948.

Electronics and their Application in Industry and Research. B. Lovell. Pilot Press, 1948.

Industrial Electronics Reference Book. Westinghouse Corp. J. Wiley, 1948.

Electronics in the Factory. H. F. Trewman. Pitman & Sons, 1949.

Applied Electronics. D. H. Thomas. Blackie & Sons, 1949.